Green Triangle Forest Industries Hub

Trees on Farms initiative

Research new shorter rotation silvicultural models for pine plantations and longer rotations for blue gum plantations

Prepared by Sylva Systems for the Green Triangle Forestry Industries Hub Project 1 – June 2023

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Information current as of June 2023

About the Trees on Farms initiative

Launched in March 2022, the Trees on Farm initiative is aimed at growing and developing the on-farm forest plantation sector, particularly in the Green Triangle region. Key components of the program, including this report, are being delivered in partnership with the Green Triangle Forest Industries Hub (GTFIH).

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While the authors have gathered much of the information in this report from their own personal experiences and from publications, the contribution is acknowledged of the many useful discussions with industry individuals with a long history of plantation management, harvesting and haulage in the Green Triangle. Indeed, information documented in this report serves as a useful repository of such insights and corporate knowledge. The project was granted access to two important tree plantings from which to derive a range of data and information. The first was an Australian Bluegum Plantations (ABP) 15-year-old *Eucalyptus globulus* trial located in western Victoria and the second was a 27-year-old private *Pinus radiata* woodlot located in the Mount Schank area (South Australia). Such access was a valuable contribution. As with any report, the contribution of individual reviewers is acknowledged and it is by such a process that this report was refined. And finally, the support and leadership of The Department of Primary Industries and Regions, South Australia is acknowledged in making this project possible.

Acronyms

Acronym		Definition
ABARES		Australian Bureau of Agricultural and Resource Economics and Sciences
ABP		Australian Bluegum Plantations
ARD		*Armillaria luteobubalina* root disease
ATO		Australian Taxation Office
BDMT		Bone dry metric tonne
CF		Clear fall
cm		centimetre
CSIRO		Commonwealth Scientific and Industrial Organisation
CTL		Cut to length
DAP		Diammonium phosphate
DBHOB		Diameter at breast height over bark
DEWLP		Victorian Department of Environment Land Water and Planning
FOB		Free on board
FSC		Forest Stewardship Council
GMT		Green metric tonne
GST		Good and services tax
GT		Green Triangle
GTFIH		Green Triangle Forest Industry Hub
ha		Hectare
KCA		Kimberly Clark Australia
kg		kilogram
KMP		Koala Management Plan
KPY		Kraft pulp yield
LED		Large end diameter
LLC		Lower Limestone Coast
MAI		Mean annual increment, measured in m^3/ha/year, based on a set plantation age
MDP		Mill door price
MGP10		Machine graded pine
MIS		Managed investment scheme
ML		Mega litre
mL		Milli-litre
mm		millimetre
MoE		Modulus of elasticity

Acronym		Definition
MTV		Mean tree volume
NCT		Non-commercial thinning
NIR		Near infrared
NPV		Net present value
OB		Over bark
OTG		Optimum thinning guide
PCT		Pre-commercial thinning
PEFC		Program for the Endorsement of Forest Certification
PIRSA		Primary Industries and Regions, South Australia
R1		First rotation
R2		Second rotation
SED		Small end diameter
SEDOB		Small end diameter over-bark
SQ		Site Quality
SQ		Site quality
STBA		Southern Tree Breeding Association
T1, T2, T3		Thinning types; T1 = first thinning, T2 = second thinning and T3 = third thinning
TBA		Tree Breeding Australia
UB		Under-bark
USD		United States dollar
USD		US dollars
WA		Western Australia
WAP		Water Allocation Plan
WFD		South Australian Woods and Forests Department
WFD		Woods and Forests Department
WSA		Wood supply agreement
WTC		Whole tree chip

The report authors

Braden Jenkin (Sylva Systems Pty Ltd) Lead author

Braden Jenkin is a forestry consultant with over 40 years' experience in domestic and international forestry, from the smallest-scale producers through to large-scale global corporate operations. Braden practices the business of forestry holding a Bachelor of Science (Forestry) and an MBA. He is a Gottstein Fellow completing an international study of long-rotation eucalypt plantation silviculture. Roles in the 1980s include with CSIRO's Australian Tree Seed Centre and WA's export woodchip industry researching Tasmanian blue gum plantation silviculture. As a District Forester with APM Forests Pty Ltd, Braden implemented eucalypt research findings into operational silvicultural prescriptions. In 1998, Braden established Sylva Systems Pty Ltd consulting in Australia and internationally including leading and significant contributions to large-scale projects for Forest and Wood Products Australia, the Australian Centre for International Agricultural Research, the Association of Green Triangle Growers, the United Nationals Development Programme, The Food and Agricultural Organization of the United Nations and the International Finance Corporation. Braden has development silvicultural regimes for temperate plantations (e.g. *Eucalyptus globulus*; *E. regnans*), tropical plantations in Papua New Guinea (e.g. *Tectona grandis* – teak; *Ochroma pyramidale* – balsa) and implemented softwood regimes.

Aleisha Campbell (Campbell Forestry)

Aleisha is part of the family business and is currently studying towards a Bachelor of Science forestry. This combines the practical aspects of a range of operational and inventory support roles with formal study. Aleisha has strong focus on R&D field work with a strict priority to data integrity.

Dan Campbell (Campbell Forestry)

As principle of Campbell Forestry, Dan Campbell has worked supporting the blue gum industry in varying roles since 2000. In 2008 he established Campbell Forestry and employs external staff and family members; some family members have progressed to further employment within the industry and management of teams of various forestry companies. Dan has specialised in routine inventory and trial assessment works

Geoff Downes (Forestry Quality Pty Ltd)

Geoff spent 20 years as a Senior/Principal Research Scientist with CSIRO. His main research interests revolve around wood quality issues in plantation forests, particularly in regard to site and climate effects on wood formation. He has led a range of projects dealing with physiological modelling of wood formation, applications of near-infra-red spectroscopy to the non-destructive prediction of wood properties, and improved wood utilisation of eucalypt plantations (CRC Forestry). He has authored / co-authored more than 100 peer-reviewed journal publications and book chapters and over 70 conference papers. He was the lead author of the 1997 book "Sampling plantation eucalypts for wood and fibre properties". He has been an invited keynote speaker at international conferences in Europe, South Africa and South America and in 2011 he was elected a Fellow of the International Academy of Wood Science. Since 2012 Geoff has been operating a private R&D company (Forest Quality Pty Ltd) which has been developing and supporting the operational use of resistance (Resi) drilling for non-destructive wood property assessment in commercial forests.

David Geddes (Geddes Management Pty Ltd)

This snapshot of historical plantation silviculture in the Green Triangle was prepared by David Geddes. In the early 1970's he worked on forest districts in southeast South Australia for the then Woods and Forests Department. At various times, he was responsible for site preparation, establishment and plantation management in both first and subsequent rotation softwood plantations. Later as a forestry consultant, since 1996, David has been involved with the development of hardwood plantations, initially on greenfield sites, and later second rotation sites. He has forestry consulting experience in every plantation region of Australia

Lew Parsons (Wokurna Forestry Pty Ltd)

Lew Parsons is a professional forester and Director of Wokurna Forestry, a forestry consulting company based in Mt Gambier which specialises in harvesting management, forest utilisation and marketing. Customers include harvesting contractors, forest owners and wood processors. Prior to 2006 Lew worked for ForestrySA, the SA Government forest authority, where he worked in forest establishment and fire protection before managing harvesting and marketing operations for 20 years.

Executive summary

This report addresses the development and testing of alternative silvicultural regimes for *Eucalyptus globulus* and *Pinus radiata* plantations in the Green Triangle (GT) region. It is important to note that while tested as part of this study, not all regimes reported have been determined to be commercially viable. For example, some regimes require development of new markets for new log products not currently processed in the GT. Indeed, this understanding allows the reader to better reflect and place into context, the information presented.

This report forms part of a portfolio projects funded by Primary Industries and Regions, South Australia (PIRSA) and indeed makes use of the insights from these other projects. The two species of focus are the current commercial hardwood and softwood species respectively. A driver for alternative plantation regimes is a need to expand the plantation estate by better understanding alternatives that may suit private growers on new first rotation sites. A matching process between grower needs and regimes is mostly driven by returns timing and financial value; matching with life events such as retirement or succession plans.

To assist in the digestion of this large body of work, this report is split into a front section providing the outcomes and insights and a series of stand-alone sub-reports presented as appendices of supporting information. These appendices contain collations of insights and published information, and reports on field work undertaken in a *P. radiata* stand planted at final stocking with high pruning and an *E. globulus* initial stocking and early thinning trial. Access to both site is gratefully acknowledged. This information formed the basis of generating a routine base case and eight alternative regimes for each species. The key variables between the regimes were initial stocking, use of thinning and pruning, timing of clear-fell and products assumed. A 'low', 'average' and 'high' productivity assumption was applied to each regime, which when combined with stocking, determines mean tree volume (MTV) at harvest. Harvesting costs are a key driver of net returns and these are driven by MTV; generally, as MTV increases, harvesting costs decrease.

A financial model was developed to assess and compare the alternative silvicultural regimes by generating a net present value (NPV) for each regime at a discount rate of 4% real. This rate was selected to reflect a reasonable balance of future compared to more immediate cashflows. The model made use of the range of information collected and presented as appendices; the history of silviculture, current products and pricing, harvest and haulage costs, wood properties and the field work outcomes. The analysis is presented on a species-specific bench-mark basis setting the routine regime to ‘1’ and presenting total wood yield over the rotation and $NPV_{4\%REAL}$ at relative values to the bench mark outcomes. Which regime is ‘a best alternative’ must be tested against the needs of the grower, hence the presentation of the outcomes as done. An important consideration is that the needs of the growers are likely to focus on returns per hectare, whereas a processor is more focused on log quality and yield. Processor ‘needs’ will define the price paid for logs and whether a sale is possible.

Routine *P. radiata* is planted at 1,600 stems/ha, thinned (usually three times) and clear fallen at age 30 to 34 years. For modelling the base case, clear falling was assumed at 34 years. The *P. radiata* alternative regime assumed planting at high initial stocking (2,000 stems/ha) or at routine stocking (1,600 stems/ha) with an early clear fall (age 12 years) were unattractive regimes due to harvesting costs and log prices. Planting at final stocking (370 stems/ha) with high pruning would only be attractive where a price premium was available for pruned sawlogs, as such a regime is unlikely to result in logs suited to structural sawmills due to low wood basic density. A decrease in rotation from 34 to 30 years with or without a third thinning where slightly less financial attractive but this would balance with the shorter time till returns. Planting at a high initial stocking (2,000 stems/ha) followed by two thinning operations and a clear fall at age 24 years was an attractive option. This is however, a high-risk regime as first thinning on-time is vital. The close initial stocking should restrict tree diameter growth and result in non-structural corewood restricted to less of cross-sectional area of the tree stems. Once released, the wood grown is likely to more fit-for-purpose for structural timber recovery.

Routine *E. globulus* silviculture is to plant at final stocking and clear fell at age 12 years. A more financially attractive variant is to use whole tree chipping (WTC) operations, but this is limited to large compartments (e.g. 40 to 50 ha) to be financially viable. A shortening of rotations to 8 years does bring forward returns but reduced MTV will increase harvesting costs and reduce such returns. From a processor perspective, the wood of younger *E. globulus* will have a lower basic density. A delay in clear falling to 18 years allowing for increased growth is an attractive option with or without any assumed sawlog type premiums. The larger trees are cheaper to harvest and have the benefit of a higher wood basic density. While not a current option in the GT, a single thinning at age eight years with clear falling at age 18 years is an attractive regime due to reduced harvesting costs at final harvest and an early cash flow. The larger trees could facilitate alternatives to the current export woodchip market; if there was adequate scale and continuity of resource available, a market could develop.

Introduction

A portfolio of projects

This report presents a broad range of options and analysis outcomes of consideration of alternative silviculture for *Pinus radiata* (radiata pine) and *Eucalyptus globulus* (Tasmanian blue gum) plantations. It is important to note that not all alternative regimes are commercially viable. The target audience for this report are technical experts who support farmers considering involvement with trees for harvest with sale of the resulting logs.

The key variation between regimes is the time frames; shorter *P. radiata* regimes than the current 34 years and both shorter (8 years) and longer rotations (18 years) for *E. globulus* rather than the current 12-year regime. This report is part of a portfolio of five South Australian Department of Primary Industries and Regions (PIRSA) projects implemented by the Green Triangle Forest Industry Hub (GTFIH). Each project has been designed to as a separate project (see Box 1), with each providing relevant information to interested landholders. This project (project 1) in effect, pulls together insights and outcomes from the other projects (except project 4 in regard to carbon). Carbon has been addressed by a specific project and the ability to claim carbon has been considered by that project (see Wilson, 2023). This project does not include carbon returns as part of the wood flows and returns from the trees grown.

Box 1: The Green Triangle Forest Industry Hub and South Australian Department of Primary Industries and Regions project portfolio.
• Project 1: Research new shorter rotation silvicultural models for pine plantations and longer rotations for blue gum plantations. • Project 2: Conduct a study on the barriers which inhibit processors, harvesters, and hauliers processing smaller amounts of logs from farm forests and how they may be addressed. • Project 3: Conduct a spatial analysis study of suitable land areas for farm forestry based on growth potential and proximity to processing facilities. • Project 4: Conduct a study on the benefits of participating in the Emissions Reduction Fund under the plantation forestry method compared to the farm forestry method. • Project 5: Engage a tax expert to provide forestry tax information relevant to farmers.

Alternative silviculture

There are multiple potential silvicultural regimes for the Green Triangle (GT) and assessment can take multiple forms in isolation or in combination. While some are unlikely to be commercially viable, the intent was to provide a broad base for detailed consideration. Indeed, a useful outcome is to determine which are potentially viable and those that are specifically not so. This has been facilitated by applying broad-brush productivity assumptions and a range of GT specific knowledge. Indeed, this report with the supporting appendices provides a collation of a broad range of information. It is possible and legitimate to simply plant the type of trees that an individual likes, provided that this is an informed decision and choice. An alternative is to consider the fit with the farming family and the farmer involved. This includes consideration of succession planning and retirement needs, business structure and farming enterprises (see Jenkin, 2023). From a tree crop perspective, a fundamental requirement is to understand current and active markets for any wood resources grown. This will define the species to grown, the target log size and the potential value of such logs to a grower. This has been addressed by Geddes and Parsons (2023), and is considered in more detail (see Appendix 3: Log products and prices in the Green Triangle).

Harvesting costs are as important as product value in defining grower returns. While Geddes and Parsons (2023IMP) address these costs, this report addresses these in greater detail (see Appendix 4: Harvest and transport costs in the Green Triangle). This analysis includes reliance on a set of composite GT harvesting cost profiles and these are highly indicative. Haulage costs to a mill gate or buyer are defined by haulage distance, truck type and products. Haulage distance has been addressed by Wilson *et al*. (2023) and truck type and costs in a broad sense are addressed by Geddes and Parsons (2023). A more detailed consideration is presented in Appendix 4: Harvest and transport costs in the Green Triangle. A next consideration is the site and the site attributes relative to tree growing; which trees will grow and how fast? This has been addressed on a regional basis by Wilson *et al.* (2023) by generating a productivity mapping layer for the Green Triangle. All these elements have been collated in a financial model to present scenario outcomes.

Document structure

To assist the reader, this document is structured around a ‘front section’ that provides a standalone synthesis of the outcomes of the analysis in a form that can assist the reader in decision making or to support other parties in regard to selection of an alternative silvicultural regime, or to deploy a current regime (Table 1). In a similar manner, each supporting appendix is a standalone sub-report that distils existing information or presents information generated in support of this project. Each appendix has been prepared by authors with specific experience in the topic presented.

Table 1: A roadmap of the report structure and supporting appendices.

Section	Description	Primary authors
Main body of the report	This provides a distillation of a broad range of information and the outcomes of the analysis of each alternative regime compared to based case (routine) regimes.	
Appendix 1: The financial model and analysis	Details of the financial analysis basis and the outcomes for each regime.	Braden Jenkin
Appendix 2: A history of silviculture in the Green Triangle	A history of silviculture in the GT as a basis of understanding options for alternative regimes.	David Geddes
Appendix 3: Log products and prices in the Green Triangle	A summary of current log products generated and the prices received by the sellers as an input to the financial analysis.	David Geddes
Appendix 4: Harvest and transport costs in the Green Triangle	A summary of current harvest and haulage costs for a range of silvicultural regimes as a basis of inputs into the financial analysis.	Lew Parsons and Braden Jenkin
Appendix 5: Stocking and wood quality	A summary of variation in wood properties with different silviculture with a focus on standing stocking rates.	Geoff Downes
Appendix 6: A wide spaced P. radiata woodlot	A report on an assessment of an actual 27-year-old wide spaced *P. radiata* stand in the GT as a basis of developing a wide spaced alternative regime and its evaluation.	Braden Jenkin and Geoff Downes
Appendix 7: Eucalyptus globulus stem analysis	A report on an assessment of an actual 15-year-old *E. globulus* initial stocking and thinning trial in the GT. The first report developed a one-way volume function as an input to understanding the implications of initial spacing options.	Braden Jenkin and Geoff Downes
Appendix 8: Eucalyptus globulus wood disc analysis	A report on an assessment of an actual 15-year-old *E. globulus* initial stocking and thinning trial in the GT. The second report, reports on stand basic density and other properties determined from wood samples.	Braden Jenkin and Geoff Downes
Appendix 9: Eucalyptus globulus trial; DBHOB and basic density assessment	A report on an assessment of an actual 15-year-old *E. globulus* initial stocking and thinning trial in the GT. The third report, reports on stand growth and wood properties.	Braden Jenkin and Geoff Downes

Current standard plantation regimes in the Green Triangle

A snap-shot of the Green Triangle

The Green Triangle is located in south-west Victoria and south east-South Australia and has a plantation estate of 344,710 ha integrated with domestic processing and export markets. The plantation estate is composed mainly of *P. radiata* (Figure 1) supplying a range of roundwood products, and export woodchips and *E. globulus* (Figure 2) targeted at export woodchips. While others species have been planted historically, *E. globulus* and *P. radiata* are the only species with deep current and active markets. The current log output from the GT is around 6.3 million GMT/y. Of importance is a lack of local peeling and pulp log processing and manufacturing capacity.

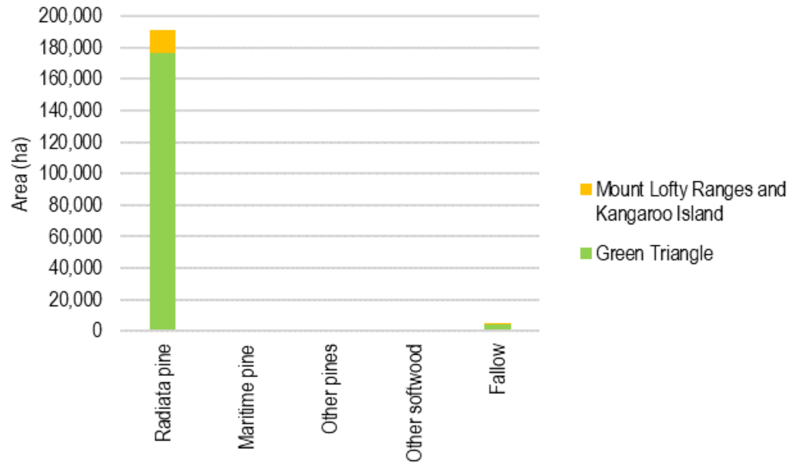

Figure 1: The GT softwood plantation estate as at 2020/21 based on ABARES (2022, p.6).

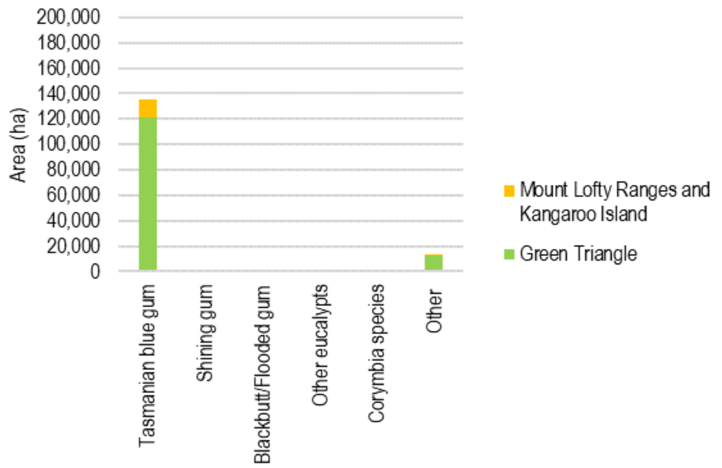

Figure 2: The GT hardwood plantation estate as at 2020/21 based on ABARES (2022, p.7).

Plantation productivity results from silviculture, genetics and site. Plantation productivity is critical as the volume of trees grown combined with stocking rates defines a stand's mean tree volume (MTV). The MTV (expressed in green metric tonnes per stem) of trees to be harvested, defines harvesting costs as a significant cost and driver of net returns to growers. Site attributes include natural attributes (e.g. effective rainfall, temperature and sunshine) and anthropogenic modifications (e.g. residual nutrients from agriculture). The only precise estimate of site productivity is based on a specific site assessment of by a competent party. It is possible to make use of regional models. Broadscale mapping of productivity is possible and has been undertaken for the region making use empirical models (e.g. Burns *et al.,* 1999) which apply correlations of yield with combinations of site attributes (e.g. generally soil and rainfall). As part of the portfolio of projects (see Box 1), a process-based modelling exercise has been undertaken (see Wilson *et al*., 2023).

Current silviculture

Softwood

Current *P. radiata* silviculture is presented in Table 2; *P. radiata* is harvested and delivered to processors with the bark on, hence all values are over-bark. Trees are grown over a long-rotation of 34 years (the assumed base case), however there has been a shift to, a shorter rotation of 30 years applied. The stands are commercially thinned two to three times. This silviculture is the culmination of over a century of experiences (see Appendix 2: A history of silviculture in the Green Triangle. The current planting spacing for standard *P. radiata* plantation establishment is 2.5 m between rows and 2.5 between the trees within a row resulting in an initial stocking of 1,600 stems/ha. Establishment costs of around $1,610/ha for R1 sites are incurred depending on the site. In this case, establishment costs are assumed to be those costs in the same financial as the trees were planted in. That is, if the trees are planted in June, all works from July onwards are maintenance costs. Broadcast pruning is not undertaken.

Hardwoods

Current *E. globulus* silviculture is presented in Table 3; *E. globulus* is harvested, de-barking and delivered to processors as logs without bark, hence all values are under-bark. Trees are generally grown over a short-rotation of 12 years (the assumed base case), with in some cases a longer rotation, not by intent, but due to woodflows and harvesting priorities by managers (e.g. exiting leasehold blocks as a priory over plantations on land owned). The stands are not thinned. This silviculture was informed by lessons from the softwood estate across Australia and specific research for this species. The current planting spacing for standard *E. globulus* plantation establishment is 4.0 m between rows and 2.5 between the trees within a row resulting in an initial stocking of 1,000 stems/ha. Establishment costs of around $1,320/ha for R1 sites are incurred depending on the site. As with *P. radiata*, establishment costs are assumed to be those costs in the same financial as the trees were planted in. That is, if the trees are planted in June, all works from July onwards are maintenance costs. Broadcast pruning is not undertaken.

Table 2: A summary of conventional *P. radiata* plantation regimes (see Appendix 4: Harvest and transport costs in the Green Triangle).

Operation		(Units)	Thinning			Clear fall		
			T1	T2	T3	Routine	Early	Early, no T3
Age		(y)	12	18	24	34	30	30
Initial stocking		(stems/ha)	1,550	700	450	300	300	450
Stems removed		(stems/ha)	850	250	150	300	300	450
Residual stocking		(stems/ha)	700	450	300	0	0	0
Bark			Bark-on	Bark-on	Bark-on	Bark-on	Bark-on	Bark-on
Harvest yield	Lower	(GMT/ha)	60	55	105	360	270	400
	Average	(GMT/ha)	90	80	130	460	370	500
	Upper	(GMT/ha)	120	105	155	560	470	600

Table 3: A summary of *E. globulus* plantation regimes by harvesting with cut-to-length or whole-tree chipping in the GT (see Appendix 4: Harvest and transport costs in the Green Triangle).

Operation		(Units)	Clear fall	Clear fall
			Whole tree chipping	Cut to length
Age		(y)	12	12
Initial stocking		(stems/ha)	950	950
Stems removed		(stems/ha)	950	950
Residual stocking		(stems/ha)	0	0
Bark			Debarked	Debarked
Harvest yield	Lower	(GMT/ha)	105	105
	Average	(GMT/ha)	205	205
	Upper	(GMT/ha)	305	305

Motivation for change

A key motivation for change from current silviculture is to bring forward the final harvest age in softwood plantations and to seek to generate alternative log types from hardwood plantations by increasing the rotation length (Table 4). With softwoods, a shorter rotation would bring forward returns and contribute to making investment more attractive, assisting in encouraging estate expansion. A shorter rotation would also allow a more rapid turnover of genetics with deployment of the latest advanced materials improving wood properties and yield. A longer rotation hardwood regime would allow trees to grow larger with potential for processing beyond pulpwood; realisation of this potential would require fit-for-purpose wood properties.

Table 4: A change matrix presenting alternative silviculture options for *P. radiata* and *E. globulus*.

		Softwood	Hardwood
Current		30 to 34 years clear falling	Target 10 to 12 year clear falling.
Change	Longer	Not an option.	A longer rotation producing larger logs for alternative products.
	Shorter	A shorter rotation regime to supply similar log products in the same markets.	A shorter regime to supply the same markets.
		A shorter rotation regime by planting at final stocking to maximise individual tree growth.	An option.
	Much shorter	A much shorter regime to supply a reduced range of products.	An option with likely smaller MTV.

Assessment of alternative regimes

The fit-for-purpose of any alternative regime will be defined by the end user of the log outputs (e.g. total yield, log size and wood properties) and meeting the needs of the grower. Grower needs may or may not relate to the physical nature of the resulting logs nor the total yield as these are more the concern of industry. It is more likely that a grower has a focus on returns per hectare where the intent is to sell the resulting logs; considering the quantity, timing and associated risks of cashflows relative to individual needs. The quantity of returns can be compared to alternative investments and the timing can relate to anticipated future events (e.g. retirement). Risk is a specific issue with plantations exposed to biological (e.g. disease and insects), physical (e.g. fire and wind) and markets (e.g. future markets for the final crop). A specific consideration is where an alternative regime is predicated on market access (e.g. for thinning to enable a regime) or an expectation of a new market (e.g. a price premium for pruned logs).

To assist with assessment of alternative regimes, a net present value (a pre-tax NPV at 4% real) financial model was been constructed which allows generation of a wide range of scenarios (see Appendix 1: The financial model and analysis). This model incorporates the insights presented in the appendices to this report (see Table 1) and has the flexibility to test each scenario. The driver of the financial outcome is the margin between cost of production and log price at the mill gate. In some situations, the costs are higher (e.g. harvesting smaller trees costs more per green tonne of wood handled) but the mill gate price remains the same reducing the margin. The outputs of this assessment are presented as cashflows (see Appendix 1: The financial model and analysis) on a relative basis to the base case. This matrix sets the base case at a value of '1' and then reports each regime on a relative basis for the resulting total yield of logs and the pre-tax $NPV_{4\%\ REAL}$ in a chart format. A guide to interpreting the outcomes is presented in Table 5. A grower with no interest in log end-use, would focus on results equal to or better than the base case (above the relative pre-tax NPV = 1 line). Where a grower seeks to align timing of final harvest with their needs, it is possible to select alternative regimes with suitable timing. This analysis will assist to determine which is more financially attractive. The reader should seek appropriate technical support and seek to match their needs with the regime options.

Table 5: A matrix of the outcomes of the alternative regimes tested.

		Total yield		
		Less than 1	Routine regime = 1	Greater than 1
$NPV_{PRE\ TAX}$	Greater than 1	The alternative regime: • Generates less wood resource. • Has a better financial outcome at $4\%_{REAL}$ and pre-tax.		The alternative regime: • Generates more wood resource. • Has a better financial outcome at $4\%_{REAL}$ and pre-tax.
	Routine regime = 1			
	Less than 1	The alternative regime: • Generates less wood resource. • Has a poorer financial outcome at $4\%_{REAL}$ and pre-tax.		The alternative regime: • Generates more wood resource. • Has a poorer financial outcome at $4\%_{REAL}$ and pre-tax.

Alternative softwood silviculture

Alternative regimes

The regimes

There are four broad alternative softwood regimes (see Table 4) and Table 6 presents a summary of the regimes tested. The first is a shorter rotation targeting the same log output mix. That is, sawlogs as the primary objective supported by a range of logs into alternative markets. This can be achieved by shortening the current regime by replacement of T3 with a clear falling at age 24 years. This regime is predicated on commercial thinning and markets for the resulting logs. The second is to plant at a 2,000 stems/ha rather than 1,600 stems/ha and thin at T1 to a routine spacing. A third and more radical regime is to plant at final stocking, more intensively manage individual trees (e.g. high pruning) and clear falling at 20 to 27 years; this is likely to generate similar size trees. A much shorter regime established at 2,000 stems/ha would be clear felled at routine T1 age (between 10 to 15 years) with no thinning to generate non-sawlogs or to plant at routine initial stocking and clear fall at routine T1 age.

Table 6: A high level summary of the *P. radiata* regimes modelled.

		Initial stocking	T1	T2	T3	CF	Current status
		(stems/ha)	(y)	(y)	(y)	(y)	
Routine clear fall		1,600	12	18	24	34	A current regime with active markets and service providers.
Early clear fall		1,600	12	18	24	30	A current regime with active markets and service providers.
Early clear fall	No T3	1,600	12	18		30	A current regime, but with active markets and service providers.
Wide spacing	Short rotation	370				20	A non-current regime, with no active markets for pruned logs.
Wide spaced	Short with log price premium	370				20	A non-current regime, with no active markets for pruned logs. There is no price premium currently available.
Wide spaced	Long rotation	370				27	A non-current regime, with no active markets for pruned logs.
Routine initial stocking	Short rotation	1,600				12	A non-current regime, reliant on on-time harvest to reduce the risk of wind damage and losses.
High initial stocking	Short rotation	2,000				12	A non-current regime, but with active markets for pulp logs and preservation logs. There are current service providers.
High initial stocking	Long rotation	2,000	12	18		24	A non-current regime, but with active markets for pulp logs and preservation logs. There are current service providers.

Wood properties considerations

Wood properties are an important consideration to the party purchasing logs. Industry has commenced a practice of pre-harvest IML PD Series Power Drills (Resi) assessment of stands to gain an understanding of expected wood properties. This can be used to accept or not stands, and/or to assist in price determination were permitted by any wood supply agreement (WSA) in place. Assessment of a 16-year-old *P. radiata* spacing trial located at Gurnang (NSW) with initial stocking ranging from 333 to 2,220 stems/ha was undertaken by another project (Downes *et al.*, 2022, p.1). The mean diameter at breast height over bark (DBHOB) of the trees was smallest with the highest stocking with a continuum to being largest for the lowest stocking (Downes *et al*, 2022, p.6; see Appendix 5: Stocking and wood quality). This research found that there was no difference in stem radial basic density variation between initial spacings but that the 333 stems/ha trees had lower disc basic density (the weighted average of the radial trace determined by stem DBHOB). This lower density was found to continue to the mature wood. A conclusion was that faster grown individual trees had lower basic density (Downes *et al*, 2022, p.1). This is expected to translate to a lower percentage of log volume recovered as structural timber (MGP10 or greater) when processed by a sawmill. Field work undertaken by this project considered the impact of wide-spaced planting at final stocking (see Appendix 6: A wide spaced P. radiata woodlot). The trees grown under a wide spaced initial planting regime are unlikely to be accepted by structural pine sawmills due to low potential recovery of MGP10 or better structural timber. This is consistent with implications of the outcomes presented by Downes *et al.*, (2022). A more radical regime planting at higher stocking and thinning to routine stocking at T1 aims is to confine the corewood (non-structural quality wood) to a minimal cross-sectional area and after thinning, the resulting radial growth should be of better quality (MGP10 or better) wood.

Outcomes

Consideration of the outcomes of the analysis of the range of regimes commences with total yield (see Figure 3). The analysis considered ‘low’, ‘average’ and ‘high’ productivity options. The average productivity base-case is presented as a benchmark, with the yield bar highlighted in red. A change of regime (shortening) will reduce the total yield and volume of logs recovered at harvest as there is less time to grow wood. A matrix comparing the financial outcome of the alternative regimes to the base-case is presented in Figure 4. The x-axis presents the impact on yield and the y-axis, the impact on pre-tax $NPV_{4\%REAL}$. The financial analysis includes growing, harvest and haulage costs. Any alternative above the ‘1’ line is better financially and any alternative to the right of ‘1’ line has a better yield (see Table

5). Therefore, values both above and to the right of '1' are better options, however, from a grower perspective, the focus is likely financial.

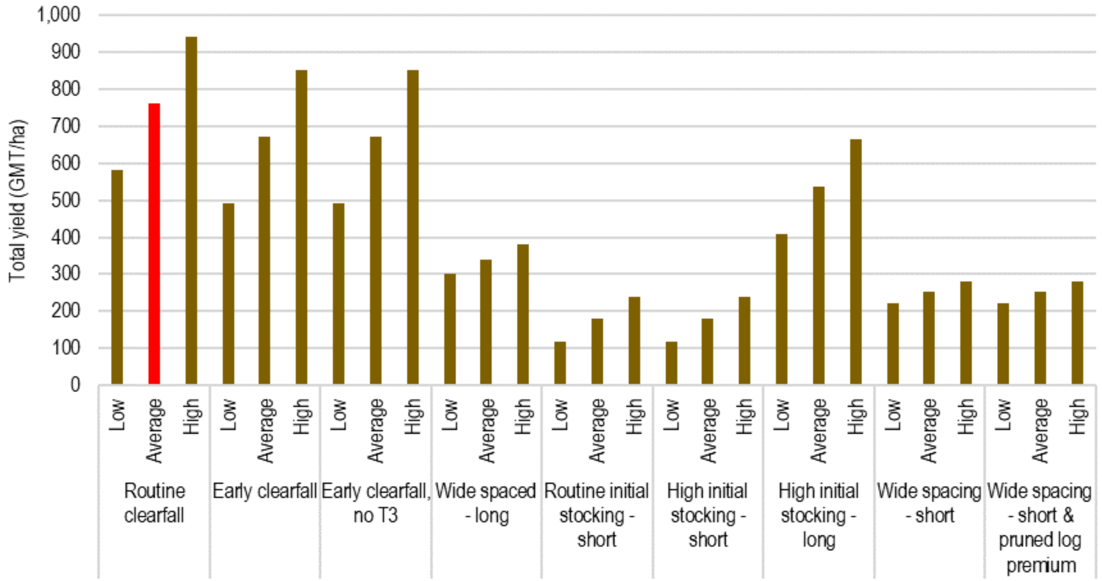

Figure 3: The total yield outcome of the alternative *P. radiata* regimes considered; each includes a 'low', 'average' and 'high' productivity scenario. The red bar presents the assumed average for the base case

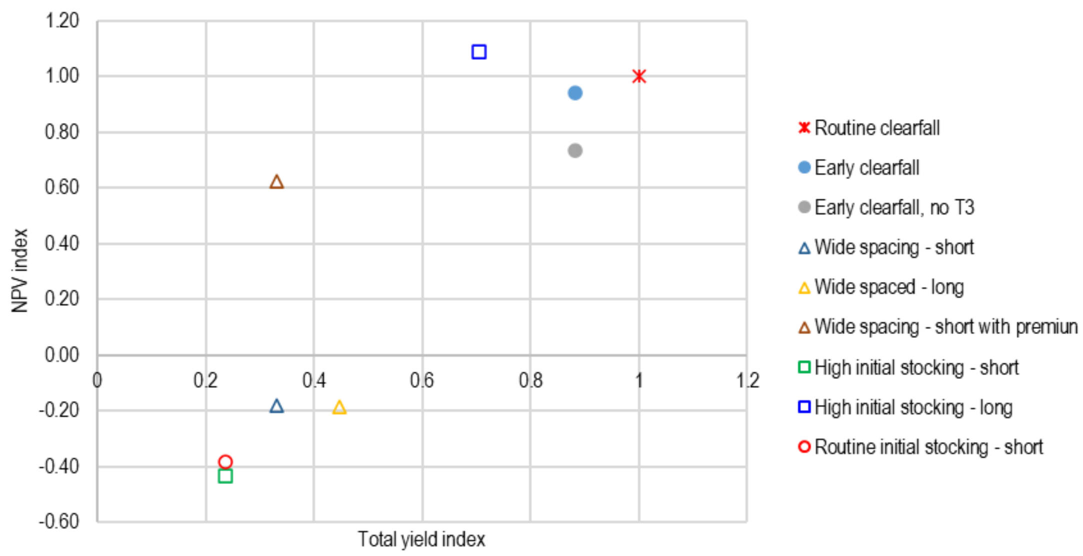

Figure 4: The outcome of the alternative *P. radiata* regimes analysis; each is the average productivity scenario.

Outcomes of the individual regimes

Early clear fall

There are two routine early clear fall alternatives setting final harvest at 30 years. The first is an early clear fall scenario with three standard thinning events. This is a current approach taken by some managers in the GT. A shorter rotation has an advantage that final returns are quicker. However, with a shorter rotation and less time to grow wood, such stands have reduced yield (a modelled reduction of 90 GMT/ha for the 'average' treatment) and product mix changes with less larger sawlogs produced. With reduced yield at clear fall, harvest costs increase from $11.59/GMT to $13.17/GMT reducing returns. This reduction in rotation should have minimal impact on log wood quality and therefore markets. The second is to omit the T3 with an early clear fall, which is also a current approach taken by some managers. While maintaining the advantage that final returns are quicker, there are reduced cashflows due to a lack of a T3. Assuming the same growth rates, the final harvest MTV is reduced due to higher stocking (no T3), increasing final harvest costs from the base case rate of $11.59/GMT to $13.82/GMT. The modelled outcome was that an early clear fall with three thinning operations would be financially more attractive than the base case, whereas omitting the T3 operation reduces the value of the stand slightly (see Figure 4).

Wide spaced at establishment

While historically promoted, the impact of a wide spaced initial planting on returns is generally unknown. The modelled outcome of two wide spacing scenarios is presented. In both cases stands were assumed to be planted at 370 stems/ha with investment in pruning required to control significant retained branching. Branching is controlled in routine stands by the shading effect of neighbouring trees. While there are establishment cost savings (e.g. fewer plants needed), a stand planted at final stocking rates only generates income at final harvest (at rotation) rather than over the rotation. With the time value of money, this places increased pressure on financial outcomes. The initial saving in planting stock costs (from c.$670/ha to $137/ha; a saving of $535/ha) results in an additional cost of pruning. With multiple lifts at a total cost of $4.50/stem, this equates to an extra $1,665/ha and with the saving in planting stock, the net result is an extra cost of $1,130 /ha. The first scenario is a final harvest at age 20 years. While a short rotation has an advantage that final returns are sooner, there is less time to grow wood (and fewer trees to grow) and such stands will have reduced yield (a modelled reduction from the base case of 508 GMT/ha). With reduced yield at clear fall, MTV will reduce and harvest costs increase from the base case of $11.59/GMT to $16.68/GMT. The second scenario was a final harvest at age 27 years. Such stands have reduced yield compared to the base case (a modelled reduction of 420 GMT/ha for the average treatment) reducing MTV. With a reduced MTV at clear fall, harvest costs increase from the base case of $11.59/GMT to $15.21/GMT. As discussed, such trees have reduced wood density and are unlikely to be accepted by a structural sawmill. Further, while the trees are assumed to be high pruned to recover a 6 m long pruned log, there are no current price premiums. Noting a lack of a current market for pruned logs, a scenario was run with wide spacing and a 20-year clear fall assuming a price premium for the logs (assumed at the current highest log price). This scenario improved financial returns but they would remain below those of the base case. Regardless of rotation length, the quality of potential logs above the pruned section will be compromise by the heavy branching with limited potential for recovery of saw logs. The modelled outcome was that wide spaced regimes are unattractive, and with a pruned log price premium they would be slightly more attractive (see Figure 4).

Short rotation regimes

There are two broad options for a short rotation softwood regime; plant at routine (1,600 stems/ha) or at a higher (2,000 stems/ha) stocking. With a routine stocking regime, it is possible to clear fall a stand at the age at which a T1 would be undertaken (age 12 years). The total yield is much reduced and the logs recovered are pulp wood and/or preservation logs. The harvested trees would have a smaller MTV than for a routine clear-fell with a harvesting cost increase from $11.59/GMT to $30.10/GMT. The high cost of harvest combined with a low pulp log price makes this regime less financially attractive than a longer rotation base-case regime.

The second option is to plant at a higher initial stocking. The intent of a high initial stocking short rotation regime is to maximise clear fall production of pulpwood and/or preservation logs recovered at age 12 years. With higher initial stocking, the individual trees will be smaller in DBHOB with tighter growth rings and a likely higher basic density. The regime assumes increasing initial stocking from 1,600 stems/ha to 2,000 stems/ha with an increase in planting stock costs from $670/ha to $837/ha. With closer spacing other establishment costs also increase and these have been modelled. With a higher stocking rate, even after initial losses (survival assumed at 97%), MTV at clear fall is smaller than the base case T1 regime. Comparing costs for the base case T1 to this regime, harvest costs increase from $30.74/GMT to $32.20/GMT. When compare to the base case final harvest costs, the cost increases from $11.59/GMT to $32.20/GMT. The high cost of harvest combined with a low pulp log price makes this regime less financially attractive, however, the routine stocking and short rotation is a more attractive very short rotation option.

A high initial stocking with medium length rotation

The intent of a high initial stocking, medium rotation regime is to maximise stem corewood basic density and recover pulpwood and/or preservation logs at T1. The core of each tree will have tighter growth rings and subsequent wood grown should be of better mechanical properties. A T2 thinning was assumed with a final harvest at age 24 years. The T1 thinning MTV are smaller than the base case regime with increased costs; from $30.74/GMT to $33.05/GMT. With a T2 thinning and early clear fall, the MTV of the final harvest trees was assumed to reduce from a base case of 1.53 GMT/stem to 1.02 GMT/stem increasing final harvest costs from $11.59/GMT to $14.53/GMT. If log wood properties are enhanced, this is an attractive alternative regime. While this is a potentially attractive regime, the absolute need for on-time T1 thinning makes this a high-risk regime. Pressure on getting T1 thinning undertaken can come from a lack of markets and/or local harvesting capacity as has occurred in the past.

Alternative hardwood silviculture

Alternative silviculture

The regimes

There are three broad alternative regimes (see Table 4) with a subset of whether trees are cut to length (CTL) or whole tree chip (WTC), an inclusion of thinning or not and pruning after thinning (see Table 7). The base case regime assumed was a CTL operation clear falling stands at age 12 years. A current and common variant of the base case is to undertake WTC of the trees recovered. This can occur at the same age. While not common, there is the option to undertake final harvest at an earlier age either with CTL or making use of WTC operations. The MTV of the trees is reduced. A later (either at age 15 or 18 years) clear fall is an option and is a current regime by default rather than by intent. While thinning is not usual in *E. globulus* stands in the GT, a longer rotation targeting a different log output mix by thinning is possible. That is, 'sawlogs size' logs as the primary objective supported by a range of logs into alternative markets. This can be achieved by lengthening the current regime with a thinning event at age 8 years (as applied in Tasmania for *E. nitens* destined to produce sawlogs and veneer logs). This regime is predicated on commercial thinning and markets for the resulting bigger logs. A longer rotation is likely to have carbon related benefits when compliant with eligibility requirements.

Wood properties

Routine *E. globulus* silviculture recovers wood for processing into woodchips and exporting for production of fine papers. Wood basic density and pulp yield are key attributes that define market acceptance. Utilisation of logs for alternative products requires specific attention. It is possible to grow a bigger tree and recover bigger logs, but will they be able to utilised by other processes beyond pulpwood? This will be driven by whether the resulting wood properties fit-for-purpose. Downes *et al.* (1997) presents a discussion of variation in wood properties in eucalypts. Variation in wood properties of *E. globulus* have been considered with field work undertaking Resi assessment of standing trees and destructive sampling for recovery of samples for assessment (see Appendix 7, 8 and 9). Sampling of a 15-year-old initial spacing with one thinning treatment trial was undertaken. Analysis found that wood basic density was roughly consistent for half of the tree diameter after which it increased. Assuming uniform DBHOB increment, wood density improved from roughly age 7 to 8 years of age. Trees harvested earlier will have a lower average basic density than trees harvested later.

Table 7: A high level summary of the *E. globulus* regimes modelled.

		Initial stocking	T1	T2	T3	CF	Current status
		(stems/ha)	(y)	(y)	(y)	(y)	
Routine clear fall	Logs CTL	1,000				12	A current regime with active markets and service providers.
Routine clear fall	With WTC	1,000				12	A current regime with active markets and service providers.
Early clear fall	Logs CTL	1,000				8	A non-current regime, but with active markets and service providers.
Early clear fall	With WTC	1,000				8	A non-current regime, but with active markets and service providers.
Late clear fall	Logs CTL	1,000				18	A current regime by default rather than intent, with active markets and service providers. No sawlogs assumed.
Late clear fall	Logs CTL	1,000				18	A current regime by default rather than intent, with active markets and service providers. Recovery of sawlogs assumed.
Medium clear fall	Logs CTL with a T1	1,000	8			15	A non-current regime, but with active markets for pulp logs and some exports possible of sawlog size logs. There are current service providers.
Late clear fall	Logs CTL with a T1	1,000	8			18	A non-current regime, but with active markets for pulp logs and some exports possible of sawlog size logs. There are current service providers.
Late clear fall	Logs CTL with a T1 & pruning	1,000	8			18	A non-current regime, but with active markets for pulp logs and some exports possible of sawlog size logs. There are current service providers. Assumes stands are high pruned.

Outcomes

Again, consideration of the outcomes of the analysis of the range of regimes commences with total yield (see Figure 5). The analysis considered 'low', 'average' and 'high' productivity as options. The base-case is presented as a benchmark, with the average productivity bar highlighted in red. A change of regime (shortening) will reduce the total yield and volume of logs recovered at harvest, and a longer regime will increase the total volume produced. The analysis assumed that the same volume was recovered with CTL and WTC operations, but the harvesting cost profile is different (e.g. WTC costs more per green metric tonne). Further, the value of the woodchips produced and sold is greater that for logs from a CTL operation and is in-excess of the increased harvesting costs. Therefore, the WTC option is more attractive but limited to large scale operations. A matrix comparing the alternative regimes to the base-case is presented in the Figure 6. The x-axis presents the impact on yield and the y-axis the impact on pre-tax $NPV_{4\%REAL}$. Any alternative above the '1' is better financially and any alternative to the right of '1' line has a better yield (see Table 5). Therefore, values both above and to the right of ‘1’ line are better options if yield is considered an issue. Growers are more likely focussed on the financial results.

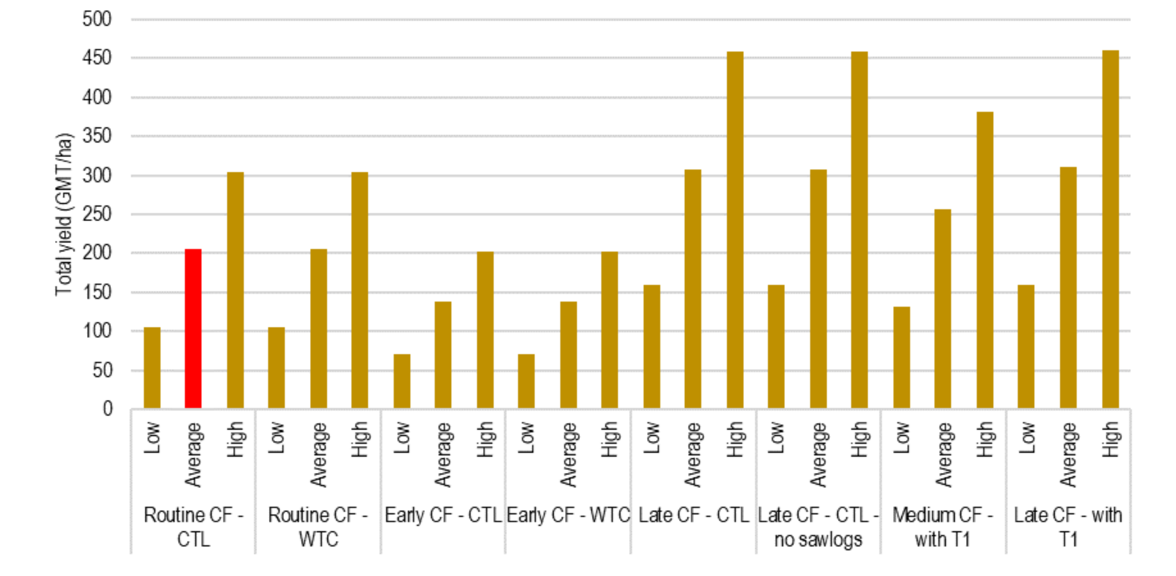

Figure 5: The total yield outcomes for the alternative *E. globulus* regimes; each includes a ‘low’, ‘average’ and ‘high’ productivity scenario. The base-case is presented as a red bar.

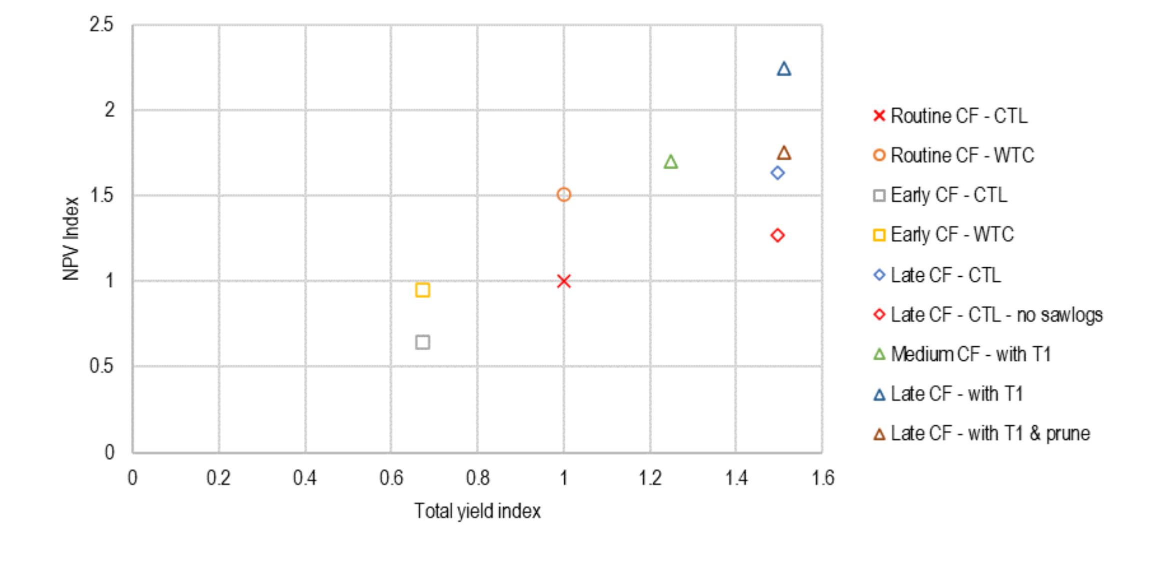

Figure 6: The outcome of the alternative *E. globulus* regimes analysis; each is the average productivity scenario.

Outcomes

Whole tree chipping

A WTC *E. globulus* regime applies a different approach to harvest and products delivered; stems are chipped onsite and woodchips transported to the mill gate. As presented in Figure 6, use of WTC is a more attractive financial option than CTL harvesting and log delivery (the bench mark). This is driven by the cost deference between WTC and CTL ($25.75/GMT to $33.00/GMT) and the difference in price paid for woodchips compared to logs (around $21.00/GMT); an improved margin of $12.20/GMT results. While this is attractive, this option is limited to large-scale plantations (a minimum harvest area of 40 to 50 ha) due to the cost of machine movement and daily through-puts. A further limitation is that internal roading must be of a higher quality to the plantation edge (roading charges were assumed to increase from $2.00/GMT to $4.00/GMT). Stem skidding distance must be minimal and only a single product is produced (woodchips).

A shorter rotation

A shorter eight-year rotation *E. globulus* regime can reduce annual maintenance costs, but results in less volume at harvest for the same site productivity. A lower volume will reduce MTV, increasing harvesting costs from $25.75/GMT to $29.73/GMT, resulting in a lower net return to growers. The wood properties of younger trees are likely to be different with lower basic density reducing the weight of wood sold and therefore gross returns. The overall outcome for 4 years saved is a lower financial result compared to the base case (Figure 6).

A longer rotation

Rotations for *E. globulus* in the GT longer than 12 years are common, but not by initial intent. Three options have been considered (Figure 6). The first is a longer no-thin option with harvest at age 18 years. Such a regime has been undertaken in the GT, with sites able to support the trees with limited losses in some cases and with self-thinning in others. With continued growth, such stands will yield a larger volume of logs compared to the base case regime. Therefore, the older trees are individually larger reducing harvesting costs from $25.75/GMT to $23.31/GMT. With larger trees it is possible to recover larger logs which may be classed as sawlogs for export purposes. There is no current plantation grown hardwood sawlog market processing such logs in the GT. A price premium over chip logs of $9.00 to $13.00 at the port gate was assumed with 20% sawlog size log recovery for harvest. With the same regime and assuming no sawlog size price premiums, the regime has reduced financial performance, but remains superior to the base-case outcome.

It is possible to commercially thin *E. globulus* stands with an aim to increase the average size of the residual stems grown over a longer rotation. A thinning at age eight years can be commercial, generating a net positive return assisting with cashflows. A final harvest at age 15 years with larger trees, decreases harvest costs from $25.75/GMT to $22.80/GMT. With an assumed 30% sawlog type logs for export recovered, the financial outcome is better than for the base case. With the same assumed thinning age of eight years, a rotation can be extended to 18 years. This further reduces harvesting costs from $25.75/GMT to $21.22/GMT and with an assumed 50% sawlog type logs, the financial outcomes are better than the base case (Figure 6). A grower would need to consider whether they would wish to wait the extra six years and whether log exports will be possible, or the development of a local processor.

Observation in the GT indicate that in the absence of pruning, *E. globulus* can hold onto branches (Figure 7). From a market perspective, there is no price premium for pruned trees. To test the implications that market access for larger logs required pruning, a regime was run with thinning and pruning. The outcome was a decrease in financial attractiveness compared to the base case regime (Figure 6). To warrant pruning a log price premium is required, hence if a market requires pruned logs, this reduces the financial attractiveness of this regime in the absence of a price premium

Figure 7: A 15-year-old an un-pruned *E. globulus* with retained branches (left) and a cross section of a tree stump on the same site showing a dead branch trace from bark to pith (above). (Sylva Systems©.)

Implications and use of this information

To assist in considering which regime to apply in a plantation project, Table 8 and Table 9 present a narrative summary of this analysis. A potential grower is free to grow any tree species in any configuration. If a grower seeks to claim ‘primary producer’ status with the trees grown classed as a ‘forest operation’ from an Australian Taxation Office (ATO) perspective, there is a need for an intent to harvest and sell the trees planted for a profit (Jenkin, 2023). Evidence of such intent could be supported by growing current commercial species with active markets under a current silvicultural regime. For the GT this is either *E. globulus* or *P. radiata*. This analysis has identified and considered nine each *P. radiata* and *E. globulus* regimes at ‘low’, ‘average’ and ‘high’ productivity. Regimes varied from current routine and minor variants to more radical and non-current. Whether a regime chosen can satisfy the ATO requirements for primary production status would need to be determined.

A grower may seek to align harvest cashflows with their personal or farm business timing needs. This can be achieved by aligning of harvest ages and timing of cashflow needs. This may require a compromise on plantation returns (e.g. opting for an earlier harvest) or a need to plant one species compared to the other. A point of caution is a need for potential price premiums in response to management inputs. While some regimes are claimed to produce ‘high-value trees’, they are in effect ‘high-cost trees’ until a market places a premium on log prices in excess of routine prices. This is the high value myth. For example, pruning and in particular high pruning, is an expensive operation that to be justified, requires a price premium for the resulting logs. In the absence of a viable and ongoing market, pruning for wood quality is not good management.

Table 8: A high level summary of the *P. radiata* regimes modelled.

		Initial stocking	CF	Current status	Pros	Cons
		(stems/ha)	(y)			
Routine clear fall		1,600	34	A current regime with active markets and service providers.	This is a routine and proven regime.	It is a long-time frame for an individual to invest in; it can be an intergenerational crop.
Early clear fall		1,600	30	A current regime with active markets and service providers.	This is a routine and proven regime.	It is a long-time frame for an individual to invest in; it can be an intergenerational crop.
Early clear fall	No T3	1,600	30	A current regime, with active markets and service providers.	This is a routine and proven regime.	It is a long-time frame for an individual to invest in; it can be an intergenerational crop. A lack of a T3 reduces pre-final harvest cashflows.
Wide spacing	Short rotation	370	20	A non-current regime, with no active markets for pruned logs.	A much shorter time frame for returns. There is potential for some concurrent agricultural use of the land under the trees.	This is an un-proven regime. The regime requires significant investment in pruning to 6 m with no current active market for pruned logs.
Wide spaced	Short with log price premium	370	20	A non-current regime, with no active markets for pruned logs. There is no price premium currently available.	There is potential for some concurrent agricultural use of the land under the trees.	This is an un-proven regime. The regime requires significant investment in pruning to 6 m with no current active market for pruned logs.
Wide spaced	Long rotation	370	27	A non-current regime, with no active markets for pruned logs.	There is potential for some concurrent agricultural use of the land under the trees.	This is an un-proven regime. The regime requires significant investment in pruning to 6 m with no current active market for pruned logs.
Routine initial stocking	Short rotation	1,600	12	A non-current regime, reliant on on-time harvest to reduce the risk of wind damage and losses.	From a tree growth perspective, a proven regime but not from a final harvest at T1 timing consideration. A much shorter time frame for returns.	Relies on an ability to clear fall on time to avoid increase stand instability.
High initial stocking	Short rotation	2,000	12	A non-current regime, but with active markets for pulp logs and preservation logs. There are current service providers.	A shorter rotation with potentially multiple local markets.	An unproven regime. Relies on an ability to clear fall on time to avoid increase stand instability. The ability to recover higher value preservation logs is uncertain.
High initial stocking	Long rotation	2,000	24	A non-current regime, but with active markets for pulp logs and preservation logs. There are current service providers.	There is a shorter time frame with periodic cashflows. It is possible that the resulting trees and therefore logs will have better wood properties.	An unproven regime. Relies on an ability to T1 on time to avoid increase stand instability. The ability to recover higher value preservation logs is uncertain.

Table 9: A high level summary of the *E. globulus* regimes modelled.

		Initial stocking	CF	Current status	Pros	Cons
		(stems/ha)	(y)			
Routine clear fall	Logs CTL	1,000	12	A current regime with active markets and service providers.	A current and proven regime.	A single market exposed to export prices.
Routine clear fall	With WTC	1,000	12	A current regime with active markets and service providers.	A current and proven regime.	A single market exposed to export prices. Only suitable for larger-scale operations (40 to 50 ha harvests). A higher standard of road required.
Early clear fall	Logs CTL	1,000	8	A non-current regime, but with active markets and service providers.	A current and proven regime.	A single market exposed to export prices. Younger trees have reduced wood basic density.
Early clear fall	With WTC	1,000	8	A non-current regime, but with active markets and service providers.	A current and proven regime.	A single market exposed to export prices. Only suitable for larger-scale operations (40 to 50 ha harvests). A higher standard of road required. Younger trees have reduced wood basic density.
Late clear fall	Logs CTL	1,000	18	A current regime by default rather than by intent, with active markets and service providers. No sawlogs assumed.	A current and proven regime. A likely improvement in wood properties.	A single market exposed to export prices. A longer time frame for returns.
Late clear fall	Logs CTL	1,000	18	A regime by default rather than by intent, with active markets and service providers. Sawlogs assumed while not current for local processing.	A current and proven regime. A likely improvement in wood properties.	Assumed access to markets for sawlogs while diversifying products is generally non-current. Assumed access to sawlog size log markets with a price premium.
Medium clear fall	Logs CTL with a T1	1,000	15	A non-current regime, but with active markets for pulp logs and some exports possible of sawlog size logs. There are current service providers.	A likely improvement in wood properties.	Assumed access to markets for sawlogs while diversifying products is generally non-current. A non-current regime not supported by current harvesting capacity.
Late clear fall	Logs CTL with a T1	1,000	18	A non-current regime, but with active markets for pulp logs and some exports possible of sawlog size logs. There are current service providers.	A likely improvement in wood properties.	Assumed access to markets for sawlogs while diversifying products is generally non-current. A non-current regime potentially not supported by current harvesting capacity.
Late clear fall	Logs CTL with a T1	1,000	18	A non-current regime, but with active markets for pulp logs and some exports possible of sawlog size logs. There are current service providers. Pruning is assumed.	A likely improvement in wood properties.	Assumed access to markets for sawlogs while diversifying products is generally non-current. A non-current regime potentially not supported by current harvesting capacity. Increased costs due to pruning in the absence of a pruned log price premium.

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Appendix 1: The financial model and analysis

Project 1: Research new shorter rotation silvicultural models for pine plantations and longer rotations for blue gum plantations. Sub-report title: Development of a financial analysis tool and application to the potential plantation management regimes.

Prepared by

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Summary

A financial model was developed to assess and compare alternative silvicultural regimes for *E. globulus* and *P. radiata* plantations in the Green Triangle. The model generated a net present value (NPV) for each regime at a discount rate of 4% real. This rate was selected to reflect a reasonable balance of future compared to more immediate cashflows. The model made use of a range of information collected and presented as appendices to this report; the history of silviculture, current products and pricing, harvest and haulage costs, wood properties and field work in a wide spaced *P. radiata* stand and a *E. globulus* initial stocking and thinning trial. This information was used to generate for testing, a standard or routine base-case regime and eight alternative regimes each for *P. radiata* and *E. globulus* at assumed 'low', 'medium' and 'high' productivity. The outcome of the analysis is presented on a species-specific bench-mark basis setting the routine regime to '1' and presenting the total wood yields and $NPV_{4\%REAL}$ of each at relative values to this bench mark.

Introduction

There are numerous potential silvicultural regimes and assessment can take multiple forms in isolation or in combination. An important consideration is fit with the farming family and the farmer. This includes consideration of succession planning and retirement needs, business structure and farming enterprises (see Jenkin, 2023). From a tree crop perspective, a fundamental requirement is to understand current and active markets for any wood resources grown. This will define the species to grow, the target log size and the potential value of such logs to a grower. This has been addressed by Geddes and Parsons (2023) with a more detailed consideration presented (see

Appendix 3: Log products and prices in the Green Triangle). Harvesting costs are as important as product value in defining grower returns. While Geddes and Parsons (2023) address such costs, this report addresses these in greater detail (see Appendix 4: Harvest and transport costs in the Green Triangle). Haulage costs to a mill gate or buyer are defined by haulage distance, truck type and products. Haulage distance has been addressed by Wilson *et al*. (2023) and truck type and costs in a broad sense are addressed by Geddes and Parsons (2023). A more detailed consideration is presented (see Appendix 4: Harvest and transport costs in the Green Triangle). A next consideration is the site and the site attributes relative to tree growing; which trees will grow and how fast? This has been addressed on a regional basis by Wilson *et al.* (2023) generating a productivity layer for the Green Triangle (GT). All these elements have been collated in a financial model to present scenario outcomes comparing options on the same theoretical site, hence land costs are excluded.

Revenue basis

Stumpage and residual stumpage

Log price can be on a stumpage or residual stumpage basis (Box 2). Residual stumpage is determined by the difference between cost of production, and price paid. For trees sold at the stump, a purchaser pays for harvesting, transport and processing prior to sale as finished goods. Equation 1 defines residual stumpage based on the supply of wood from natural forests through to initial processing (Buttrick, 1950, p.366).

Box 2: Two broad methods of log price basis

Term	Narrative	Reference
Stumpage	*'...the value of timber as it stands uncut, in terms of an amount per cubic unit'.*	Winters (1983, p.264).
Residual pricing (stumpage)	*'…. the value of round-wood is derived from the market price of its products. Thus, the residual value of standing timber is derived by subtracting all the production costs from the selling price of the products that could be made from it.'*	Byron & Douglas (1981, p.13).

Equation 1: Determination of residual stumpage.

$$S_{residual} = P_s - (P_c + P + R)$$

$S_{residual}$	Residual stumpage value to the grower
P_s	Selling price of products
P_c	Costs of production
P	Profit
R	Risk allowance

Available price data

Limited data is available on log prices driven by a general simplicity of markets with one main buyer. Historically, a national market report was published in Australian Forest Grower (e.g. Bhati, 1998) but this is no longer reported. The Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) publishes aggregated national statistics (the Australian forest and wood products statistics series). Data is presented on sales, production and trade; volume and value are presented separately and can be used to calculate averages at national and in some cases, on a state level basis. While a guide, it does not provide specific market insights. Commercial providers of price data are available on a fee--for-service basis (e.g. Industry Edge).

The high-value myth

Raw material and product value are defined by markets which set the price paid. An often-stated claim is the production of high-value trees by thinning and pruning over a longer rotation (e.g. Keenan, 2007, p.28; Brown & Beadle eds 2008). This is the high- value myth. Indeed, such management results in high-cost trees with value assigned independently by a buyer. Unfortunately, a willing buyer may not exist as noted by North (2010, p.14) in regard to 200 GMT of large diameter *E. globulus* logs from a wide spaced, thinned and pruned stand in south west Western Australia. Curiously, across prior pages in the same issue of the same publication, researchers claimed similar ‘sawlogs' of *E. globulus*, *E. viminalis* and *E. saligna* had a modelled value of $100/m^3 (Washusen *et al*., 2010, p.10-11). The two sites where at Bridgetown and Middlesex respectively; 47.2 km apart. A focus on cost inputs combined with market evidence, will focus management inputs to those generating an actual return on investment. Regardless of market evidence, some farmers persist with a philosophical pursuit of more ‘worthy markets' for trees grown. Jacobs (1967, p.3) noted that industries based on pulpwood add more value to raw material than any other industries based on wood; industries based on pulpwood and chips are the most sophisticated in the forest products field (Jacobs, 1967, p.9). This was demonstrated (Jenkin, 2007, p.26) by the market value of *E. globulus* pulpwood free on-board as woodchips, as air-dry pulp and as finished goods (A4 copy paper). An updated analysis is presented in Table 10. However, some regard woodchips as an unworthy product.

Table 10: The value of hardwood plantation grown wood after processing at each stage in the supply chain.

		($/unit)	($/tree)	($/m^3)	($/ha)
Export woodchips	Bone dry metric tonne	$220.00	$22.45	$112.24	$22,449
Bleached eucalypt kraft (BEK)	Air dry tonne	$780.00	$37.50	$195.00	$39,000
A4 paper	Ream	$5.00	$184.80	$700.00	$140,000

Site assumptions modelled

The current GT softwood and hardwood estate is in a cycle of harvest and, sometimes replanting with the same species, a swap between species or remediation to agriculture. This analysis has a focus on new or first rotation sites. Such sites are currently under agricultural enterprises; mostly pasture and cropping. The model assumed no removal of native vegetation. An important point is that this analysis assumes integration of trees into farming rather than replacement 'fence to fence' of agriculture with trees. Indeed, with integration into a farm, trees can be established on land-units that either complement the farm enterprise (e.g. as tax deductable shelterbelts) or to address sections of a farm less suitable to the agricultural enterprise (e.g. sandy rises which are difficult to maintain pasture on; see Jenkin, 2022). Such integration of trees makes reliance on whole-farm land expectation values (e.g. Burns *et at.,* 1999) problematic as a correct comparison would be in regard to the specific unit of land planted. This reinforces excluding land value from this analysis.

Drivers of site productivity are well understood and with extensive experience in the GT it is possible to provide guidance to expected productivity for a specific site. Wilson *et al.* (2023) presents a modelled productivity map for the region. Rather than address specific sites, productivity outcomes have been modelled based as 'low', 'average' and 'high' (see Appendix 4: Harvest and transport costs in the Green Triangle).

Assumptions

There are four broad areas of assumptions included as follows.

- Silvicultural costs: The cost of establishment and maintenance of the planted trees.
- Harvesting: The cost of harvesting the planted trees, including thinning and final clear falling, from the stump to on-truck.
- Haulage: The cost of transport of the logs to a processor or mill gate.

- Returns: Modelled returns are based on log products recovered and delivered, and the unit price for such logs.

Silvicultural costs and modelling

There are a range of specific inputs to site preparation and establishment of a plantation as presented in Table 11. There are differences between first (R1) and second rotation (R2) sites. For an R1 site, this includes site assessment and administration issues whereas R2 sites include management of harvest residues. Establishment is assumed to be completed at the end of June. Establishment is assumed to occur in year zero of a regime with the growth and aging of the trees defined as commencing once planted. Hence, by the end of June in the subsequent year, the trees will reach an age of one year. Initial spacing at establishment and subsequent thinning is a key model variable. To address impacts on cost, standard costs are adjusted base on a ratio of applied compared to standard spacing. For example, tillage works are linear in nature, hence as between row spacing increases, there is less distance travelled per hectare. It is recognised that turn-around at the end of each row is fixed and a change of row spacing from 4 m to 6 m will add a minor increase in time taken. The cost of planting stock is an important variable with regimes modelled planting from 370 to 2,000 stems/ha. Eucalypt seedlings are assumed to cost $300 to $420 per 1,000 units and *P. radiata* planting stock vary from $250 to $440 per 1,000 units.

Maintenance costs

Table 12 presents a summary of plantation maintenance costs. Pruning is a generally discretionary maintenance operation undertaken in multiple lifts to remove green or dead branches to improve wood properties and/or for fire protection. Pruning for wood properties is only warranted if there is a market for pruned logs with a price premium.

Harvesting and haulage costs

The cost of harvesting is a significant cost. These costs are driven by the mean tree volume (MTV expressed in GMT/stem) of the trees harvested. Harvesting costs and can be expressed as mathematical functions (see Appendix 4: Harvest and transport costs in the Green Triangle). Based on the individual harvest operation cost profiles, a single harvest cost models were generated for *P. radiata* and *E. globulus* cut to length (CTL) operations. A separate model was applied for whole tree chipping operations (WTC) of *E. globulus* which is a different type of operation beyond harvesting. Given the nature of the WTC cost model, this option was excluded from operations with MTVs of greater than 0.3 GMT/stem. Such models take account of volume and the number of stems removed at harvest which determine the MTV. As MTV increases, harvesting costs reduce; there is more volume handled per machine movement diluting operating costs. Haulage costs are defined by the distance travelled and the truck-type used. While truck-type defines log weight moved per truck movement, this is independent of site productivity. Haulage was modelled to assume to be by B-double for logs and woodchips over a 100 km lead. Haulage costs were calculated based on the models developed (Appendix 4: Harvest and transport costs in the Green Triangle). Roading costs per unit of log output were set at $2.00/GMT as standard, except for WTC operations which require higher quality roads, hence a charge of $4.00/GMT was applied.

Table 11: A summary of the range of silvicultural inputs to plantation establishment (based on Geddes, 2023).

Category	Activity	Sites	Narrative
Site planning	Soil suitability survey	R1	An assessment of a site in regard to potential plantation productivity.
	Development application to Shire	R1	Addressing administrative requirements.
Initial site works	Clear and burn scattered trees	R1	As legally permitted; most likely planted confers.
	Remove internal fences	R1	To facilitate best plantation layout or to redesign farm layout and operation with trees.
	Repair external fences	R1	Depending on site and intent to graze under planted trees.
Residue management	Debris heaping	R2	Addressing previous crop harvest residues by heaping larger materials (e.g. stem wood).
	Chopper rolling	R2	Broadcast mechanical treatment of harvest residues.
Tillage	Rip planting lines (1 or 2 rows/pass)	R1	
	Mound plough (1 row/pass)	R1	Creation of a minor mound in ex-pasture for planting.
	Bracke	R2	Creation of planting spots.
	Mounding	R2	Creation of a mound in ex-harvest sites.
Pre-plant WC	Pre-plant weed control (inc. chemicals)	R1 & R2	Treatment of a site most likely broadcast to control a range of weeds.
Planting	Machine planting & strip spray (1 row/pass)	R1	On ex-pasture sites, it is possible to machine plant.
	Manual planting	R1 & R2	On ex-plantation sites, where harvest residues prohibit machine works.
Planting stock	Seed & seedlings ($/1000)	R1 & R2	The planting stock to be planted.
Fertiliser	Fertilise planted trees (1 or 2 rows/pass)	R1 & R2	Application of nutrients to enhance tree growth.
Pest animals	Rabbit control	R1 & R2	More on ex-pasture sites, treatment of pest animals.
Fire preparation	Grade external firebreaks	R1 & R2	Treatment of firebreaks as part of fire protection.
Management	Management and monitoring costs	R1 & R2	An ongoing requirement for informed input to management and potentially marketing

Table 12: A summary of the range of silvicultural inputs to plantation maintenance.

Category	Activity	Narrative
Post-plant WC	Post planting spraying (autumn at age 10 months)	As required, treatment of competing weeds on a site.
	Spring post-plant weedicide	As required, treatment of competing weeds on a site.
Fertiliser	Fertiliser application and products applied	Either on a prophylactic basis or in response to site assessment.
Pest animals	Insect control	As required, treatment of pest insects on a site.
Pest animals	Rabbit control	As required, treatment of pest animals on a site.
Fire preparation	Grade external firebreaks	An annual programme pre-fire season.
Management	Management and monitoring costs	An annual programme and regime; it should respond to site needs
Management	Survival counts	In the first year after planting (e.g. at 9 months) or in the same planting season to allow refilling.
Pruning	First, second and third lifts	Undertaken in multiple lifts.

Log products

In general, *P. radiata* logs are supplied with the bark on and *E. globulus* logs are supplied de-barked. The current approach to log pricing is a limited consideration of wood properties, with logs sold on a weight over a weighbridge. While generally not part of a wood supply agreement, wood properties drive the returns of a purchasing party. These are addressed at a high level rather than as part of log pricing. Log product values are defined by the species of tree planted, tree size and the end use. A summary of the modelled assumptions is presented in Table 13 (based on Appendix 3: Log products and prices in the Green Triangle) with the percentage of each product recovered (based on Appendix 4: Harvest and transport costs in the Green Triangle).

Table 13: A summary of the products recovered and the modelled mill door price of each for softwoods and hardwoods.

Output type	Units	Softwoods	Hardwoods
Pulp logs	($/GMT)	$40	$87
Preservation logs	($/GMT)	$85	
Industrial log	($/GMT)	$53	
Small sawlog	($/GMT)	$83	$130
Large sawlog	($/GMT)	$125	
Sawlogs	($/GMT)		
Woodchips	($/GMT)		

Financial analysis

Broad overview

A financial model was developed to test the range of current and potential alternative silviculture. The model functionality allowed variation of all inputs and assumptions, generating a net present value (a pre-tax NPV, at 4% real). Returns are based on GT mill gate prices and assumed log product mix. While the model can apply a 'low', 'average' or 'high' establishment and maintenance expense profile, an 'average' expense profile has been applied. This assumes that such costs are fixed and the outcome productivity reflects the site and the quality of the management inputs. With outcome productivity as a variable, harvesting costs defined by MTV, are driven by site productivity assumptions and number of trees removed at harvest. Similarly, returns are driven by site productivity, product mix and product price. The product mix varies within each broad scenario recognising that larger trees can have a different mix as defined by log small end diameter (SED). The model assumed the average log prices for the range. The analysis presents the outcomes of assumed 'low', 'average' and 'high' productivity. Given the nature of this comparison, each alternative regime pre-tax NPV is reported on a relative basis to a base-case standard regime for each species.

The alternative silviculture regimes

P. radiata plantation regimes

A base case and the alternative *P. radiata* regimes tested are presented in Table 14. The cashflow outcomes of each regime are presented in Figure 8 to Figure 16 on a dollars per hectare basis.

Table 14: A high-level summary of the *P. radiata* regimes modelled.

	Initial stocking	T1	T2	T3	CF	Productivity			Establishment costs	Maintenance costs	Log price
	(stems/ha)	(y)	(y)	(y)	(y)	Low	Average	High	Average	Average	Average
Routine clear fall	1,600	12	18	24	34	X			X	X	X
							X		X	X	X
								X	X	X	X
Early clear fall	1,600	12	18	24	30	X			X	X	X
							X		X	X	X
								X	X	X	X
Early clear fall, no T3	1,600	12	18		30	X			X	X	X
							X		X	X	X
								X	X	X	X
Wide spacing – short rotation	370				20	X			X	X	X
							X		X	X	X
								X	X	X	X
Wide spaced – long rotation	370				27	X			X	X	X
							X		X	X	X
								X	X	X	X
Wide spaced – long with a pruned premium	370				27	X			X	X	X
							X		X	X	X
								X	X	X	X
Routine initial stocking – short rotation	1,600				12	X			X	X	X
							X		X	X	X
								X	X	X	X
High initial stocking – short rotation	2,000				12	X			X	X	X
							X		X	X	X
								X	X	X	X
High initial stocking – long rotation	2,000	12	18		24	X			X	X	X
							X		X	X	X
								X	X	X	X

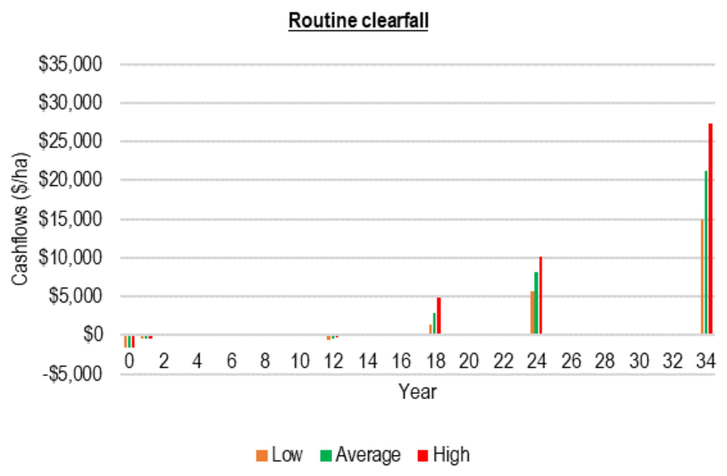


Figure 8: The cashflow outcomes of the base case or routine regime.

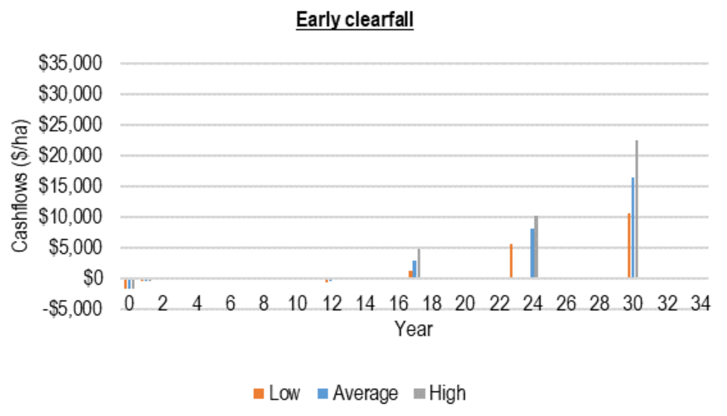


Figure 9: The cashflow outcomes of the early clear fall regime.

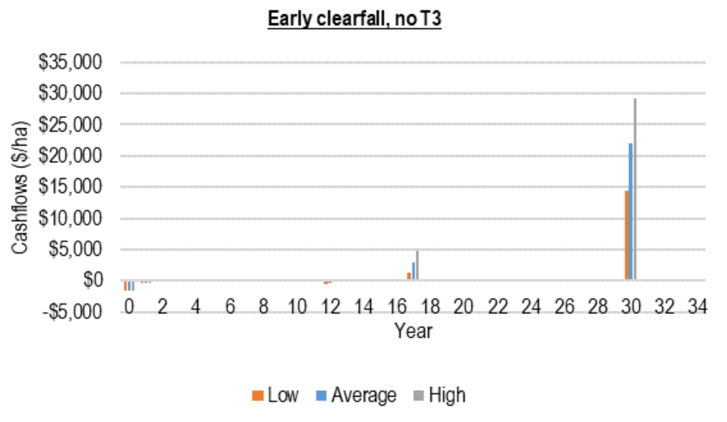


Figure 10: The cashflow outcomes of the early clear fall with no T3 regime.

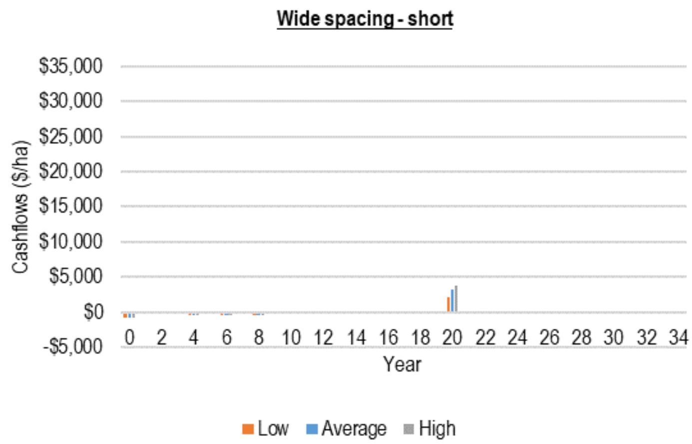


Figure 11: The cashflow outcomes of the wide-spaced, short rotation regime.

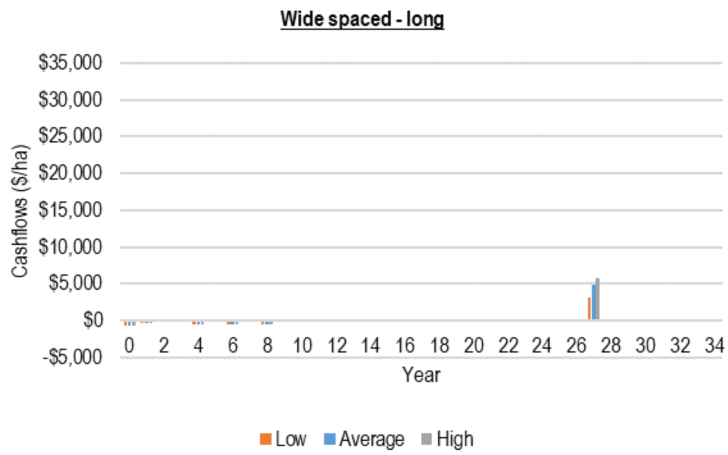


Figure 12: The cashflow outcomes of the wide-spaced, long rotation regime.

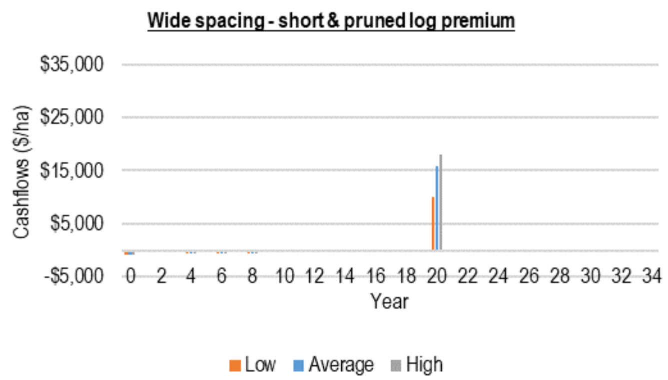


Figure 13: The cashflow outcomes of the wide-spaced long rotation regime with a pruned log premium.

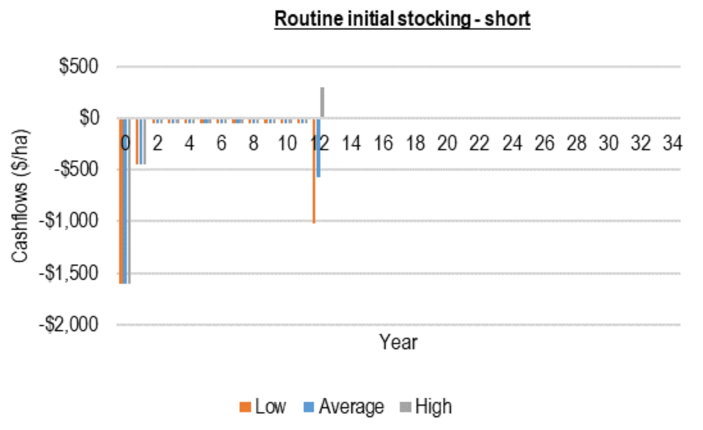


Figure 14: The cashflow outcomes of the routine initial stocking and short rotation regime.

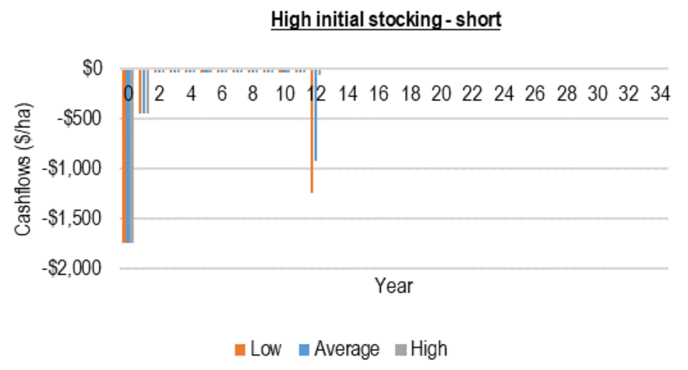


Figure 15: The cashflow outcomes of high initial stocking and short rotation regime.

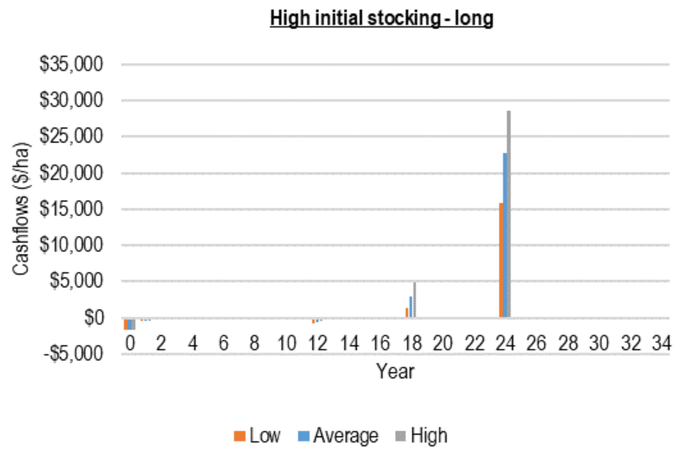


Figure 16: The cashflow outcomes of high initial stocking, with a medium rotation with thinning regime.

Hardwood plantation regimes

A base-case and alternative *E. globulus* regimes tested are presented in Table 15 and the outcomes are presented in Figure 17 to Figure 25 on a dollars per hectare basis.

Table 15: A high level summary of the *E. globulus* regimes modelled.

	Initial stocking (stems/ha)	T1 (y)	T2 (y)	T3 (y)	CF (y)	Productivity			Establishment costs	Maintenance costs	Log price
						Low	Average	High	Average	Average	Average
Routine CF - CTL	1,000				12	X			X	X	X
							X		X	X	X
								X	X	X	X
Routine CF - WTC	1,000				12	X			X	X	X
							X		X	X	X
								X	X	X	X
Early CF - CTL	1,000				8	X			X	X	X
							X		X	X	X
								X	X	X	X
Early CF - WTC	1,000				8	X			X	X	X
							X		X	X	X
								X	X	X	X
Late CF - CTL	1,000				18	X			X	X	X
							X		X	X	X
								X	X	X	X
Late CF – CTL with sawlog size logs	1,000				18	X			X	X	X
							X		X	X	X
								X	X	X	X
Medium CF - with T1	1,000	8			15	X			X	X	X
							X		X	X	X
								X	X	X	X
Late CF - with T1	1,000	8			18	X			X	X	X
							X		X	X	X
								X	X	X	X
Late CF - with T1 with pruning	1,000	8			18	X			X	X	X
							X		X	X	X
								X	X	X	X

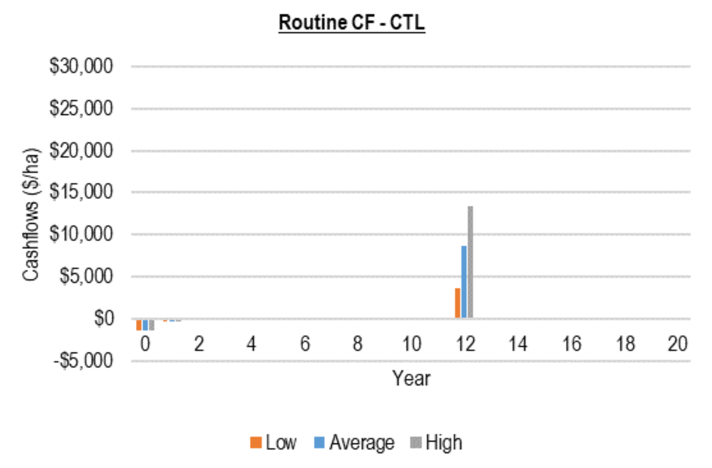


Figure 17: The cashflow outcomes of the base-case routine CTL regime.

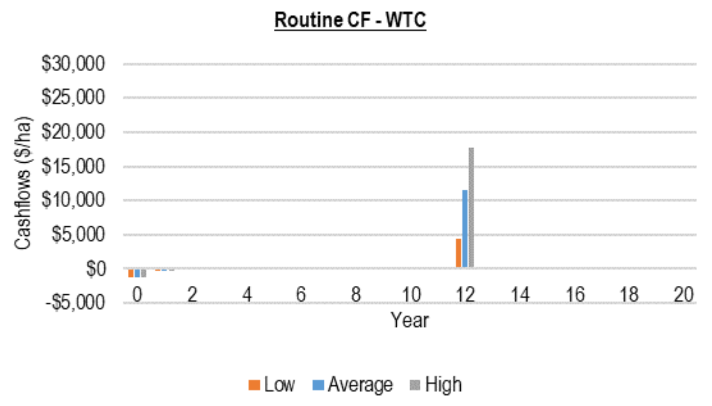


Figure 18: The cashflow outcomes of the base case routine WTC regime.

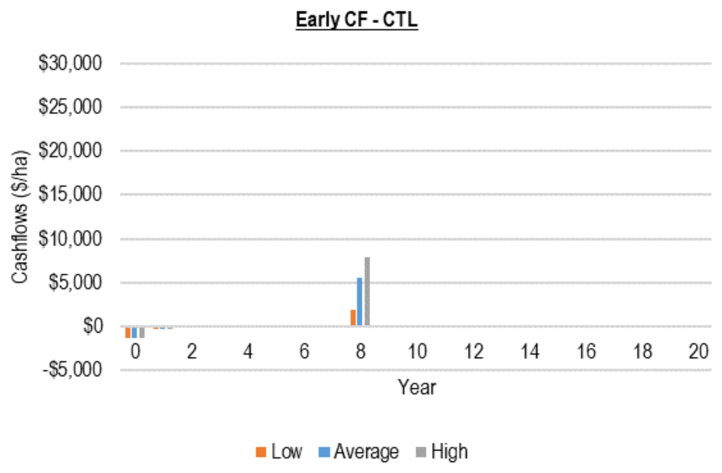


Figure 19: The cashflow outcomes of the early clear fall, CTL regime.

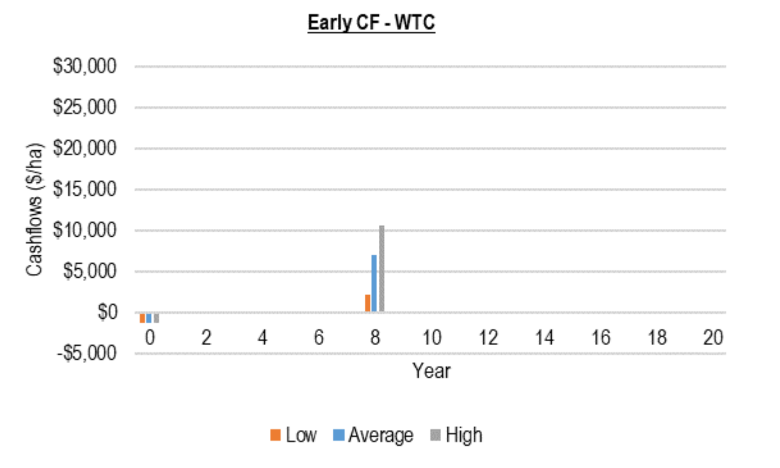


Figure 20: The cashflow outcomes of the early clear fall, WTC regime.

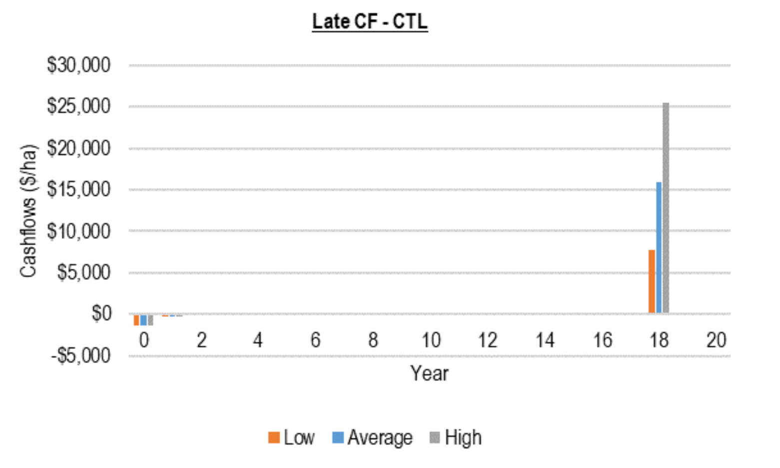


Figure 21: The cashflow outcomes of the late clear fall, CTL regime.

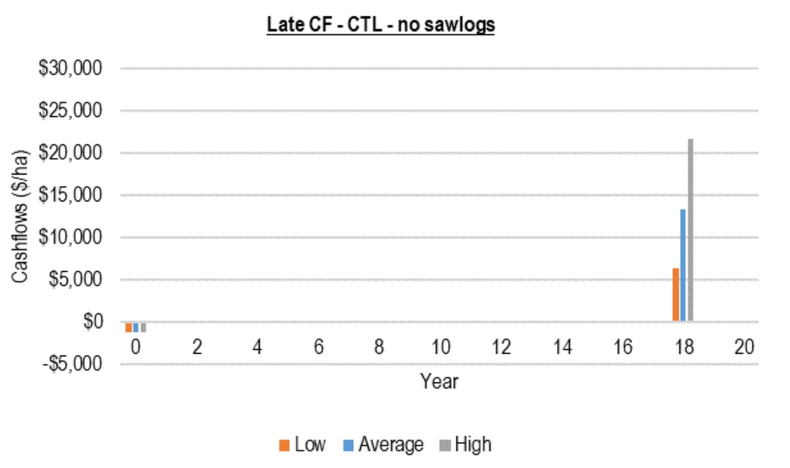
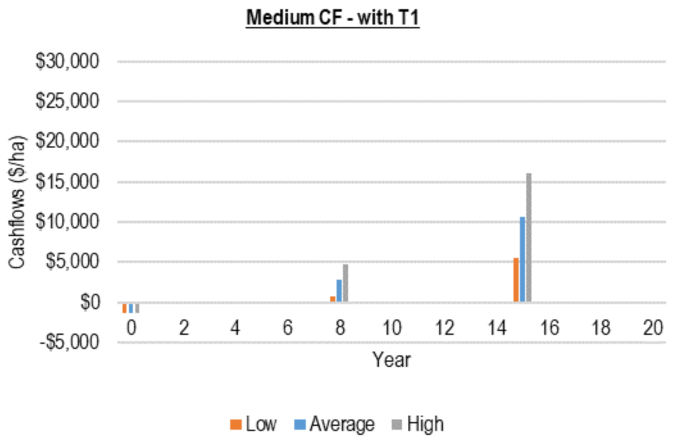
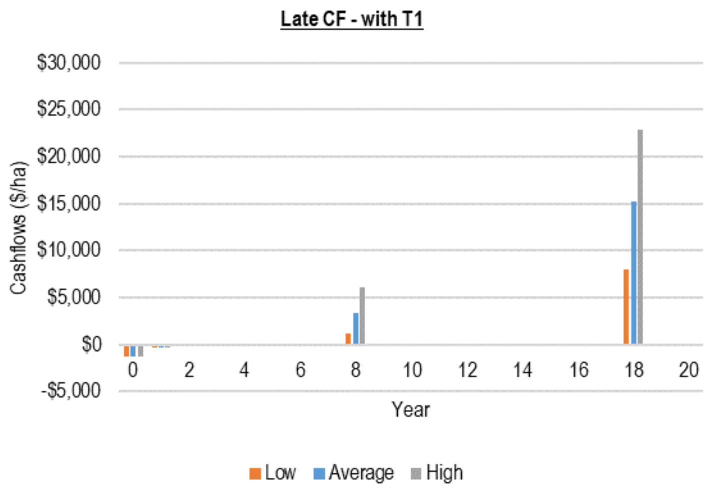
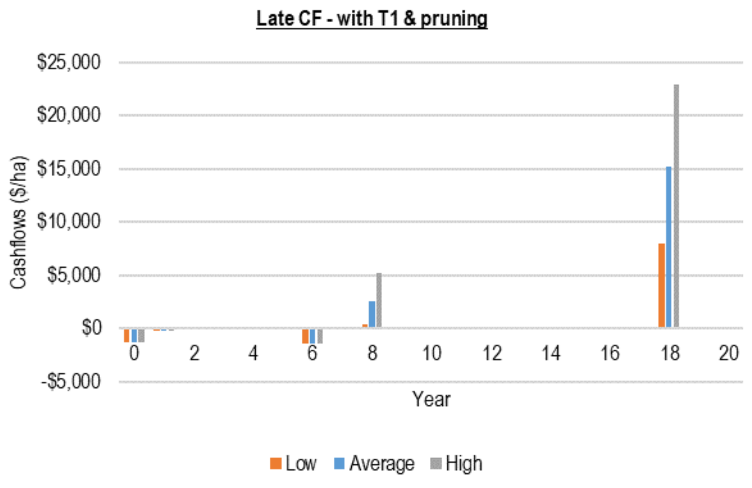


Figure 22: The cashflow outcomes of the late clear fall CTL regime; no sawlog size logs.

	Figure 23: The cashflow outcomes of the medium clear fall with a T1 regime.
	Figure 24: The cashflow outcomes of the late clear fall, with a T1 regime.
	Figure 25: The cashflow outcomes of the late clear fall with a T1 and pruning regime.

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Appendix 2: A history of silviculture in the Green Triangle

<u>Project 1: Research new shorter rotation silvicultural models for pine plantations and longer rotations for blue gum plantations. Sub-report title: Changes in Green Triangle plantation silviculture since the mid-1970's.</u>

Prepared by

David Geddes

Summary and key points

The Green Triangle (GT) Region of southeast South Australia and southwest Victoria is the largest-scale plantation forestry region in Australia and includes softwood (*Pinus radiata*) and hardwood (*Eucalyptus globulus*) plantations. While considerable silvicultural improvements occurred in the first century of softwood plantation development from 1876, this report traces silvicultural changes that have occurred in the region since the early 1970's. Changes described are provided in overview form only. The listed references indicate where more detail is available.

<u>Softwoods</u>

During the 1970's and into the 1980's, softwood silviculture went through rapid changes, in terms of site preparation, weed control and nutrient management, including retention of needles and fine litter on second rotation sites. Low residue harvesting was used by all managers. Site preparation changed from windrowing and burning harvest residue, to retaining residues on-site and using chopper rollers to make re-planting easier. Bräcke intermittent cultivators were used on most sites to create a residue-free planting site, while on lower lying sites subject to waterlogging, mound ploughs were used to prepare planting rows. Tree spacing remains mainly at 2.5 x 2.5 m planting or at 1,600 stems/ha, although some managers establish at stockings below 1,400 stems/ha. The use of soil residual herbicides transformed management of weeds prior to and in the year following planting. The 1983 Ash Wednesday fires not only resulted in more than 20,000 ha of softwood plantations being burnt, but also triggered a significant outbreak of bark beetles that bred up in the large volumes of salvage harvest residues. A few years later, in 1987, the GT experienced Australia's largest-scale Sirex wasp outbreak, with more than 1.8 million trees

killed. An innovative CSIRO biological control program was used to prevent further mortality. In 1983, the Southern Tree Breeding Association (STBA) was formed as the first tree-breeding cooperative in Australia and New Zealand. By 1990, STBA took on breeding activities for eucalypts. Initially it managed seed orchards and breeding, but now production of seed is carried out by other companies. There have been significant economic gains to the industry as a result of cooperative tree breeding. In the early 2000's, a large-scale experiment confirmed new ways in which later age fertiliser application and thinning could improve profitability of softwood plantations.

Hardwoods

In 1991, a new plantation species was introduced for commercial production. *Eucalyptus globulus* plantations were encouraged to be established to supply the local pulp mill with short fibre hardwood woodchips to blend with the existing long-fibre softwood woodchips. More than 66,000 ha of short-rotation hardwood plantations were planted by 1999, mainly by Western Australian based Managed Investment Scheme (MIS) companies focused on supplying large volumes of export woodchips to Japanese paper manufacturers. The hardwood plantation estate peaked in about 2009 (at 168,200 ha), and since that time, there has been a decline in the hardwood estate area as some plantations were not replanted after harvest. Being a new species to the region, there were inevitable silvicultural challenges to overcome, including site selection, weed control and insect control. *Eucalyptus globulus* requires higher rainfall sites than softwood plantations and is also more frost sensitive. In 1991, all hardwood plantations were grown from wild seed collected from selected natural forests trees by provenances in Tasmania and Victoria. By 1995, there had been analyses of early tree breeding programmes and by the early 2000's, genetically improved seed was available. Seedlings from improved seed grew into straighter trees with improved pulping characteristics.

Populations of koalas are endemic to natural forests near Portland and Heywood in Victoria. In the early 1990's, it was envisaged that koalas would not move into *E. globulus* plantations, because it was not their primary food source. But by 2009, koalas were regularly observed in older-age *E. globulus* plantations. Larger-scale harvesting also began around this time. By 2010, the industry recognised that while koala browsing was insignificant to growth, potential injury to koalas during harvesting was a matter to be addressed. Harvesting guidelines were developed to reduce the risk of injury to koalas during harvesting operations. Recent research has identified that koala populations in *E. globulus* plantations between the South Australia / Victorian state border and Port Fairy are now about four times higher per hectare of plantation than in natural forests. In 2020, under existing legislation, the Victorian

Government brought in new koala management requirements for hardwood managers operating in a defined koala zone. Meeting these regulations has significantly added to harvesting costs. Environmental certification is now required by customers purchasing softwood logs and woodchip from hardwood and softwood plantations. Maintaining certification is a vital part of forest management. Plantations in the southeast of South Australia are part of the groundwater management in the region. This is because planted tree roots are deemed to extract aquifer water (where the water table is less than 6 m deep) and plantations are deemed to restrict recharge of the aquifer from rainfall. In some water management zones, there are replanting restrictions after harvest.

Introduction

Australia is a net importer of timber products and there is an Australia-wide shortage of timber for construction purposes. Representing the GT plantation and processing industry, the Green Triangle Forest Industry Hub (GTFIH) is seeking ways in which to expand the plantation estate in order to provide more fibre for local processing and for export. Expansion of the estate can be by existing plantation companies operating in the region, or by landholders wishing to diversify their agricultural enterprises. While plantation companies have the knowledge to develop new plantations, it can be difficult for other landholders to find the appropriate information about site selection, silvicultural management, markets and harvesting planning. There have been significant improvements in plantation silviculture since the first plantations were established in 1876. This report focusses on changes that have occurred since the 1970's for softwood and hardwood silvicultural.

The background to the South Australian and Green Triangle plantation estate

Commencement of plantation forestry

The Green Triangle (GT) Region of southeast South Australia and south west Victoria is one of the oldest plantation regions in the world. Plantation forestry in South Australia is due to observations of Surveyor General, George Woodroofe Goyder who was concerned about excessive clearing of native vegetation for agriculture. His influence was such that on 7 September 1870, Mr F.E.H.W. Krichauf moved in the South Australian House of Assembly that there will be planting of timber producing trees (Lewis 1975, p 14). An Act was passed in 1873 to *Encourage the planting of forest trees* and on 10 November 1875, a Forestry Board was appointed. Early trials of potential forest tree species began in 1876, with a nursery established in near Leg of Mutton Lake at Mount Gambier. During the late 1870's, a number of *Pinus* and *Eucalyptus* species were trialled in plantations, along with various species of ash, cypress, elm, poplar, oak, sycamore, walnut and willow. By 1900, it was clear that the species most likely to be commercially successful were *Pinus radiata* (radiata pine), *P. pinaster* (maritime pine) and *E. globulus* (Tasmanian blue gum). During the first half of the 1900's, *P. radiata* was the primary plantation species established, with *P. pinaster* only planted on poorer fertility deeper sandy sites (Lewis *et al.* 1976, p.13-17). From 1950, a *P. radiata* tree breeding program began. By the late 1960's, establishment of *P. pinaster* ceased, with *P. radiata* then planted on all suitable site types. There is more than 80 years history of tree breeding of *P. radiata* in Australia. In the 1950's all the states commenced breeding and seed production in *P. radiata* with significant research provided by the Forest Research Institute; the federal precursor to CSIRO Division of Forest Research.

In 1991, Kimberly-Clark Australia (KCA), owner of the local pulp mill, decided to improve the quality of their tissue and absorbency products by adding short-fibre hardwood to the existing long-fibre softwood intake (Phillips, 1996, p.7). It was known from trials conducted by the Woods and Forests Department (WFD) in the 1880's and from several small-scale plantations established between the 1940's and 1988, that *E. globulus* had growth potential in the GT. With the assistance of the WFD, KCA began encouraging farmers to establish *E. globulus* woodlots to supply fibre for pulp production and the first KCA plantations were established in 1991.

Plantation developers and the plantation estate

While all early plantations in the GT were established by the South Australian Government, private softwood plantation development began in the 1920's (Geddes, 2011, p.11). There are now four corporate softwood growing companies in the region (i.e. OneFortyOne Plantations, New Forests Asset Management, Green Triangle Forest Products and HVP Plantations) and two corporate hardwood growing companies (Australian Bluegum Plantations and New Forests Asset Management) as well as small-scale privately-owned softwood and hardwood plantations. Currently, the GT has the largest area of plantations in Australia (ABARES, 2022) and is the second largest softwood region (after the Murray Valley Region). By 2022, the region had approximately 180,602 ha of softwood plantations (all *P. radiata*) and 133,809 ha of hardwood plantations (mostly *E. globulus*). This estate is on a mixture of freehold owned land, South Australian Government land and land leased from other parties. While the softwood plantation area grew steadily from the 1960's, the growth in new plantations slowed through the 1990's and since then, there has been little expansion as after harvest, corporate growers concentrated on re-establishing land they already owned and, in some cases, exited from leased land. In 1995, one of the large-scale managed investment scheme (MIS) companies based in Western Australia, began developing *E. globulus* plantations in the GT. Three years later (by 1998), there were seven MIS companies operating in the region, including four large-scale WA based companies. They purchased a large number of farming properties on which to establish plantations, driving up GT land prices. The total area of *E. globulus* plantations increased from less than 200 ha in 1988 to 66,130 ha in 1999 (ABARES, 2022, pivot table by NPI Regions), with most of this area planted between 1996 and 1999. The MIS companies were building a resource in order to export competitive volumes of high-quality woodchip to Japanese paper makers. The hardwood plantation area continued to expand until 2009/10, and since then a decline in area has resulted as some plantations were not re-established after the first rotation trees (crop) were harvested.

Cooperation between growers

When the CSIRO Forest Research Station was re-located to near the Mount Gambier Airport in 1966, they determined to positively interact with the four large-scale softwood growers (WFD, Softwood Holdings, SA Perpetual Forests and the Victorian Forest Commission). While the WFD continued with their practical silvicultural research, there was joint research between CSIRO and growers, as well as in-house research by the other three large-scale growers (Softwood Holdings, SA Perpetual Forests and the Victorian Forest Commission). This resulted in regular seminars hosted by CSIRO presenting findings, as well as field days hosted by individual companies. All growers were encouraged to share silvicultural knowledge to improve the GT sawlog output. Field day topics included site preparation, weed control, initial stocking options, nutrition, pest control and tree breeding. An outcome of this interaction was a rapid take up by all growers of improved silviculture, leading to increases in GT sawlog output.

Softwood plantations

A brief outline of the first century of softwood silviculture

For more than a century, silvicultural research was led by the then South Australian WFD. Boardman (1988) identified various phases of plantation silviculture in South Australian softwood plantations as presented in Box 3. This report only considers silviculture from the early 1970’s and does not discuss the earlier silvicultural findings of Boardman (1988).

Box 3: A timeline of plantation development in the Green Triangle.

- From 1880: Extensive trials of forest species of timber value to determine those most likely to produce logs for sawmilling.
- From 1908: Testing began of the wood properties of trial species, including seasoning of sawn boards and the use of wood preservative chemicals.
- From 1916: Investigations began on methods to overcome tree leader dieback. The cause of dieback (zinc deficiency) was not found until 1936, and zinc sulphate spraying began in 1940.
- From 1928: Measuring tree growth from permanent sample plots, taking into account soil types, initial tree spacing and establishment techniques.
- From 1944: Improving tree growth in spindle stands.
- From 1957: Developing silvicultural guidelines for nurseries (seedling culture, rotational cropping and chemical control of weeds), controlling plantation weeds with chemicals, and use of fertilisers.
- From 1966: Work began of fixing the decline in productivity between rotations.
- From 1973: Using weed control and fertilisers to boost productivity on both first and second rotation sites.
- From 1980: Fine tuning inputs to reduce costs without jeopardising growth.

Rotation length

Prior to the Ash Wednesday fires in February 1983, rotation ages varied from 35-45 years. Since then, rotation ages have reduced, and now vary from 30-35 years, depending on grower objectives.

Site preparation and planting

First rotation sites

Initial plantation development included conversion of natural forests on sites with greater than an average rainfall of 600 mm/year. Well ahead of development control of native vegetation clearance (South Australian Planning Act 1982 and the Native Vegetation Act 1991), forestry companies took a proactive conservation approach. From the mid-1970's most properties purchased for plantation development were cleared farmland. Prior to purchase, a soil survey was undertaken to determine suitability for *P. radiata* establishment. These soil surveys were on a grid of often 200 x 200 m. Sample holes were dug with a hand auger to identify soil types at each depth / layer and to determine the depth to clay (a water impeding layer). Prior to the mid-1970's, deep sands were destined to be established with *P. pinaster*. From the mid-1970's, all suitable properties were established with *P. radiata*. On first rotation sites, after blanket weed control with amitrole and atrazine (Vorox AA®), site preparation normally consisted of ploughing if there were woody weeds or bracken, or otherwise direct planting into the ground. If a coffee rock layer was present (identified by the soil survey), sites were ripped to a depth of about 75 cm when the soil was dry. Geologically, coffee rock was formed as decayed plant matter washed through sandy soils until it gathered on top of the B-horizon at about 40-60 cm depth. Typically, coffee rock is only 5-10 cm thick, but unless broken with a ripper, it can prevent deep tree root penetration of the soil profile. Poorly drained sites or sites where there was potential for winter flooding were mounded to ensure newly planted tree roots did not become waterlogged. Except on mounded sites, by the early 1980's, planting machines (Figure 26) began to be widely used, replacing the previous hand planting systems. This resulted in reduced establishment costs.

Figure 26: Pine planting machines in 1979 planting an ex-pasture site. Note the application of herbicide in the same pass (photo by DJ Geddes©).

Second rotation sites

With second and subsequent rotation plantations, growers were already aware (based on previous research) of the need to conserve site fertility (Boardman, 1988, p 140, 142 & 143). From the early 1970's, blanket burns of harvest residues on clear fell sites (which depleted soil nutrients) had been phased out and replaced with the residues raked into windrows which were subsequently burnt. This process retained nutrient-rich pine needles and fine litter on site between the windrows, reducing the broadscale impact the previous broadcast burns. By the mid-1980's, harvesting equipment was able to separate merchantable and non-merchantable logs from clear fell harvests. This allowed non-merchantable logs to be removed for chip sales or burning. Over the next 20 years, 'low residue harvesting' was adopted by all four growers. Reduced harvest residues remaining after harvest could either be crushed (with a chopper-roller) and/or could be Bräcke cultivated. Chopper rollers are towed by large bulldozers. A chopper roller consists of a large heavy drum, fitted with blades that cut and crush woody harvesting residues over which it travels. Often there are two rollers, with the second at an offset angle to the first to improve the cutting and crushing action (see Figure 27). Dimensions of the implement are illustrated by Geddes (1981, p.19).

Figure 27: Chopper rolling a clear fell site (photo by LJ Parsons©).

Bräcke intermittent cultivators (Figure 28) are chain driven implements with two sets of scarifying wheels, each with four steel teeth that drag into the ground at set intervals. They are normally towed by a bulldozer, skidder or forwarder. They can be calibrated to create individual planting sites at an appropriate tree-planting spacing, with two rows being treated per pass. The scarified site or spot is typically about 45 cm wide, 60 cm long and 15 cm deep, and having been cleared of woody debris, is ideal for manual planting on a second rotation site (see Figure 29). Planting can either be in the ditch, or on the mound left by the Bräcke. Bräcke cultivators are now available in models that can treat more than two rows at a time.

Figure 28: Second rotation site preparation with a Bräcke spot cultivator (photo by LJ Parsons©).

Figure 29: 10-month-old *P. radiata* planted on a second rotation Bräcke cultivated site (photo by DJ Geddes©).

On wetter sites by the late 1980's, mounding of tree planting rows became the normal site preparation method (see Figure 30). The purpose of a mound is to ensure early tree root development can occur in well aerated soil without being inundated. Mounds are best formed at least several months prior to planting to ensure the soil settles.

Figure 30: A mounded second rotation site, ready for planting (photo by DJ Geddes©).

A partial move to containerised planting stock

Previously, open rooted seedlings (Figure 31) were delivered from nurseries in damp hessian wraps, boxes or plastic bags ready for planting. These methods had been effectively used for more than a century. From about 2006, there was a partial move to the use of containerised plants, while use of bare-rooted plants remains. There were seedling management benefits in the nursery as it was possible to move the plants around the nursery for different treatment types, as well as manual handling benefits and greater automation. In the field, newly planted containerised trees (with soil around undisturbed roots) were able to better cope with drier soil conditions.

Figure 31: Collecting open rooted pine seedlings from a nursery in 1981 (photo by DJ Geddes©).

Tree breeding

In February 1983, the Ash Wednesday fires devastated more than 20,000 ha of plantations in the GT (18,070 ha WFD and 1,940 ha of private plantations). Amongst the losses, were two of the three WFD seed orchards and the seed store at Mount Burr Forest (Keeves & Douglas, 1983, p.159). To offset the loss of seed orchard seed, the WFD commenced large-scale propagule production from cuttings selected from the genetically improved plantations established in the previous year. The loss of seed production capacity coincided with the formation of the Southern Tree Breeding Association (STBA), the first tree-breeding cooperative in Australia and New Zealand. Foundation members were CSIRO, SA Perpetual Forests, Softwood Holdings and the WFD. Formation of STBA allowed the widespread introduction of genetically improved seed from seed orchards. Over the next 15 years, STBA experienced rapid growth in membership. By 2008 it had 25 members, and breeding extended to eucalypt species. Members joined STBA to obtain genetic material from one or a combination of the species available. Some sought seed whereas others sought only germplasm. A strength of the organisation was its range of membership type with large and small growers, softwood and hardwood growers and research members. A benefit of membership was the ability to share the cost of tree breeding. In about 2000, Economic Breeding Values were introduced to the members to determine selection of traits with the highest economic return for production of high-quality sawlogs, in terms of plantation growth rates, wood density, wood stiffness and stem straightness. By the early 2000's, options for pine propagule production were introduced, aimed at rapid deployment of advances in genetic material. These included the following.

- Higher Site Quality sites: Vegetative reproduction pathways; propagating cuttings from small amounts of control pollenated seed, and the use of containerised stock for both cuttings and seedlings for higher Site Quality sites.
- Lower Site Quality sites: Continued use of open pollinated and traditional open rooted stock, on lower Site Quality sites.

Originally, STBA owned the trees in its seed orchards and also undertook all the breeding. Those functions have now been split, with other companies managing the seed orchards and the formation of Tree Breeding Australia (evolved from STBA) as the Australia's peak body for tree breeding and genetic improvement.

Weed control

From the late 1970's all growers were routinely using chemical weed control in first and subsequent rotation plantations. Both survival and early tree growth were significantly improved when competing vegetation was controlled around each tree. As most of the farmland on which new plantations were being established had dense pasture grasses, it was vital these were controlled prior to planting. The term 'instant getaway' was coined by Mr N.B. Lewis (from the WFD) to describe the rapid early growth of softwood trees on farmland where there was no weed competition. However, a lack of adequate weed control in the first 18 months usually meant tree growth was seriously impeded. By the late 1970's, woody weeds were no longer a problem due to purchase of pasture sites, but there were with tree competition differences between pasture weed types. Fog grass (*Holcus lanatus*) and phalaris (*Phalaris paradoxa*) have dense root systems that could compete with newly planted trees for soil moisture. Broadleaf weeds such as sorrel (*Rumex angiocarpus*) and bracken (*Pteridium esculentum*) have extensive rhizome root systems. Other typical pasture weeds which required controlling were capeweed (*Arctotheca calendula*) and flatweed (*Hypochoeris radicata*). These pasture weeds were more resistant to amitrole and atrazine herbicides used in the past. In second rotation plantations, one of the most common current weeds is fleabane (*Conzya bonariensis*). By 1975, two new products; from Monsanto, Roundup® (glyphosate) and from Dupont, Hexazinone® (hexazinone; a broad-spectrum organic weedicide), improved knockdown and residual control of most weeds in *P. radiata* plantations in the GT. By the early 1990's, Brush-Off® (metsulfuron-methyl) became available and provided a more effective control of woody and problem weeds such as sorrel and bracken. A breakthrough came when Oust® (sulfometuron-methyl; a DuPont produced member of the sulfonylurea herbicide family) was found to be successful when applied pre-emergent or post-emergent to previously difficult-to-kill-weeds, particularly sorrel. However, permits were required because it wasn't registered for plantations. Granular herbicides became available in the early 1990's and were safer to handle and could be applied aerially over plantations.

Nutrition

Fertiliser application

Prior to the 1970's, superphosphate (phosphorus; P) was used on infertile deep sandy sites to boost productivity. While use of this fertiliser was successful, as ideal phosphorus levels were restored, copper (Cu) and zinc (Zn) trace element deficiencies became evident. Since 1940, zinc sulphate (Zn) had been routinely applied to young plantations to prevent zinc dieback. Dieback was a phenomenon where prior to canopy closure at about 6-8 years of age, the main leader dies back and is taken over by the next whorl of branches, which in turn die back (Thomas, 1957, p.24). It resulted in multiple stems, and an unproductive tree in terms of sawlog harvest. From the mid-1970’s, both zinc and copper were routinely applied to address trace element deficiencies.

Fertiliser research

By the early 1970’s, experimental plots showed positive responses to nitrogen (N) and potassium (K) fertilisers, but researchers found results were unpredictable, particularly for nitrogen, which could sometimes depress tree growth. In 1973, Woods (1976) had been able to demonstrate an effective way in which to apply nitrogen, phosphorus and trace element fertilisers without depressed growth. This method was termed by Woods as the ‘Maximum Growth Sequence’, and was adopted by most of the GT growers, with a resultant productivity lift (Boardman, 1988, p.143). While it was an expensive program, with high fertiliser costs, growers were able to lift overall productivity class by a whole Site Quality class. Site Quality is a measure of stand productivity and is measured in seven classes, SQ 1-7 (see Figure 32 presenting mean annual increment (MAI) based on total production at age 35 years). Zinc sulphate applications were no longer required as zinc was combined in the bespoke fertiliser mix.

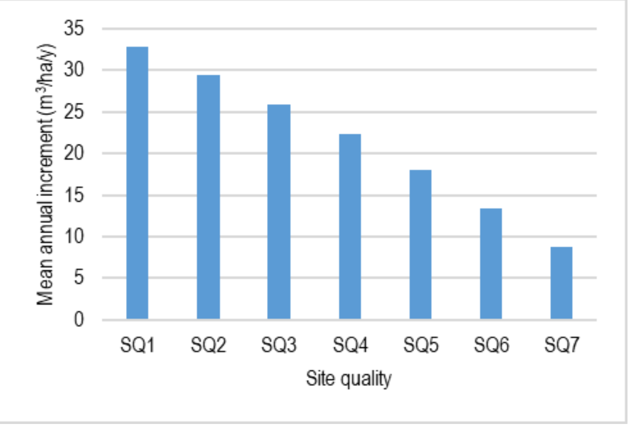

Figure 32: Mean annual increment (m^3/ha/y) at age 35 years by SQ (adapted from Lewis *et al*., 1976, Table V.2, p 77-80).

By 1980, weed control had improved significantly, and research into more economical fertilising gained momentum. A large-scale regional cooperative trial at four different sites over a three-year period was established to assess reducing the (expensive) levels of nitrogen fertiliser. From 1984, other fertiliser trials in the fire replacement plantations demonstrated there were strong growth responses in both nitrogen and phosphorus fertilisers, resulting in different second rotation fertiliser applications between fire replant and normal unburnt re-establishment. Prior to 1985 most of the fertiliser research was in young plantations. Between 1985 and 2000, experiments were conducted to determine economic benefits of later-age fertilising (by fixed wing aircraft), particularly after plantations had stabilised following first thinning. In 2004, there were sufficient results from a trial (known as

EP190) to show that where fertiliser had been applied, lower than traditional stocking after thinning could remain productive (O'Hehir, 2001). The outcome resulted in faster growth resulting in larger diameter (and therefore more valuable) sawlogs were achievable, and pre-tax net present values (NPV) increased by earlier volume production.

Use of legumes

After the 1979 Caroline Fire, legumes were spread by air over several areas to test whether nitrogen fixed by these pasture species could replace the nutrient losses caused by the fire (Geddes, 1981, p.22&23). The trials demonstrated nitrogen gains were soil type dependent and varied from 106-133 kg/ha of nitrogen in the first two years. In February 1983, more than 20,000 ha of plantations were burnt in the Ash Wednesday fires. Based on the success of the Caroline Fire results, in autumn 1983, there was an aerial nitrogen fixing legume sowing program over the burnt plantations. More than 10,000 ha was sown with legumes and fertiliser (Keeves & Douglas, 1983, p.159). Subsequently, nitrogen fixation rates of 60-100 kg/ha over three years were achieved.

Current practice

Harvest residue retention (e.g. needles and fine litter) when re-establishing second rotation sites is an important nutrient retention practice. This replaced the earlier practice of broadacre burning of clear-felling harvest residues. Softwood growers now prioritise later-age fertilising post-third thinning, as a higher priority than post-second thinning which has a higher priority than post-first thinning. Higher Site Quality plantations are not routinely fertilised. Fertilising is not undertaken within three years of scheduled clear-fall.

Layout, stocking and thinning

Row direction

Depending on compartment shape, row direction was mostly north-south, with rows ideally less than 400 m long. During the 1970's, some growers had a preference for northwest - southeast row direction for two reasons. In the GT, trees naturally have slight lean to the southeast, and when trees were harvested manually with chainsaws, it was easier to fell the trees in a southeast direction. But with the introduction of mechanised harvesting in the mid-1970's, directional felling was no longer a consideration. The other motivation was for firefighting. The logic was that a fire entering a plantation from the northwest could be better contained with a canvas hose lay on the fire flanks. It is easier to run the hose lay along the rows than across the rows. From the early 1980's, the preference was for north-south rows.

Tree spacing

Over the last 60-70 years, *P. radiata* tree breeding has produced spectacular results in terms of improved growth, wood density and stem straightness. Unlike some other *Pinus* species, *P. radiata* will grow large diameter branches if grown at wide spacings. Genetic improvements have not been able to fully control branching. Therefore, it is important to initially establish softwood plantations at stockings which restrict early branch growth, and then undertake several thinning operations as the trees grow taller. From the 1980's, the routine initial spacing was 2.5 x 2.5 m resulting in a stocking of 1,600 stems/ha. On higher productivity sites, initial spacing was 2.5 x 2.0 m resulting in a stocking of 2,000 stems/ha. In the late 1990's, some growers also established plantations at higher stockings than 1,600 stems/ ha on sandy sites in order to increase the supply of roundwood suitable for treating as fencing products. By the late 1990's, it was realised that unless highly stocked plantations were thinned on time (as per Figure 33 below), there were tree stability (e.g. wind-throw) risks after thinning. And as described below, there have been times when it has not been possible to thin on time. Since the early 2000's, the initial stocking most commonly adopted by softwood growers in the GT is 1,480-1,600 stems/ha (most commonly 1,600 stems/ha), with stocking after first thinning taken down to 680-740 stems ha (most commonly 700 stems/ha).

Thinning regimes

Thinning of softwood plantations aims to improve health and vigour, and to maximise commercial productivity. This requires a balance between obtaining a commercial yield at each thinning event whilst retaining sufficient growing stock to ensure future growth and yields are optimised. Softwood plantations are normally thinned multiple times prior to clear fall. Traditionally, GT growers have first thinned (T1) their plantations in line with the Optimum Thinning Guide (OTG) (see Figure 33), as described by Lewis, *et al*. (1976 p 84-88, & 92). The OTG prescribes thinning intensity for plantations older than 10 years of age, with the aim to maintain stocking between the 'Minimum and Maximum Stocking Curves', for any given predominant height and site quality. First thinning is critical, with the timing depending on individual stand growth rates. For fast growing plantations, T1 can be scheduled at about age 10-years, while for slower growing plantations, T1 can be as late as at age 15-years. Second thinning (T2) is normally scheduled about 5-6 years after T1, with third thinning (T3) after 5-6 years, and final harvest (clear fell) about 8-10 years after T3 or at a pre-determined rotation age. Post-thinning stocking below the Minimum Stocking Curves will increase the risk of wind damage, increase branch sizes and will potentially result in loss of volume.

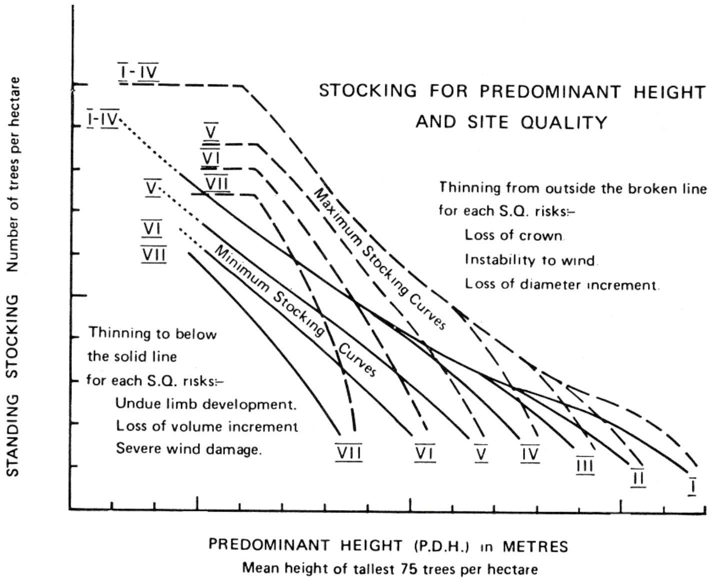

Figure 33: The Optimum Thinning Guide (Lewis *et al*., 1976, p.92).

Thinning and fertiliser application

Application of later-age fertiliser combined with thinning is a viable option. O'Hehir (2001) found that where fertiliser is applied, stockings that are lower than the OTG recommendations can remain highly productive. This results in additional early volume recovered from thinning more heavily (without compromising total site volume production), faster growth of larger more valuable logs and improved financial returns due to the combination of earlier volume production and larger trees.

Issues with achieving thinning

Delaying T1 increases the risk of stand instability and potential severe wind damage when the thinning is undertaken. A delay also increases crown abrasion (resulting in partial needle loss) and risks loss of stem diameter growth. There have been periods when markets for T1 logs were difficult to obtain, resulting in thinning delays. It can take many years for T1 estate-wide backlogs to be caught-up. In the GT there have been three recent periods of thinning delays as follows.

- In the late 1970's and early 1980's, the local pulp mill was unable to accept all the wood volume from T1 harvests. A woodchip export market was eventually developed enabling the thinning program to get back on schedule.
- In 2012, the local pulp mill closed. It was several years before an export pulp log market could be developed, during which time there was very little T1.

- In 2020, pulp log exports to China stopped. Alternative pulp log markets in India and Korea were found, but these markets can be less reliable, and prices paid have been less than for the previous Chinese market.

Non-commercial and pre-commercial thinning

During periods of commercial thinning delays and because of the imperative to thin on time, some growers implemented non-commercial stocking reduction; pre-commercial thinning (PCT) and non-commercial thinning (NCT).

- A PCT is normally carried out at about 4-6 years of age and involves selected (poorer) trees being felled and wasted (see Figure 34). Trees left on the forest floor decompose and recycle nutrients and sequester carbon. Several growers undertook PCT in the early 1980's and between 2012 and 2014 in both high Site Quality areas near Mount Gambier and in lower rainfall (and therefore slower growing) areas in the northern parts of the region.
- A NCT involves a harvesting machine felling either every third, fourth or fifth row and leaving the trees to rot in that row. In some cases, the bays between out-rows are also thinned to waste. Several growers have undertaken NCT in plantations near Beachport (SA) and in plantations in the northern parts of the region.

While both PCT and NCT achieved the objective of avoiding a delayed commercial T1, they are costly, with no immediate revenue offset. Other disadvantages arise from the woody debris (harvest residues) retained in the plantation. These felled trees can take more than five years to decay. In the meantime, they reduce access within a plantation and due to high volumes of dry woody material, create an elevated future fire risk.

Figure 34: Pre-commercial thinning, with selected trees felled and left to rot (photo by DJ Geddes©).

Pests and disease

Diseases

Because of the dry summers in the GT, common *P. radiata* diseases found in Victoria, New South Wales and Tasmania (e.g. as *Dothistroma*, *Cyclaneusma* and *Diplodia*) are rare. *Dothistroma* has not been recorded west of the Otway ranges. *Diplodia sapinea (syn. pinea)* is a fungal disease that causes leader dieback, crown wilt and whorl canker. It normally occurs in warm and humid conditions or in situations where trees are stressed. Greater levels of *Diplodia* damage have been detected in the GT from aerial surveys since 2019, with patches of trees affected between Kentbruck (Vic) (in the east) and Kongorong (SA) (in the west), typically in areas overdue for T1 and in terrain-hollows where moist air can gather. Normally the best corrective mechanism is to thin early to allow better airflow through a plantation. Another disease impacting GT softwood plantations is *Armillaria luteobubalina* root disease (ARD). It causes needles to droop, turn yellow and then redden, and has occurred spasmodically in low-lying areas of plantations, often near swamps. But damage levels have been insignificant and it was of little concern to the industry. Mound ploughing during site preparation reduced chances of ARD tree damage.

An insect pest; the 1987 Sirex outbreak

Sirex noctilio is an introduced insect pest that attacks softwood trees. The wasp injects its eggs into stressed or dying trees. Larvae hatch-out and then bore tunnels through the wood. Fungal contamination from the larvae will eventually kill a tree, and borer holes make the wood unsuitable for sawn products. *Sirex* can be controlled through a nematode inoculation program, along with a release of parasitic wasps. There are several predator insects of *Sirex* including *Ibalia leucospoides*, *Megarhyssa nortoni*, *Ryssa hoferi, R. persuasoria* and *Schlettererius cintipes*. Originally from Europe, it was detected in Australia in 1952, initially in Tasmania, and then it spread to Victoria, then New South Wales, and began building up in large numbers in GT *P. radiata* plantations in 1987. Prior to that, there had been annual aerial detection flights in the GT since the early 1970's, with subsequent ground surveillance of identified suspect trees. In May 1987, GT plantation growers met to discuss control options (Haugen & Underdown, 1990). At that stage, it was thought about one million softwood trees had been attacked. An option was to release four species of parasitoid insects, but only one, (*M. nortoni*) was able to be bred up in sufficient numbers. At the same time, it was decided to implement a nematode control program developed by CSIRO which involved inoculations of logs using the parasitic nematode *Deladenus siridicola*. There was also a harvesting program to salvage affected trees.

In July 1987, a large-scale inoculation program commenced with all growers involved. Each grower directed operations within its own plantations. Work involved aerial assessments of tree mortality, ground assessment and tree felling for inoculation and the actual inoculation itself. The target was an average of 3,300 trees/day to be fallen and inoculated. Trap-trees were established in areas where there was no inoculation. Nematodes were produced by the CSIRO Division of Entomology in Hobart. Haugen and Underdown (1990, p.36) provide details of the complex inoculation procedures. By the end of 1987, it was estimated 1.8 million trees had been killed by *Sirex,* with a value at the time of $5-6 million. It was a significant loss to the GT industry. However, the inoculation program was successful and *Sirex* is now under control, surviving at low background levels. The National *Sirex* Committee still operates. It is soon to investigate the efficacy of the nematode strain used by Australian softwood growers in *Sirex* populated areas.

Other insect pests

Three bark beetle species have been found in softwood plantations (Neumann, 1987); *Hylastes ater*, *Hylurgus lignipurda* and *Ips grandicollis*. They usually attack weakened, dying, or recently felled trees and fresh harvesting residues. Adult males build tunnels under the bark (eventually ring barking the tree), and at the same time carry a fungus that causes bluestain, that can downgrade logs for different timber uses. The management strategy is to ensure harvest residues are removed from residual trees after harvesting and ensure all residues are lying on the ground, rather than leaning against residual trees. Another strategy is to avoid T1 of young trees adjacent to recently clear-felled blocks (as a source of the insects). There have been two main periods of bark beetle outbreaks in the GT. In the late-1970's numbers of *Ips* built up on sandy sites where trees suffered drought stress, with damage more serious in the plantations near the state border. After the 1983 Ash Wednesday bushfires, there was a significant outbreak of *Hylurgus* over an 18-month period as a result of extensive volumes of clear-felling harvest residues from fire salvage harvesting operations. Neumann (1987) found that by the end of the 1985/86 summer, the beetles had travelled up to 25 km from the harvested areas and affected hundreds of trees aged between 4 and 14 years old. Attacks were mainly on stem wood near ground level. Once the salvage harvesting was complete (and the insect breeding habitat reduced), *Hylurgus* number rapidly declined. There have been no serious outbreaks of *Ips* or *Hylurgus* in the last 30 years. The Monterey pine aphid (*Essigella californica*) was first recorded in Australia in March 1998 on *P. radiata* trees in Canberra. It is now widespread in GT softwood plantations and is recognised for causing serious productivity losses. It causes yellowing and premature needle loss. Biological control methods began being developed in 2001 (Sasse *et al*., 2009).

Pest animals

Rabbits have always been a problem. While they cause little or no damage to older trees, they can nip off the tops of young trees or even chew-off the whole tree. During the period when a number of farm properties were purchased for softwood establishment, netting fencing was often used to exclude rabbits, along with fumigating burrows, warren ripping and baiting. Baiting using oats or carrots treated with 1080 (sodium fluoroacetate) was a very successful control measure. The introduction of calicivirus virus in 1996 has meant that now, rabbits are rarely a problem.

Hardwood plantations

History of hardwood plantations; a new commercial plantation enterprise in 1991

While past research woodlots had demonstrated *E. globulus* could be successfully grown in the GT, essentially it was a new species in the region to be grown at commercial scale. As a result, compared with the long history of research in the softwood sector, there was an initial lack of local knowledge about site selection, site preparation and plantation management. In support, eucalypt plantations growing in Tasmania and in Western Australia provided some guidance, although the soils and climate are different to the GT. In spite of this knowledge gap, a very large area of *E. globulus* was established in a relatively short period of time. It was inevitable there would be many silvicultural challenges to fine-tune. In the period from 1991 to 1995, there was initial cooperation between the growers, as they were all eager to learn the best way to manage *E. globulus* plantations including site preparation, weed and pest control. With the arrival of large-scale MIS companies, there was an increase in business competitiveness. By 2010, new owners had purchased most of the plantations previously controlled by MIS companies. After that, cooperation rapidly improved between the companies. There are now cooperative arrangements with fire management, plantation health, nutrition and koala management and they are members of the Green Triangle Forest Industry Hub (which includes both softwood and hardwood growers).

Management and rotation length

The time to harvest is an important consideration. Some MIS companies had set-rotation lengths legally defined in their investment offer documents; for example, harvest at 10 years of age (the ITC Eucalypts 1999 Green Triangle Project), harvest by 11 years of age (the Australian Eucalypt Project 1996 Prospectus), and harvest between 8 and 12 years of age (the Timbercorp 1999 Prospectus). Others (such as the Australian Blue Gum Project 1999

Prospectus) stated that that the trees would be harvested when *'deemed mature'*. *Eucalyptus globulus* plantations in the GT are not currently thinned prior to clear-fell. Harvest costs vary depending on the mean tree volume. The higher the volume, the cheaper the harvesting costs per green metric tonne. This is because a harvesting machine can fell and de-limb a 'large tree' in approximately the same time as a 'small tree' driven by linear feed rates. There are trade-offs between a shorter rotation age (and reduced annual fixed costs) and growing a plantation for a few more years in order to have a larger mean tree volumes and therefore lower unit harvest costs. Without MIS restrictions, *E. globulus* rotations are now determined in order to optimise growth and net financial returns and to meet market demand. This allows for a variety of rotation lengths, depending on site circumstances. Typically, rotation lengths are now 12-15 years. Nevertheless, there is remains a backlog of older age plantations that are overdue for harvest.

Site selection

Average annual rainfall

Between 1991 and 1994, *E. globulus* plantings on farmland showed rapid early growth. Sites received from 550-800 mm/y rainfall. On the basis of early growth, the expectation was that sites with suitable soil and with more than 600 mm/y average rainfall would be satisfactory for commercial plantations. By the early 2000's, many of the early plantations were close to maturity, providing more information about actual growth rates. Generally, it was found there was poorer growth than expected on lower rainfall sites. The industry then began to recognise that *E. globulus* requires at least 650 mm/y average rainfall to achieve satisfactory financial returns.

Soil depth and type requirements

It soon became apparent that soil depth and soil type (Harper *et al*., 1999, p.3), were also important attribute for successful plantation growth. Backhoe machinery began to be used in about 1996 to speed up site suitability surveys. Initially soil pits were dug to 2.5 m in a grid across each property to check soil type changes and to identify any impeding layers. In estimating potential site productivity, soil limiting factors such as deep sands or heavy clays were considered. It was vitally important to locate any rock or potential tree root barriers. By the late 1990's, soil profiles were described to 3.0 m, and instead of a grid pattern, foresters were using terrain as a guide to soil pit location, and then if underlying rock was found, more pits would be dug to map rock boundaries. With more experience it was recognised that soil depths greater than 3.0 m indicated better growth. By 2005, companies were routinely checking soil depths to 4.0 m and some were also using drilling rigs to check for impeding layers to 8.0 m. An innovation in the early 2000's, as site suitability surveys became more sophisticated, was routine use of EM38 technology (electromagnetic soil mapping) to avoid planting saline soil types.

Site productivity models

Most of the larger-scale plantation companies had in-house confidential process-based productivity models applied when assessing properties being considered for purchase. Such models (e.g. Battaglia *et al.,* 2007) were based on theoretical plant growth and used soil type/depth and temperature/rainfall inputs to estimate future plantation growth. Examples of models that were developed by the CSIRO include 3-PG (Physiological Principles in Predicting Growth), ProMod and CABALA.

Establishment methods

Planting timing

In the GT, depending on break-of-season autumn rain, the ideal planting period is from early June to late August, as by June soils had been sufficiently wetted by rainfall. However, for a period the Australian Taxation Office (ATO) MIS rules required that planting must be completed by 30 June in the project year for which MIS woodlots were sold. This deadline provided challenges with large-scale areas being established by MIS companies. By 2010, most plantations established under MIS structures had been purchased by either Australian Bluegum Plantations or New Forests Asset Management and were no longer under an MIS framework. As a result, plantations established since 2010 had a better start, because planting commenced when the soils had achieved the desired level of moisture (rather than being forced to complete planting by 30 June).

First rotation

After removal of internal fences and any blanket herbicide spraying to control pasture grasses, compartment boundaries were surveyed. The sites were then ploughed and, in some cases, mounded over rip lines (Figure 35). Most of the *E. globulus* plantations in the GT were established on cleared former agricultural land. Many of those farms had a long history of annual superphosphate fertiliser applications. Typically, agricultural fertilisers would leach through the soil until they stopped at the clay B-horizon. While pastures could only access soil fertility down to about 25-30 cm, *E. globulus* trees were able to access nutrients much deeper in the soil profile. As a result, early growth in most of the *E. globulus* plantations was excellent, and only slowed later in the rotation when soil moisture became more limiting.

Figure 35: Mound ploughing over rip lines (photo by DJ Geddes©).

While some machine planting had been used on former farm sites, the majority of *E. globulus* plantations were manually planted using the Pottiputki tree planting tool (Figure 36). This device was designed in Sweden to plant containerised trees. It was been designed to allow a planter to walk along the planting row without a need to bend down to plant each tree.

Figure 36: Planting *E. globulus* seedlings with a Pottiputki planting tool (photo by DJ Geddes©).

Second rotation

Harvesting of small areas of the *E. globulus* estate in the GT commenced in 2005 with rapidly increasing areas harvested over the next few years. In 2012, more than 8,000 ha was harvested, and the harvest area tripled over the following four years. While some of these plantations were not replanted (because of financial viability due to too high haulage costs, or poor productivity), most were re-established in a 15-month period after harvest. Between 2005 and 2012, while there was some re-planting with new seedlings, many second rotation plantations were not re-planted but rather managed the coppice growing on the harvested stumps. This was a relatively cheap option because there was no site works required and little need for weed control. The main cost was that the multi-stem coppice needed to be thinned back to one or two stems per stool (stump) at about age 1.5-2.5 years (see Figure 37). Disadvantages of coppice plantations were twofold. Firstly, not all stumps would regrow (typically 10-20% mortality), leaving sites not ideally stocked. Secondly, the original trees were often grown from seed from natural forest provenances, rather than with the growth benefits of trees grown from genetically improved seed.

Figure 37: Two-year-old second rotation coppice *E. globulus* plantation in need of thinning (photo by DJ Geddes©).

The re-establishment program of the *E. globulus* estate occurred at a time when there were clear lessons from the softwood sector to conserve nutrients. There are two types of harvesting systems in the GT, and they have different implications in regard to managing harvest residues remaining on a site.

- Cut-to-length: In cut-to-length (CTL) operations each tree is individually felled, de-limbed, debarked and cut into log lengths by a harvesting machine at the stump. This leaves harvest residues (e.g. leaves, small branches, bark and the treetop) distributed evenly across a plantation.
- Whole-tree-chipping: With whole-tree chipping (WTC) operations, trees are harvested with a feller-buncher, bunches of felled trees are skidded to a mobile chipper on the plantation edge and fed through a flail de-limber which also removes the bark. In the early period between 2006 and 2012, harvest residues from the mobile chipper were routinely burnt on-site. Managers now relocate piles of harvest residues from the in-field chipper back into the plantation to retain nutrients on-site.

Chopper rolling of harvest residues is common, followed by mounding over the former mounds and stumps (Figure 38). Mounds are left to settle for several months to avoid air pockets during manual replanting with seedlings.

Figure 38: Ten-month-old second rotation planted *E. globulus* on mounded and chopper rolled site (photo by DJ Geddes©).

New developments in second rotation site preparation include the following.

- Genetics: Most plantations are now re-established with seedlings (grown from genetically improved seed), rather than from coppice regrowth.
- Equipment: Heavier equipment is used to cope with harvest residue levels. For example, site preparation equipment is now fitted to forwarders, skidders or bulldozers, rather than agricultural tractors used in the first rotation.
- Harvest residues: On sites with large harvesting residue loads, coulter wheels are rolled over the old stump line with pin wheel rakes removing woody material from the mound to facilitate re-mounding.
- Coppice treatment: Stumps are routinely sprayed at harvest (with a spray unit on the felling head) to prevent coppice regrowth.
- Drone use: Survival assessments are now undertaken using drones, rather than measuring gridded sample plots. Drone technology removes the need for people to 'clamber' over slippery harvesting residues.

Tree improvement and genetics

While there was a long history of tree breeding improvements in *P. radiata* plantations in the GT, in 1991 there was no improved seed available for *E. globulus*. The seed used had been collected from individual *E. globulus* trees showing better growth in various natural forest provenances. Forestry Tasmania was the early seed supplier with seed from 14 different Tasmanian provenances; Flinders Island, Scamander, Freycinet, Swansea, Forestier, Taranna, Buckland, Channel, Pelverata, Leprena, Bruny, Geeveston, West Coast and King

Island. Other suppliers had seed available from the Otway (Victoria) provenance. Differences in growth rates and tree form resulted between the provenances. In 1990, STBA commenced working on *E. globulus* genetics in cooperation with APM Forests Pty Ltd (Gippsland, Victoria) and North Forests (Burnie, Tasmania) and undertook its first combined *E. globulus* genetic analysis in 1995. While this gave much more confidence in progeny performance, it was several years later that the first genetically improved seed became available to members. In the meantime, genetically improved seed was available from private companies.

Weed control

Maintaining adequate soil moisture is one of the most important aspects of *E. globulus* silviculture in the GT. Managers aim to reduce competition with newly planted trees; ideally by controlling grasses and weeds in the first 18-24 months (Figure 39). Post-plant weed control in *E. globulus* plantations was a challenge in the early years because many of the herbicides used in softwood plantations could kill *E. globulus*. In the mid-1990's typical pre-plant weed control was achieved using glyphosate and metsulphuron methyl, while simazine and sulfometuron-methyl were used post-planting, along with amitrole on the inter-row. Glyphosate was also used on the inter-row in post-planting weed control, but care was needed to avoid spraying *E. globulus* leaves. Since late 2022, an innovation has been the use of drones to apply herbicides. With up to a 40 kg payload, drones are more versatile than helicopter applications and they are able to better negotiate obstacles, such as retained koala trees. They also do not require the buffer distances (e.g. from sensitive area) of helicopter operations. Drone use remains in a developmental phase.

Figure 39: A first rotation one-year old *E. globulus* plantation showing good inter-row weed control (photo by DJ Geddes©).

Nutrition

Historic routine treatments

If trees are not able to obtain sufficient nutrients from the soil or added fertiliser, their growth rates will be impacted. The addition of fertiliser aims to improve tree health and therefore maximise the potential for tree growth. In the early years of *E. globulus* establishment in the GT, fertiliser was routinely applied at time of planting. Within a few years it was recognised many properties selected for purchase already had a history of regular fertiliser applications, and did not necessarily require fertiliser at time of planting. During the late 1990's in first rotation *E. globulus plantations*, diammonium phosphate (DAP) was commonly used. It was a relatively cheap source of nitrogen and phosphorus. From the early 2000's, DAP became more expensive and there was a trend towards the use of blended / tailored fertiliser mixes specific to nutrient deficiencies. Urea has been commonly used in second rotation plantations because it is a relatively low-cost form of nitrogen. However, the nitrogen in urea can be volatilized easily, and is less effective in wet weather because it dissolves rapidly.

Use of soil and foliar testing

Soil testing and later age foliar sampling have been used. While each plantation company had different policies, generally for any farmland being considered for purchase, a number of soil samples at a depth of about 15 cm were taken from each soil type identified across a site during the suitability survey. By the early 2000's, foliar sampling was routinely undertaken by the larger growers, from age-2 years. Samples were collected in late winter when the trees were not drought stressed and tree growth was assumed to be minimal. Samples were typically taken from the youngest set of fully expanded leaves of an actively growing non-shaded branch from a co-dominant tree and from the mid to upper third of the canopy (Dell *et al*., 2001, p.164). Leaves with severe insect damage were avoided. Adelaide and Perth based laboratories analysed foliar samples. Foliar nutrient analyses results could then determine any corrective action required. Dell *et al.* (2001, p.155, Table 4) provides suggested deficient and adequate levels of nitrogen, phosphorus, potassium, calcium, magnesium and sulphur, as well as a range of micro-nutrients for *E. globulus* plantations. The most common nutrient deficiencies in *E. globulus* trees are nitrogen, potassium and phosphorus. They are highly mobile nutrients in the phloem of *E. globulus* and as a result, deficiencies appear first in old leaves and move gradually towards the shoot apex (Dell *et al.,* 2001, p.11). Nitrogen deficiencies can be recognised when older leaves turn pale green to yellow. Potassium deficiencies can be recognised when edges of older leaves lose their green colour. Phosphorus deficiencies can be recognised when older leaves become mottled with orange patches.

Initial spacing and stocking rates

First rotation sites

In 1991, sites were prepared in autumn by ripping planting lines at 3 m row spacing, with trees planted at about 2.5 m apart in the rows, for a nominal stocking of 1,300 stems/ ha. By 1992, growers began using heavy-duty Grizzly mound ploughs to prepare planting rows. This larger implement necessitated rows being widened to 4 m in order to allow for the amount of soil to be collected from each side of the planting row for the mound (Figure 35). Trees were planted at about 2.5 m apart in the rows for a nominal stocking of 1,000 stems/ha. By 1996, row widths had increased to 4.5 - 5.0 m based on experiences in WA. This was partly to reduce costs (with wider rows and closer tree spacing within the rows, there were fewer rows and therefore less machinery costs), and partly to provide better vehicle access between the rows for future plantation management. For several years, one MIS company even adopted tramline plantings, with two rows 2.5 m apart and 6-7 m spacing between the tramline rows. This reduced machinery costs even further, because the two tramline rows could be ripped and mounded in a single pass. However, biologically plantation trees grow best when each tree has approximately the same space in both directions from its neighbouring trees. With wider rows, tree growth is not optimised because the trees are closely spaced within the rows and are further away from the ideal 'on the square' spacing.

Second rotation sites

Row direction and row width is still somewhat dictated by rows from the first rotation. When there are opportunities to make changes in the second rotation, the preference is for initial replanting stocking of 1,000 stems/ha, with rows 4.5 m apart, trees 2.2 m apart in the row and row direction to facilitate future harvesting.

Other considerations

Susceptibility to frost

Eucalyptus globulus is susceptible to frost, particularly on low lying sites. They can survive mild frosts, even if many leaves have been burnt off (Figure 40), but they are killed by severe frosts. There have been two major frost events in the GT that killed large areas of *E.*

globulus plantations. The first was in autumn 1999, when large areas of 9-10-month-old trees planted in winter 1998 in the Mumbannar (SA) area died and needed to be replanted. Trees planted in the previous winter were largely unaffected by the frost because their crowns were high enough above the ground and (tougher) adult leaves were already present. The second event was during the drought year of 2006. A number of severe frost events occurred between May and July, were made worse by the extremely dry air. Frost damaged and killed trees planted in winter 2005 and also newly planted trees in May and June 2006.

Figure 40: A young *E. globulus* tree recovering from mild frost (photo by DJ Geddes©).

Koalas

During the early phase of *E. globulus* plantation development in the mid-1990's in the GT, koala populations were not considered a management issue because it was thought *E. globulus* were not a preferred food species. Nevertheless, from about 2009, koalas were regularly observed in older-age *E. globulus* plantations. Larger-scale harvesting also began around this time. By about 2010, the Green Triangle Regional Plantation Committee (GTRPC) recognised that while koala browsing was insignificant to tree growth, potential injury to koalas during harvesting was a matter to be addressed. Over the next few years, harvesting guidelines were developed to assist growers (GTRPC, 2013). These guidelines suggested that when harvesting plantations where koalas were likely to be present, there be inspections to identify koala locations, and any trees in which koalas were spotted be marked to alert the harvesting operator. At that time a minimum of five trees were to be retained immediately adjacent to the marked tree, but in the next few years, the number of trees to be retained increased. Also, the felling of trees likely to impact any tree with koalas present were to be directed away from the koala tree. This policy worked well, and all harvesting crews diligently followed the guidelines.

Subsequently, the Victorian Department of Environment Land Water and Planning (DEWLP; now the Department of Energy, Environment and Climate Action) recognised that *E. globulus* had become a preferred food tree (Conservation Regulator, 2021, p.5). Heard and Ramsay (2020, p.1&17) found that koala populations in the *E. globulus* plantation areas of southwest Victoria were considerably higher than the rest of Victoria, with an average of 0.89 koalas/ha, compared with 0.03 koalas/ha in the plantation areas of the Strzelecki Ranges and 0.22 koalas/ha in suitable natural forest habitats. This infers there are four times the number of koalas per hectare in southwest Victorian hardwood plantations than in suitable native forest habitats. The 2013 guidelines have been superseded by a DEWLP Regulatory Guide (Conservator Regulator, 2021) which applies particularly to the area of hardwood plantations located between Mount Gambier in the west, Casterton in the north and Port Fairy in the east, known as the 'koala zone'. Prior to any plantation harvest operation in Victoria, hardwood plantation managers are required to develop and implement a Koala Management Plan (KMP) and then apply to the Victorian Government Conservation Regulator for an Authorisation under the *Wildlife Act 1975* to disturb koalas during plantation management operations. The Conservation Regulator assesses each application on its merits, particularly the acceptability of the KMP. The Authorisation *'sets out specific steps and minimum standards that a blue gum plantation owner or manager must take to minimise impacts and ensure the welfare of koalas is protected during plantation management operations'* (Conservation Regulator, 2021, p.10). Managers are now required to retain at least nine trees around a tree in which a koala has been identified (Figure 41).

Figure 41: Koala trees remaining after the next plantation has been established (photo by DJ Geddes©).

Pests and diseases

Disease control

There are several *E. globulus* diseases that attack adult trees; Armillaria (a root rot), Sooty mould (grows on the honeydew secreted by sap sucking insects such as scale insects) and Corky Leaf Spot, but these are not common. The most common *E. globulus* disease in younger trees is Crinkle Leaf Disease (*Mycosphaerella* spp). This can cause early leaf shedding. Normally, infected trees will grow out of the problem after a few years (Phillips, 1996, p.138). Healthier trees that are not nutrient or drought stressed are less susceptible to this disease. Since 2020, *Mycosphaerella* has been more prevalent in the GT. There is currently a biological control research program into the disease.

Insect pest control

During the first few years of *E. globulus* plantation development in the GT (between 1991 and 1995), there were very few problems with leaf eating insects, apart from grasshoppers (which were mainly restricted to sandy sites). It was thought that perhaps the GT was free of a number of insects including Autumn gum moth, Chrysomelids, Sawfly larvae and weevils that had caused serious damage in WA *E. globulus* plantations. However, by about 1997, insect populations began to increase in the GT. Western Australian experience demonstrated that an integrated pest management program was the best way forward, because while many insects damaged planted *E. globulus* trees, predator insects can attack damage causing insects. As part of its contribution to the KCA *E. globulus* plantation program, the forest entomologist from Primary Industries SA (Dr Charlma Phillips) published a reference on insects and their management (Phillips, 1996). This work identified that a large number of insects can attack *E. globulus*. Larvae or adult insects can attack tree roots (e.g. African black beetle or cockchafers) and chew the leaves. There are many leaf chewing insects; for example, Chrysomelid larvae, Chrysomelid beetles (Figure 42), Autumn gum moth larvae, weevils and sawfly larvae. There are insects that suck the sap (e.g. scale insects) and those that feed on the stems (e.g. borers). Trees under stress (e.g. in times of drought or during nutrient imbalances) are more vulnerable to insect attack. By the early 2000's, forest managers commenced carefully monitoring of insect pest build-up, and only applied insecticides when damage was expected to have an adverse financial impact. It was found that *E. globulus* could quickly recover from low-level leaf damage. Today, the main insect pests for *E. globulus* are Autumn gum moth larvae and Chrysomelid beetles, with occasional outbreaks of sawfly larvae. An innovation since 2014 has been the use of systemic insecticide applied as a soil drench soon after planting. It provides effective control of Chrysomelid beetles attacking *E. globulus* trees and avoids damage to other beneficial insects. But it is not effective on other common leaf chewing insects such as Autumn gum moth larvae.

Vertebrate pests

Unlike eucalypt plantations in other parts of Australia (e.g. the Otway and Strzelecki Ranges in Victoria, in Tasmania and on Kangaroo Island), wallaby browsing was insignificant in first rotation GT *E. globulus* plantations. However, wallabies can cause damage in young trees on second rotation sites, mainly because of increased numbers entering from surrounding plantations. The use of 'socks' have been tested to prevent damage in newly planted trees in high-risk areas. Rabbits and increasingly feral deer need to be controlled, as they can destroy newly planted *E. globulus* plantations.

Figure 42: Chrysomelid beetle eggs and larvae on a juvenile leaf (photo by DJ Geddes©).

Other changes to softwood and hardwood plantations

Environmental certification

Globally in 1992, following the United Nations Conference on Environment and Development (held in Rio de Janeiro, Brazil), the concept of identifying forest products from well-managed forests emerged (Perera & Vlosky, 2006). Over the following decade, forest certification gathered momentum in North America and Europe. Certification requires independently assessing the quality of the forest management against a set of principles and criteria. In 2004, the first environmental certification scheme was introduced to Australia, the Program for the Endorsement of Forest Certification (PEFC). Two years later in 2006, the Forest Stewardship Council (FSC) introduced its environmental certification scheme to Australia. Forest certification is possible in Australia under the Responsible Wood certification scheme (endorsed by PEFC) or FSC (administered by FSC Australia). In the GT, most purchasers require logs or woodchips to be sourced from voluntary third party (environmentally) certified plantations. This is to satisfy subsequent customer requirements (e.g. international pulp mills purchasing export woodchips) that the trees have been grown with sustainable forest management practices. Most customers, for either sawn timbers or woodchip supplied by a sawmill, will require that the products have suitable environmental accreditation. Processors usually require Chain of Custody certification to prove to their customers that the logs purchased were obtained from voluntary third party certified (sustainably managed) plantations. Now, all the major GT softwood and hardwood plantations are certified to either PEFC or FSC or both. Maintaining certification and passing annual audits adds a cost for plantation management.

Forest water regulations in southeast South Australia

Water use is managed within the Lower Limestone Coast (LLC) of South Australia by a series of sub-catchment management zones. Since 2004, plantation forestry has been considered a water-affecting activity in the LLC and is therefore accounted for in the water management system (Geddes, 2019, p.28 to 30). This is because plantation tree roots are deemed to extract aquifer water to enhance tree growth, and plantations are deemed to restrict recharge of the aquifer from rainfall (Benyon, 2002, p.10&16). In terms of reduction in recharge and direct extraction, the deemed volume of groundwater impacted by plantations depends on several factors including the following.

- Tree species: There are deemed differences in water use between hardwoods and softwoods, particularly in regard to rotation length and the period of fallow between plantation rotations.
- Age and crown development of a plantation: There are known variations in water use throughout the plantation life cycle. While trees are in the juvenile phase, they occupy a reduced portion of the site. After harvesting, sites are left fallow prior to replanting and do not intercept rainfall or extract water from the aquifer.
- Soil type: Water holding capacity of a soil and the depth of soil to which roots can penetrate.
- Site occupancy: Plantations do not fully occupy a site. Existing plantations occupy around 85% of a site (e.g. net plantable area or the actual area planted), leaving 15% unoccupied. Some properties have less than 70% net plantable area.

Under the provisions of the *Landscape South Australia Act, 2019* (which superseded the *Natural Resources Management Act, 2014)* plantation owners are required to hold a Forest

Water Licence (Natural Resources South East, 2015). A Forest Water License authorises a specific plantation at a specific location; it attaches to the land title. It includes a water allocation, a water allocation property right, a water allocation tradeable only when no longer required and a tradable allocation based on deemed rates in the Water Allocation Plan (WAP). Where an aquifer is within 6 m of the land surface, a licence is required for plantations deemed to be extracting from the unconfined aquifer. These licences include an annual levy based on deemed water use by plantations as follows.

- Deep water-table: For a plantation over a deep water-table (i.e., greater than 6 m depth, based on the Digital Elevation Model), there is deemed to be no extraction of water. But there will be a recharge interception reduction (percentage of rain falling), based on the rainfall intercepted by the plantation canopy; 83% for softwoods and 78% for hardwoods.
- Shallow water-table: For a plantation over a shallow water-table (i.e., less than 6 m depth), there are provisions for both interception (as above for softwoods and hardwoods) and direct extraction (1.66 ML/ha/y for softwoods; 1.82 ML/ha/y for hardwoods).

In 2006, Brown *et al.* (2006, p11) raised concerns about suspected over-allocation of water. In 2012, when the updated LLC WAP was being prepared, two sub-catchment management units (Coles and Short) with extensive plantations, were considered to be over-allocated and at high risk. If plantations are located in 'at risk' water management zones, the plantation activity can continue until the trees are clear felled. At that time, a manager may either need to secure an additional water licence before a plantation is replanted, or else, only a portion of the plantation can be replanted with the remainder converted to grazing activities. Since about 2018, a number of plantation properties in Coles and Short have been harvested and have reverted to agricultural uses because it was not possible to obtain water licences.

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Appendix 3: Log products and prices in the Green Triangle

Project 1: Research new shorter rotation silvicultural models for pine plantations and longer rotations for blue gum plantations. Sub-report title: An overview of harvest products and prices from Green Triangle softwood and hardwood plantations

Prepared by

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Summary and key points

Overview

The Green Triangle is the largest scale plantation region in Australia. There are two commercial species grown. *Pinus radiata* (radiata pine; a softwood) plantations are normally grown over rotations of 30-35 years with the objective of producing sawlog for local processors that supply structural timber to the Australian house construction industry. *Eucalyptus globulus* (Tasmanian blue gum; a hardwood) plantations are grown over rotations of 10-15 years with the objective of supplying markets in China and Japan with woodchips for manufacture into high quality writing paper.

Softwood products

Softwood plantations are initially established at stockings of 1,400-1,600 stems/ha in order to restrict branch size and to encourage tall straight trees. Depending on growth rates, the plantations have a commercial first thinning between ages 10 and 15 years. This entails felling a row of trees to enable harvesting machinery access (usually every fifth row), and trees in the rows each side of those access rows are thinned out by felling the poorer quality trees. Typically, about half of the trees are felled. Then two more thinning operations are scheduled before the plantation is finally clear felled. The report provides indicative harvest schedules and harvest volumes. Products from each harvest vary as the trees mature. First thinning produce small diameter logs. As the trees mature with each subsequent thinning, log diameters increase. Key log attributes are log length (in metres) and log diameter (measured in centimetres or millimetres at the small end diameter – SED - of the log). Normally diameter measurement of standing trees is over bark while diameters of harvested logs are normally measured under-bark.

Key products from softwood harvests are as follows.

- Sawlog: These are straight logs (e.g. without bends or kinks) sold in various lengths and diameter and are the most valuable products recovered. They are normally obtained from the second and third thinning and from clear fell.

- Industrial sawlog: These include shorter-length logs (which do not meet sawlog specifications), as well as larger diameter logs with very large branch knots (typically recovered from trees on the plantation edge).

- Preservation logs: This is a specialist low-volume but high-value market with ability to supply constrained by stringent straightness and diameter criteria. Treatment products (particularly fence posts) are obtained from small-diameter logs, down to 75 mm SED under-bark (SEDUB). Preservation products include posts, rails, strainers and poles to service local viticulture, horticulture and agricultural industries.

- Woodchips (for board manufacture): These are low-grade woodchips from thinning and from clear fell harvest residues chipped.

- Export pulp log: These are typically in smaller-diameter log sizes not required by local sawmills.

Hardwood products

Hardwood plantations are normally grown over a short rotation of 10 -15 years before harvest to supply international paper makers with woodchips. The trees are planted in rows at stockings ranging from 900 - 1,000 stems/ha. Hardwood plantations are not normally thinned prior to final harvest, and the products (either woodchip or pulp logs) are less complex than for softwoods. The product recovered from cut to length harvesting operations is pulp log. Harvested logs are normally transported on log trucks to a central facility and are converted to woodchips suitable for export. The product from whole tree chipping operations is woodchip which is transported to the export facility in specialist closed sided trucks. Hardwood woodchips must comply with strict product specifications in terms of cleanliness and chip size.

Prices

Products from both softwood and hardwood harvests are normally sold on a mill door price basis. This is the payment for delivered product to the processor or export facility. For the grower to calculate the expected return, the costs of harvest, haulage, supervision and on-property roadworks need to be deducted from the mill door price. Softwood products can either be sold in dollars per cubic metre or dollars per green tonne. All hardwood products are sold on a dollar per green tonne basis. Hardwood products are global commodities and values are based on international supply and demand in US dollars per bone dry metric tonne. But GT growers normally sell their products to exporters in Australian dollars per green metric tonne. The report also provides indicative information about harvesting and haulage costs. Harvesting costs vary depending on the mean tree volume. Large sized trees can be harvested in approximately the same time as smaller sized trees, and therefore the larger the mean tree volume, the less the harvesting costs per green metric tonne. Haulage costs are based on tonnes per kilometre, with the longer the road haulage distance the higher the cost. Woodchip haulage costs are slightly higher than log haulage costs because of the additional costs of closed sided chip vans.

Introduction

The Green Triangle (GT) has the largest area of plantations in Australia (ABARES, 2022). By 2022, the region had approximately 180,602 ha of softwood plantations (all *Pinus radiata;* radiata pine) and 133,809 ha of hardwood plantations (mostly *Eucalyptus globulus;* Tasmanian blue gums). Figure 43 presents a recent plantation area trend over the last two decades. The Green Triangle Forest Industry Hub (GTFIH) seeks to encourage landholders in the GT to establish plantations on part of their properties, to provide an alternative future income and to increase the volume of fibre available to the forest industry. As part of a larger study, this report focusses on products harvested from GT softwood and hardwood plantations and presents indicative prices for those products.

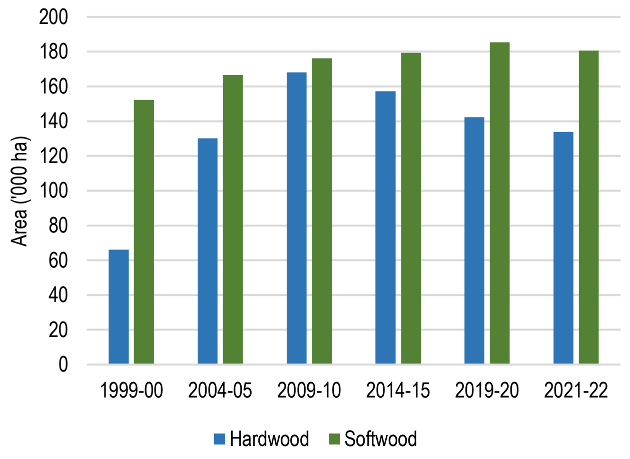

Figure 43: GT plantation area since 1999 for the specific periods indicated (ABARES, 2022, supporting dataset).

Softwood

Thinning of plantations

An overview

Softwood plantations in the GT are generally grown to supply sawlogs to local processors. These plantations are normally planted at a high initial stocking rate (1,400 to 1,600 stems/ha) to encourage tall and straight tree growth. As the trees grow taller, a plantation requires progressive thinning to provide more space and resources to the retained individual trees to allow greater diameter growth. This results in larger diameter trees which enables recovery of more valuable sawlog size logs. There are three main thinning considerations; how often to thin, controlling the site, and which trees to remove. Softwood plantations are thinned three times (T1= first thinning; T2 = second; T3 = third thinning) prior to final harvest or clear felling (CF). For fast-growing plantations, T1 can be scheduled at about age 10-years, while for slower growing plantations, T1 can be as late as at age 15-years. Second thinning is normally scheduled about 5-6 years after a T1 event, with T3 in another 5-6 years, and final harvest about 8-10 years after T3 or at a pre-determined rotation age. The residual stocking after thinning should be such that the trees in a plantation maintain control of a site to shade-out the ground preventing competing weed growth. In the northern parts of the GT with higher summer temperatures, tree bark can be damaged by sun scald with insufficient canopy to protect (shade) the tree stem. Severe sun scald can cause the cambium to die on one side of a tree, leading to wood decay which downgrades log quality, reducing potential sawlog recovery and financial returns.

First thinning

The most crucial thinning in terms of future sawlog production is T1. If a T1 is scheduled too early, the harvest volume recovered may not cover harvesting costs. If a T1 is too late, the retained trees may become unstable in windy conditions due to their height and slenderness. Wind damage after T1 includes toppling of trees (wind throw) or bent trees. The age of T1 depends on growth rates. Once a T1 is complete, there is greater flexibility in timing of future thinning, as by then the trees are better able to cope with windy weather.

Thinning strategy

Thinning can be from above (i.e. taking out the larger trees) or from below (i.e. taking out the smaller trees). As the objective at clear fell is that all trees are to be tall and straight, in the GT, thinning is usually from below. Generally, T1 involves the removal of a complete row of trees to allow machine access; this can be every second, third or fifth row. At the same time, it is possible that the remaining bays of trees are thinned from below. First thinning and T2 harvests provide an opportunity to remove trees unlikely to produce high-quality sawlogs. Such trees include suppressed (runt) trees, double leaders (i.e. trees with two main stems), trees with ramicorns (i.e. a large vertical branch), trees with deformed or bent stems and trees with poor crown growth. At T1, groups of trees can be removed where many poor-quality are trees together. At T2 and T3, there is more emphasis to ensure an even spacing between retained individual trees after thinning. Trees to be removed are either, selected and identified by a mark of paint sprayed on the stem by trained tree markers or selected by harvest machine operators. There is a cost to employ tree markers, but this cost can be offset by having a better-quality post-harvest outcome, as well as reduced harvesting costs. Harvesting costs are reduced as the harvesting operator does not need to select trees to be felled.

Harvested products from softwood plantations

Recovery and sale of multiple products

There are two main types of roundwood (logs) sold for processing by GT sawmills. Better-quality logs (in terms of straightness) are known as sawlogs (with a range of log lengths and diameters), while industrial logs include shorter-length logs (which do not meet sawlog specifications), as well as larger diameter logs with very large branch knots (typically recovered from trees on the plantation edge). Key log attributes are log length (in metres) and log diameter (in centimetres or millimetres). Log diameter is defined by the small-end diameter (SED) as the diameter of the smallest log end or large-end diameter (LED) as the diameter of the largest end of a log. Normally diameter measurement of standing trees is over bark (OB) while log diameters are measured under-bark (UB). Current GT log specifications are presented in Table 16.

The grade and value of logs sold depends on; log size (i.e. diameter and length), log quality (i.e. straightness and number and size of knots), tree age, volume available from a site, continuity of supply from a site, and the current market situation. It is common to sell multiple log-grades to more than one buyer from a single softwood plantation harvest. Returns can be maximised by organising markets for the full range of products and minimise harvest residues. This requires coordinating a single harvest with log sales to different purchasers; for example, pulpwood, sawlogs (sometimes with different diameter ranges) and fencing products such as posts, rails and strainers.

Table 16: Current GT softwood log specifications (Geddes & Parsons, 2023).

Product	Length (m)		Diameter (cm)			Sweep		Max knot diameter (cm)	
	Length	Comment	SED	LED	Comment	Basis	Comment		Basis
	(m)		(cm)	(cm)					
Sawlog	4.25, 4.85, 5.45, 6.05		15.0	55.0	Range depends on mill capacity	<SED/4		5.0	
Industrial Sawlog	2.45, 3.65, 4.85, 5.45, 6.05	Length depends on diameter and mill	15.0	no max	Range depends on mill capacity	<SED/3		20.0	SED/2
Pulpwood	4.8 to 6.0	Some mills may take shorter lengths	10.0	30.0	May be smaller, depends on mill capacity	No sharp kinks or bends.		No limit	
Preservation	1.8, 2.1, 2.4, 2.7, 3.0, 3.6.		7.5	22.5	Different lengths have different diameter ranges.	<SED/4	no double sweep	2.5	

Sawlogs

Sawlogs are sold in varying lengths and diameters (grades), with a common feature of being straight (e.g. without bends or kinks). Collectively, six local sawmills purchase the majority of the sawlogs from GT softwood plantations; OneFortyOne Wood Products, McDonnell Industries, and Whitehead Timber Sales (all located near Mount Gambier, SA), Timberlink Australia (located at Tarpeena, SA), AKD Softwoods (located at Colac, Victoria) and South East Pine Sales (located near Glencoe, SA). Three other smaller-scale sawmills process less than 2% of the softwood sawlogs available.

Preservation log

Four timber treaters purchase roundwood suitable for fencing products; Roundwood Solutions (with facilities at Yahl and Snuggery, SA), Portland Pine Products (located near Heywood, Victoria), Alliance Timber (located at Dartmoor, Victoria) and Plantation Treated Timber (located at Kalangadoo, SA). This is a specialist low-volume but high-value market with ability to supply constrained by stringent straightness and diameter criteria. Treatment products (particularly fence posts) are obtained from small-diameter logs, down to 75 mm SED under-bark (SEDUB). Preservation products include posts, rails, strainers and poles to service local viticulture, horticulture and agricultural industries. In order of market demand, product sizes are as presented in Table 17.

Table 17: The length and SED for preservative logs (Geddes & Parsons, 2023).

	Length	SED
	(m)	(mm)
Posts	1.8	100-125
	2.1	100-125 & 125-150
	2.4	100-125
Strainers	1.8	150-175
	2.4	150-175, 175-200 & 200-225
Rails	3.0	125-150
	3.6	125-150

Woodchips for board manufacture

Borg Manufacturing, operating as Australian Panel Products, is Australia's largest-scale particleboard manufacturer. Borg has two particleboard plants with one located at Lakeside and the other at White Avenue, both on the western side of Mt Gambier. The company purchases low-grade woodchips from thinning and from clear-fell chipped woody debris.

Softwood export logs and woodchips

The softwood logs are exported via Portland and are typically in smaller-diameter pulp log sizes not required by local sawmills. Previously, the main markets were in China. Volumes exported reduced considerably (from November 2020) when China implemented bans on Australian sourced logs, with lower volumes exported, mainly to customers in India. The China log export market has re-opened. Woodchips exported are largely sourced from sawmill residues, with additional volume from chipped pulp logs. There are two softwood woodchip export terminals at the Port of Portland with a combined capacity of approximately 1.0 million GMT/y.

Softwood log specifications and purchaser summary

Logs from first thinning are smaller in diameter, and as plantations mature, each successive harvesting operation can produce larger diameter (and usually more valuable) logs. Local GT softwood processors and the log lengths purchased are presented in Table 18.

Indicative harvest volumes

Frequency of thinning and a thinning regime depends on stand productivity. In the GT, site productivity is defined by Site Quality (SQ) and is described in seven classes, SQ 1-7. Figure 44 presents site quality expressed as mean annual increment (MAI) based on total production at age 35 years. Indicative harvest volumes by SQ type, and stand ages of each harvest are presented in Table 18. Over a softwood plantation rotation, taking into account thinning and clear fell, total harvested volumes vary from 900 m^3/ha for the higher SQ stands, down to 585 m^3/ha for stands of SQ 5.

Table 18: Log lengths purchased by GT softwood log processors (Geddes & Parsons, 2023).

Processor	Location	Log lengths (m)
Sawlog down to 15 cm SED		
AKD	Colac, Vic	4.85, 5.45, 6.05
OFO	Mount Gambier, SA	4.85, 5.45, 6.05
Timberlink	Tarpeena, SA	4.85, 5.45, 6.05
SE Pine	Glencoe, SA	3.65, 4.25, 4.85
Whiteheads Timber Sales	Mount Gambier, SA	3.65, 4.25, 4.85, 5.45, 6.05
New Gen Timber	Mount Gambier, SA	3.65, 6.05
McDonnell Industries	Mount Gambier, SA	3.65, 5.45
Industrial log		
Finwood	Mount Gambier, SA	2.45, 3.05, 3.65
SE Pine	Glencoe, SA	2.45, 2.75, 3.05
A2C	Portland, Vic	3.65
New Gen Timber	Mount Gambier, SA	3.65, 4.85
Domestic pulp log		
McDonnell Industries	Mount Gambier, SA	3.65
Preservation log		
Roundwood Solutions	Yahl, SA	1.8, 2.1, 2.4, 2.7, 3.0, 3.6, 4.25
Portland Pine Products	Heywood, Vic	1.8, 2.1, 2.4, 2.7, 3.0, 3.6, 4.25
New Gen Timber	Mount Gambier, SA	2.4, 3.0, 3.6
Alliance Timber	Dartmoor, Vic	1.8, 2.1, 2.4, 2.7, 3.0, 3.6, 4.25
Plantation Treated Timber	Kalangadoo, SA	1.8, 2.1, 2.4, 2.7, 3.0, 3.6, 4.25

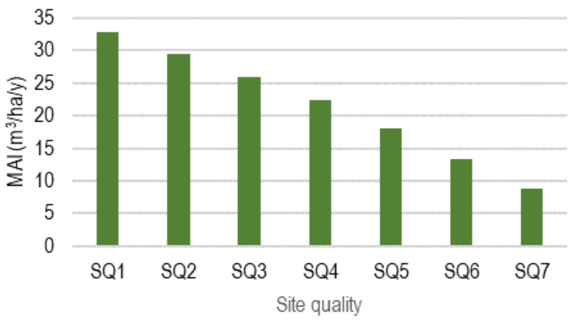

Figure 44: Mean annual increment (m^3/ha/y) by site quality (adapted from Lewis *et al.*, 1976, Table V.2, p 77-80).

Table 19: Indicative softwood harvest yields in cubic metres per hectare (m^3/ha) (adapted from Lewis *et al.*, 1976, Table V2).

	Site Quality 1-2 yield				Site Quality 3-4 yield				Site Quality 5+ yield			
	Age	Pulp log	Sawlog	Total	Age	Pulp log	Sawlog	Total	Age	Pulp log	Sawlog	Total
	(y)	(m^3/ha)	(m^3/ha)	(m^3/ha)	(y)	(m^3/ha)	(m^3/ha)	(m^3/ha)	(y)	(m^3/ha)	(m^3/ha)	(m^3/ha)
T1	10	105	0	105	12	90	0	90	15	80	0	80
T2	16	40	50	90	18	40	40	80	21	35	35	70
T3	22	30	110	140	24	43	90	133	28	35	75	110
CF	33	35	530	565	34	62	400	462	35	45	280	325
Total		210	690	900		235	530	765		195	390	585
MAI (m^3/ha/y)				27.3				22.5				16.7

Softwood returns to growers

Mill door price and stumpage

Softwood logs can be measured by weight (in green metric tonnes; GMT) or by volume (in cubic metres; m^3). The terms log volume and log weight are often interchangeable, given that in the GT one GMT of softwood log is approximately equivalent to one cubic metre of log. If an alternative conversion factor is used, it needs to be verified. Log processors normally prefer to purchase logs and other products on a mill door price (MDP) basis delivered to a mill (e.g. in \$/GMT or \$/m^3). This reflects the value of each product to the processor and is irrespective of transport distance. Practically, MDP's may vary with operation type (e.g. logs from clear fell are generally more valuable than similar size logs from first thinning), log age and diameter (e.g. generally larger diameter logs are more valuable, but it depends on the preferred log size of each processor). Grower's returns are defined as stumpage, which is the net revenue received by a grower after deduction from the MDP of the costs of harvesting the trees, transporting the logs to the processor, harvesting supervision and harvesting management. Depending on specific sale arrangements, cost of on-farm roading may or may not be taken into account in the stumpage. An indicative list of GT softwood MDP’s is presented in Table 20. As every processor has a different log pricing mechanism, the MDP’s listed are indicative only and are for 2022.

Table 20: Indicative GT softwood MDP's (as at December 2022; Geddes & Parsons, 2023).

Product	Diameter range (cm)	Mill door price, excluding GST ($/GMT)		
		Low	Average	High
Small sawlog	15-30	$70	$83	$95
Large sawlog	30-50	$110	$125	$140
Industrial log	15-60	$45	$53	$60
Pulpwood	10-30	$30	$40	$50
Preservation	10-25	$80	$85	$90

Indicative softwood harvesting to on-truck costs

Based on recent discussions with harvesting contractors, Table 21 provides indicative GT harvesting costs, presented with low, average and high values. There is a wide range of harvestings costs for each operation type driven by variations in tree size, yield per hectare, quality of trees and products to be cut. They may also be modified further to reflect plantation size and location as discussed. Harvesting costs include the cost of loading the logs or woodchips onto trucks. These indicative harvesting costs are not prescriptive. They will vary, depending on specific circumstances and are provided as a guide only; there is no guarantee they will be applicable for any specific plantation.

Table 21: Indicative GT softwood harvesting costs ($/GMT) by operation type (as at December 2022; Geddes & Parsons, 2023), excluding GST.

Operation Type	Low	Average	High
	($/GMT)	($/GMT)	($/GMT)
T1	$28.00	$32.00	$36.00
T2	$18.50	$21.50	$24.50
T3	$14.50	$16.50	$18.50
CF	$9.00	$11.50	$14.00

Indicative softwood haulage costs by distance

Based on recent discussions with haulage contractors, Table 22 provides indicative GT log haulage costs by truck type and transport distances (in kilometres). Based on road distance from a plantation to a log purchaser, these indicative transport costs provide an approximate cost of log haulage. The base rate is for B-double log trucks and change in truck type will impact the costs. For single trailers a c.15% increase in costs is required for short-length preservation logs. Woodchip haulage has a slightly higher cost than log transport (see Table 23).

Table 22: Indicative GT haulage costs of 6.1 m logs by distance (as at December 2022; Geddes & Parsons, 2023).

Distance	A-double	B-double	Single
(km)	($/GMT)	($/GMT)	($/GMT)
20	$5.81	$6.00	$6.54
40	$8.53	$8.80	$9.59
60	$11.48	$11.85	$12.92
80	$14.34	$14.80	$16.13
100	$16.80	$17.60	$19.18
120	$19.38	$20.30	$22.13
140	$21.76	$23.00	$25.07
160	$24.31	$25.70	$28.01
180	$26.87	$28.40	$30.96
200	$29.42	$31.10	$33.90
220	$31.49	$33.50	$36.52
240	$33.80	$35.95	$39.19

Table 23: Indicative wood chip haulage transport rates ($/GMT) (as at December 2022; Geddes & Parsons, 2023).

	A-double	B-double	Single
(km)	($/GMT)	($/GMT)	($/GMT)
20	$6.18	$6.38	$6.95
40	$9.07	$9.36	$10.20
60	$12.21	$12.60	$13.74
80	$15.25	$15.74	$17.15
100	$18.14	$18.72	$20.40
120	$20.32	$20.97	$22.85
140	$23.02	$23.76	$25.89
160	$25.73	$26.55	$28.93
180	$28.43	$29.33	$31.97
200	$31.13	$32.12	$35.01
220	$33.53	$34.60	$37.72
240	$35.99	$37.13	$40.47

Hardwood plantations

An overview

Hardwood plantations in the GT are normally grown over a short rotation of 10 -15 years before harvest to supply international paper makers with woodchips. The trees are planted in rows at a stocking of 900 -1,000 stems/ha. Hardwood plantations are not normally thinned prior to final harvest, and the products (either woodchip or pulp logs) are less complex than for softwoods. Harvesting of GT hardwood plantations for export woodchips commenced in 2006 and volumes exported have grown progressively since that time. In the GT, an average of 5,580 ha/y were planted between 2001 and 2020. Only a small area of hardwood plantations planted before 1996 remains in the GT (Legg *et al.,* 2021, Table 13). Overall, all hardwood trees established prior to 2005 are now over-mature and are being progressively harvested. Logs recovered from GT hardwood plantations are all exported through the Port of Portland, mainly in the form of woodchip. There are two hardwood chip export stockpiles at the Port of Portland. Based on Geddes Management data, harvest volumes from the 133,809 ha of hardwood plantations is approximately 2.8 million GMT/y (range 2.5-3.0 million GMT/y, depending on global demand). The Port of Portland has a maximum export capacity of approximately 3.0 million GMT/y of hardwood woodchip.

Product and prices for logs harvested

ABARES data (Legg *et al*., Appendix C, p.71) suggests average GT hardwood yields of c.204 GMT/ha at age 12 years; this is an MAI of 17 GMT/ha/y at age 12 years. If expected yields are less than 120 GMT/ha, then harvest costs can be excessive and have a significant impact on net harvest returns.

The product recovered from cut to length (CTL) harvesting operations is pulp log. The logs recovered are normally transported on log trucks to a central facility and are converted to woodchips suitable for export. The product from whole tree chipping (WTC) operations is woodchip which is transported to the export facility in specialist closed sided trucks. Hardwood woodchips must comply with strict product specifications. Because they are used to manufacture high quality writing paper, they must be free of contaminants such as char, metal, bitumen, plastics, sand, stone and clay which would otherwise interfere with the paper making process. There must be less than 0.5% by green weight of rot and less than 0.5% by green weight of bark. There are woodchip dimension requirements. Measured along the maximum length of a chip along the grain on the surface, only 5% of woodchips can be more than 28.6 mm long, only 3% of woodchips can be less than 4.8 mm long and 55% of woodchips must be from 9.5 to 22.2 mm long. To support this, the chippers processing logs into woodchips require regular compliance checking.

Hardwood returns to growers

Hardwood chip as an internationally priced commodity

The price paid for hardwood woodchips free on board (FOB) depends on the world price which fluctuates with global supply and demand. Hardwood woodchips are a global commodity traded in US dollars (USD) on a bone-dry metric tonnes (BDMT) basis. A BDMT is a measure of the quantity of bone-dry wood and limits the impact of variation in wood density and moisture content. While prices are based on the global USD per BDMT, all GT hardwood logs and woodchips are sold on a MDP basis to Port of Portland based exporters in Australian dollar per GMT. As with softwood logs, for hardwoods, MDP is the starting point to determine the stumpage expected. Hardwood MDP takes into account international prices, exchange rates, a dry weight factor (to determine price $/GMT), loading and stockpile management costs at the wharf, a woodchip physical loss factor from the wharf stockpile and log chipping costs. Normally, for small-scale growers, the exporter will either offer a MDP based on these calculations, or a stumpage price which also takes into account harvesting and haulage costs. The mid-2022 MDP for woodchip delivered to the wharf at the Port of Portland was approximately $105-111/GMT. The mid 2022 MDP for hardwood pulp logs delivered to the chipping facility at Myamyn was approximately $86-89/GMT.

Indicative hardwood harvesting costs

Harvesting costs are influenced by the volume per hectare of stands to be harvested. Table 24 provides indicative harvest costs for CF at age 12 years for WTC and CTL harvest operations taking into account three different stand productivity levels. For CTL operations, there is an additional cost to chip the extracted logs prior to export. Chipping costs vary depending on the source mean tree volume (MTV) of the logs to be chipped. For a plantation yielding 205 GMT/ha with 1,000 trees/ha harvested, the MTV is approximately 0.205 GMT/tree and the corresponding chipping cost is approximately $13.90/GMT. If a hardwood plantation is harvested at age 12 years using CTL clear fell, it may be chipped at the roadside using a mobile chipper, without a chain flail de-barker, and the chip direct loaded into a chip truck. This process will produce similar quality chip to the WTC method. Chipper productivity depends on the volume of pulp log stockpiled at a site which determines the need to shift the chipper. Chipping larger sized logs is more productive than chipping smaller pulp logs. Therefore, the chipping cost is linked to the harvested yield per hectare, as well as the MTV of the standing trees before clear felling; this determines the diameter of the logs to be chipped.

Table 24: Indicative GT hardwood harvesting costs ($/GMT) (as at December 2022), excluding GST

Operation type	Yield			Harvesting cost		
	Low	Average	High	High	Average	Low
	(GMT/ha)	(GMT/ha)	(GMT/ha)	($/GMT)	($/GMT)	($/GMT)
CF age 12 years WTC	105	205	305	$45.35	$33.50	$29.01
CF age 12 years CTL	105	205	305	$32.22	$23.80	$20.61

Indicative hardwood transport costs

Costs of transporting hardwood logs from CTL harvests are similar to those shown in Table 23. Most log transport is on B-doubles. A-double transport costs are about 3.0% to 6.0% lower than B-double costs, with a higher reduction on long-haul distances. While this is not a major financial saving, the attraction of A-doubles is that contractors need fewer drivers to transport a given volume of logs. Currently, sourcing trained drivers is a major challenge for the industry. Chip transport costs by B-double are 3.3% to 6.3% higher than with log trucks because of the additional capital cost of chip trailers. Tipping platform unloaders at the Port of Portland can unload a B-double in one lift, enabling trailer construction to be 'simple' boxes which requires less capital cost. Indicative haulage costs of woodchip (in $/GMT) by road distance are shown in Table 23.

Calculating the return from the MDP

A grower can calculate indicative stumpage returns by deducting harvest and transport costs from an MDP. As an example, if a plantation yielded 205 GMT/ha of WTC with a 100 km road distance to the Port of Portland using a B-double truck, the stumpage would be approximately $55.78/GMT; $108.00/GMT MDP less $33.50/GMT harvest/chip less $18.72/GMT haulage. It must be emphasised this is a highly indicative example.

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Appendix 4: Harvest and transport costs in the Green Triangle

Project 1: Research new shorter rotation silvicultural models for pine plantations and longer rotations for blue gum plantations. Sub-report title: Softwood and hardwood plantation harvesting and transport costs in the Green Triangle.

Prepared by

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Summary

Harvesting and haulage costs are a significant driver of grower returns and are an important consideration. A range of current and usual harvesting cost profiles have been prepared. The determinant of harvesting costs is the size of the trees removed. This is defined as the mean tree volume (MTV) expressed in green metric tonnes per stem. An MTV drives harvesting costs as the same broad steps and time is required to harvest and handle a tree regardless of tree size (within the limits of the equipment used). Therefore, as MTV increases, harvest costs reduce. The type of harvesting equipment used is tree-situation specific hence there are tree and harvest specific cost profiles. For each harvest cost profile, a polynomial function was generated, each of which resulted in close to R^2 = 100% indicating very strong relationships. The nature of a polynomial function is that if applied beyond the range of MTVs on which it was generated, the outcomes can be in error due to an inversion of trends. These cost profiles were combined with the MTV as the determinant, with the range of MTVs having limited to no overlap between regimes. A combined harvest cost function was generated based on a natural log function. Haulage cost models were developed for the different truck configurations.

Introduction

Harvest and haulage costs are a significant component of the overall cost of growing, managing, harvest and haulage of the resulting logs to a market; usually defined as a mill gate. Therefore, realistic estimates of likely harvesting and transport costs are required. This section provides information to be used in financial models calculating product yields and costs of production for a number of conventional and alternative silvicultural rotations in both softwoods and hardwoods. The financial analysis is to estimate stumpages and pre-tax net present values (NPV) for each regime. This report is based on actual current (December 2022) harvesting and transport costs in the Green Triangle (GT). Costs are provided for both softwood (*Pinus radiata*) and hardwood (*Eucalyptus globulus*) plantations.

Silviculture and harvesting regimes

A range of operations undertaken in *P. radiata* and *E. globulus* plantations are part of management of between-tree competition and tree growth. This impact is achieved by management of stand stocking after initial establishment. There are conventional regimes currently in operation and a number of potential regimes for alternative management of stands. For softwood harvesting, the general standard operations include first thinning (T1) at age 12 years, second thinning (T2) at age 18 years, third thinning (T3) at age 24 years and clear felling (CF) at age 34 years. Some plantations in the GT currently operate on clear fell at 30-years of age following T1, T2 and T3 at conventional ages. The clear fell at 30-years of age removes 300 stems/ha but forgoes potential yield producing smaller diameter sawlogs. For some managers, this is a financially attractive option and the smaller log sizes suit some processor sawmills. An alternative regime includes an earlier final harvest (e.g. at age 28 years). A shorter rotation will reduce the overall volume produced and may produce sawlogs at clear fell which have lower density and wood stiffness. A clear fell below 28 years has carbon accounting implications. It is considered that sawlog size logs at recovered at below 18 years of age will have significantly reduced log wood qualities, so a clear fell below that age has significant structural timber recovery implications. Within each operation type there are cost variations based on mean tree volume (MTV) of the trees to be removed; the MTV is average tree volume to a 10 cm small end diameter (SED). In hardwood harvesting operations, the conventional operations are clear fell at 12-years of age, using either whole tree chipping (WTC) or cut-to-length (CTL) harvesting (see Box 4). This analysis includes consideration of current conventional and alternative silvicultural regimes for softwood (Table 25) and hardwood plantations (Table 26).

Box 4: An overview of general harvesting operations.	
Cut-to-length	In cut-to-length (CTL) operations each tree is individually felled, de-limbed and cut into log lengths by the harvesting machine at the stump. In hardwood operations a harvester will also de-bark the stem before docking. These logs are forwarded (extracted) to the plantation edge, loaded onto trucks and delivered to a customer. In some softwood operations, certain log products may be chipped at the plantation edge, with or without debarking, and the chips loaded onto a chip truck and delivered to a customer. Softwood and hardwood plantations can be harvested with CTL systems.
Whole-tree chipping operations	With whole-tree chipping (WTC) operations, trees are harvested with a feller-buncher, bunches of fallen trees are skidded to a mobile chipper on the plantation edge and fed through a flail de-limber (which removes branches and bark) before chipping. Chips are direct-loaded into specialised chip trucks. Hardwood plantations are more likely to be harvested with WTC systems than softwoods.

Basis of developing a plantation regime specific harvesting cost profile

Units of operations and trade

For standing trees, tree growth and yield are expressed in cubic metres; growth expressed as mean annual increment (MAI) in cubic metres per hectare per year (m^3/ha/y) and yield expressed as cubic metres per hectare (m^3/ha). Tree volume is estimated based on inventory and various functions. Harvesting and haulage costs are defined on a green metric tonne ($/GMT) basis of the weight of forest products determined by a weigh bridge at the mill gate to which logs are transported. The term MTV is an industry standard term expressed in green metric tonnes per tree (GMT/stem) for all trees to be removed. Industry defines harvesting costs on an MTV basis given that harvesting is based on linear feed through processing heads after falling of the trees. The conversion between volume and green weight is important. For softwoods, a conversion factor of 1.000 GMT/m^3 is applied and for hardwoods, a conversion factor of 1.100 GMT/m^3 is applied.

Log product mix

Figure 45 and Figure 46 present the assumed log products mix for the *P. radiata* and *E. globulus* harvesting cost models. It is recognised that the *E. globulus* longer rotation with a T1 is modelled at 70% sawlogs. This is likely to vary based on tree size and the definition of a sawlog.

Table 25: A summary of softwood plantation harvesting cost regimes considered.

			P. radiata conventional T1	*P. radiata* conventional T2	*P. radiata* conventional T3	*P. radiata* conventional CF	*P. radiata* early CF	*P. radiata* early, no T3 CF	*P. radiata* composite T1 to CF
Crop			*P. radiata*	*P. radiata*	*P. radiata*	*P. radiata*	*P. radiata*	*P. radiata*	*P. radiata*
Operation			Thinning	Thinning	Thinning	Clear fall	Clear fall	Clear fall	All Operations
			T1	T2	T3	CF	CF	CF	T1 to CF
			conventional	conventional	conventional	conventional	early	early, no T3	composite
Age		(y)	12	18	24	34	30	28	12 to 34
Initial stocking		(stems/ha)	1,550	700	450	300	300	450	1,550
Stems removed		(stems/ha)	850	250	150	300	300	450	1,550
Residual stocking		(stems/ha)	700	450	300	0	0	0	0
Bark			Bark-on	Bark-on	Bark-on	Bark-on	Bark-on	Bark-on	Bark-on
Harvest yield	Lower	(GMT/ha)	60	55	105	360	270	375	
	Average	(GMT/ha)	90	80	130	460	370	500	
	Upper	(GMT/ha)	120	105	155	560	470	625	
MTV	Lower	(GMT/tree)	0.0706	0.2200	0.7000	1.2000	0.9000	0.8889	
	Average	(GMT/tree)	0.1059	0.3200	0.8667	1.5333	1.2333	1.1111	
	Upper	(GMT/tree)	0.1412	0.4200	1.0333	1.8667	1.5667	1.3333	

Table 26: A summary of hardwood plantation harvesting cost regimes considered.

			E. globulus whole tree chipping CF	*E. globulus* cut to length CF	*E. globulus* roadside chipping of CTL CF	*E. globulus* cut to length T1	*E. globulus* cut to length after thinning CF
Crop			*E. globulus*	*E. globulus*	*E. globulus*	*E. globulus*	*E. globulus*
Operation			Clear fall	Clear fall	Clear fall	Thinning	Clear fall
			CF	CF	CF	T1	CF
			Whole tree chipping	Cut to length	Roadside chipping of CTL	Cut to length	Cut to length after thinning
Age		(y)	12	12	12	8	18
Initial stocking		(stems/ha)	950	950	950	950	400
Stems removed		(stems/ha)	950	950	950	400	400
Residual stocking		(stems/ha)	0	0	0	550	0
Bark			Debarked	Debarked	Debarked	Debarked	Debarked
Harvest yield	Lower	(GMT/ha)	105	105	105	35	125
	Average	(GMT/ha)	205	205	205	75	231
	Upper	(GMT/ha)	305	305	305	135	325
MTV	Lower	(GMT/tree)	0.1105	0.1105	0.1105	0.0875	0.3125
	Average	(GMT/tree)	0.2158	0.2158	0.2158	0.2125	0.5625
	Upper	(GMT/tree)	0.3211	0.3211	0.3211	0.3375	0.8125

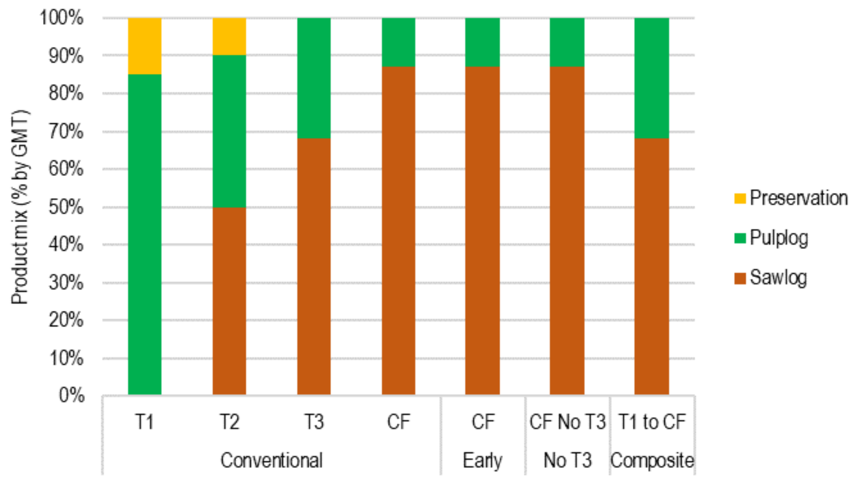

Figure 45: A series of softwood plantation harvesting log product mix.

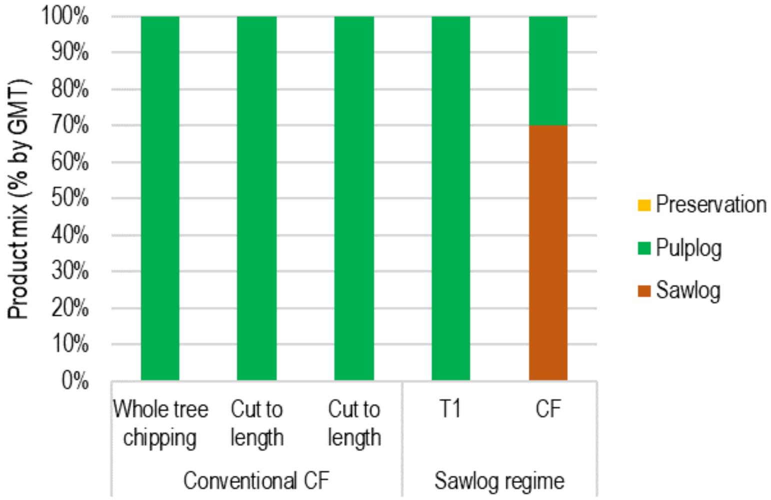

Figure 46: A series of hardwood plantation harvesting log and woodchip product mix.

Harvesting and haulage cost profile

This analysis is based on GT harvesting and transport costs as at December 2022 and a November fuel terminal gate price of $2.1314/l. All harvesting and transport costs shown exclude GST, which is the standard in the GT. This analysis is based on industry knowledge, including consultation with forest owners and harvesting contractors. The average harvesting costs are based on normal average yield for each operation considered, noting that Individual contracts are commercial in confidence. Costs have been calculated for increasing and reducing yields per hectare and MTV (high, average and low) assumptions. The costs presented are averaged over a number of operations (specifically harvest contract pricing schedules based on MTV), hence they do not represent costs of individual harvesting and transport operations. Costs of any specific operation may vary significantly from these costs. These cost profiles are not intended to be interpreted as standard contract rates for any operation and are not 'upset costs' to be used in a harvesting contract tender or negotiation process.

Softwood harvesting costs

Conventional first thinning

First thinning of *P. radiata* normally occurs at age 12 years reducing the initial stocking from 1,550 stems/ha to 700 stems/ha. This is achieved by the removal of every fifth row and thinning the remaining four rows by removing small and poorly-formed trees. The expected average yield is 90 GMT/ha and the MTV of the removed trees is 0.1059 GMT/tree. The average harvesting cost for a T1 in the GT is $32.00/GMT assuming 85% by volume as pulpwood and 15% by volume as preservation. A modified contract formula has been used to calculate the harvesting cost for yields recovered from 60 to 120 GMT/ha; this is +/- 33% around the average yield of 90 GMT/ha. This assumes similar stocking reductions for the range of yields and T1 harvesting costs per MTV are summarised in Figure 47.

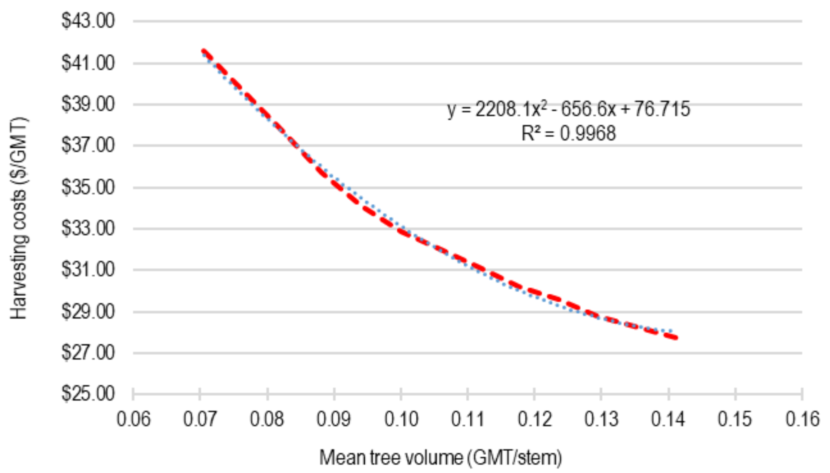

Figure 47: Softwood T1 harvesting cost for the MTV of trees removed.

Conventional second thinning

Second thinning of *P. radiata* normally occurs at age 18 years, with stocking reduced from c.700 to 450 stems/ha. Thinning of the four-row-bay is from below removing small and poorly-formed trees, as well as ensuring even spacing between retained trees. Average yield of c.80 GMT/ha is expected with an MTV of the removed trees of c.0.3200 GMT/tree. The average T2 harvesting cost is $21.50/GMT; this reflects 50% volume as sawlog, 40% volume as pulpwood and 10% volume as preservation logs. In the GT c.$1.50/GMT premium is applied for sawlog recovery over pulpwood to ensure maximum recovery of more valuable sawlogs. The modified contract formula calculated the applicable cost for a range of yields from 55 to 105 GMT/ha, which is +/- 30% about the average yield of 80 GMT/ha (see Figure 48). This assumes similar stocking reductions for the range of yields.

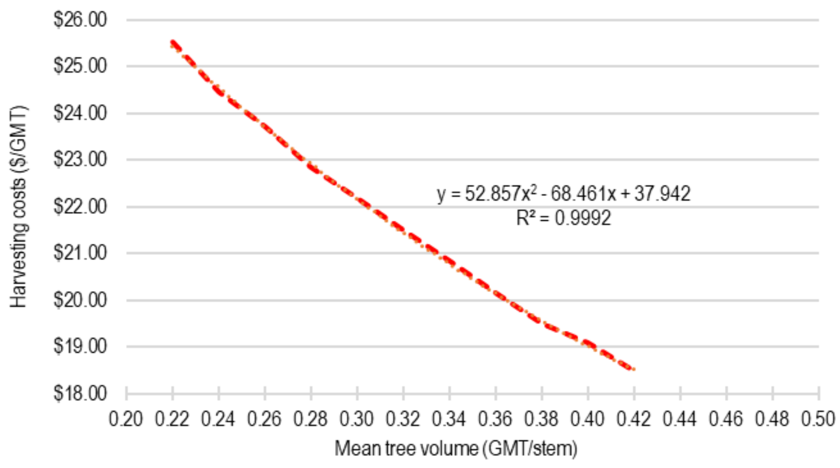

Figure 48: Softwood T2 harvesting cost for the MTV of trees removed.

Conventional third thinning

In the GT, third thinning of *P. radiata* stands normally occurs at age 24 years, with stocking reduced from 450 to 300 stems/ha by thinning the four-row bay by removing smaller trees, as well as ensuring even spacing between trees. An average yield of 130 GMT/ha is expected with an MTV of the removed trees of c.0.8667 GMT/tree. The average harvesting cost for T3 is $16.50/GMT derived from 68% as sawlog and 32% as pulpwood. The sawlog premium over pulpwood is approximately $1.50/GMT. The modified contract formula calculates the applicable costs for 105 to 150 GMT/ha (Figure 49); this is +/- 19% around the average yield of 130 GMT/ha. This assumes similar stocking reductions for the range of yields.

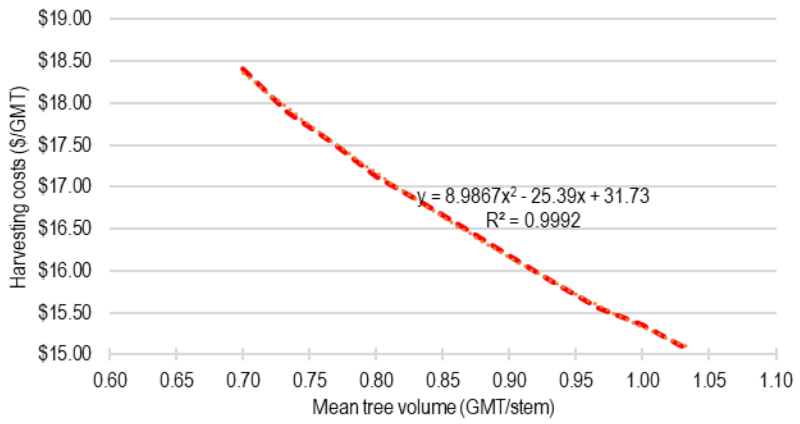

Figure 49: Softwood T3 harvesting cost for the MTV of trees removed.

Conventional 34-year-old clear fell after thinning

The following is a calculation of the harvesting cost for the current conventional regime to produce sawlog. The normal GT silvicultural prescription is T1 at age 12 years, T2 at age 18 years, T3 at age 24 years, and clear fell at age 34 year. This clear fell is of 300 stems/ha with an average yield of c.460 GMT/ha; an MTV of the removed trees of c.1.5333 GMT/tree. The average harvesting cost is $11.50/GMT derived from 87% as sawlogs and 13% as pulpwood. The modified contract formula calculates the applicable cost for yields from 360 to 560 GMT/ha (Figure 50); this is +/- 22% of the average yield of 460 GMT/ha. This assumes similar stocking prior to clear fell.

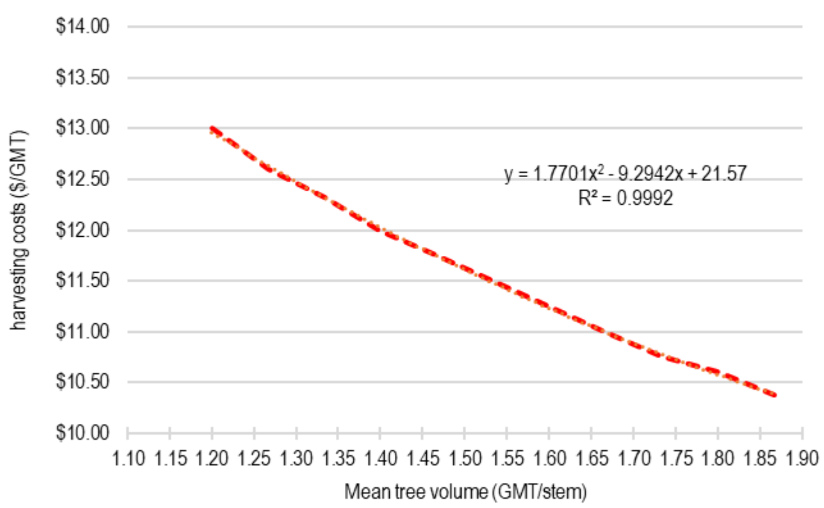

Figure 50: Softwood conventional rotation clear fell harvesting cost for the MTV of trees removed.

Conventional early clear fell at Age 30, after conventional thinning.

The following is a calculation of the harvesting cost of a current short-rotation option to produce sawlogs. This prescription follows the normal GT silvicultural prescription of T1 at age 12 years, T2 at age 18 years, and T3 at age 24 years, but clear fell is brought forward to age 30 years. The clear fell is of 300 stems/ha with an average yield of 370 GMT/ha resulting in an MTV of the removed trees of c.1.2333 GMT/tree. Some forest owners in the GT are currently operating this regime forgoing potential yield and producing smaller diameter sawlogs than a 34-year rotation. Regardless, such a regime may be financially attractive and the smaller-log sizes may suit some processor sawmills. The average harvesting cost for this early clear fell is $12.80/GMT derived from 87% sawlogs and 13% pulpwood. The modified contract formula calculates the applicable cost for yields from 270 to 470 GMT/ha (Figure 51); +/- 27% about the average yield of 370 GMT/ha. This assumes similar stocking prior to clear fell.

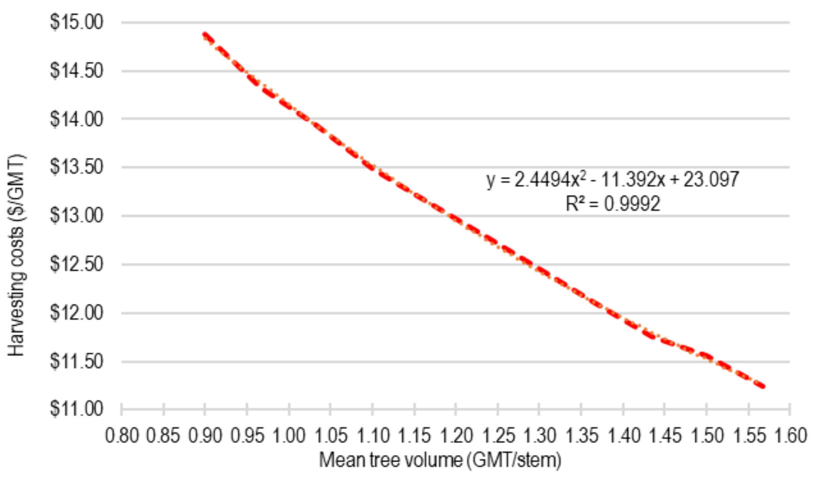

Figure 51: Softwood short rotation clear fell harvesting cost for the MTV of trees removed.

Alternative regime; early clear fell at age 28, with no T3

One short-rotation prescription is a T1 at age 12 years, T2 at age 18 years and clear fell at age 28 years. The clear fell of the post-T2 stocking of 450 stems/ha has an average yield of 500 GMT/ha and an MTV of the removed trees of c.1.1111 GMT/tree. The average harvesting cost for an early clear fell would be $13.40/GMT derived from 87% as sawlog and 13% as pulpwood. The modified contract formula calculated the cost of yields from 400 to 600 GMT/ha (Figure 52); this is +/- 20% about the average yield of 500 GMT/ha and assumes similar stocking prior to clear fell.

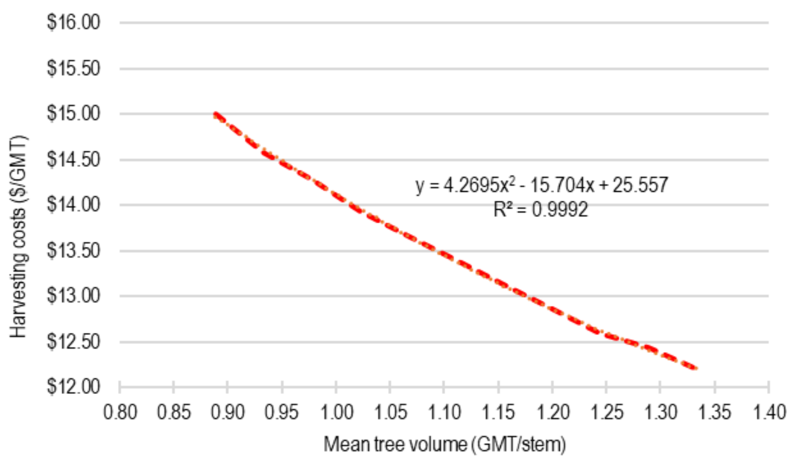

Figure 52: Softwood shorter rotation clear fell harvesting cost for the MTV of trees removed.

The nature of the harvest cost profiles; a need for a combined cost function

A harvest cost based on MTV is for a specific range of MTV for each regime. While the polynomial functions have close to 100% R^2, applying these functions beyond their range is problematic. For example, see Figure 53 which applies the function over MTVs from 0.000 to

0.230, rather than the range over which this function was developed (0.70 to 0.14 GMT/stem). A key point is that the nature of a polynomial function inverts the trend to increase in unit costs with increasing MTV. This is not appropriate.

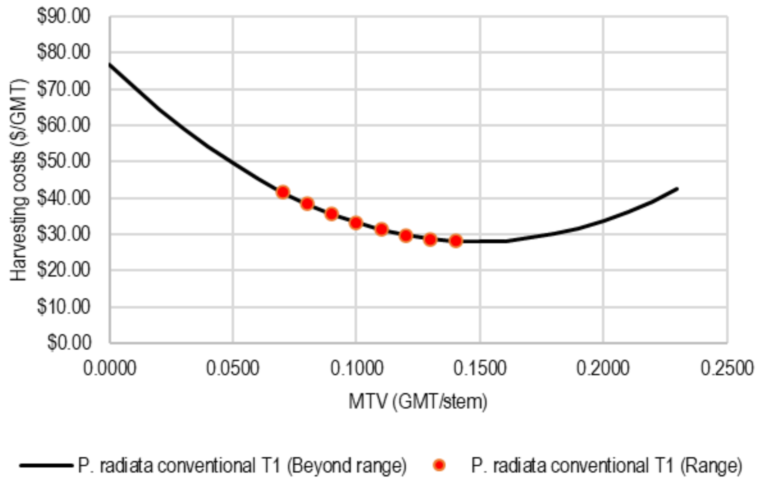

Figure 53: The T1 harvest cost function applied over a range of MTV of trees removed and beyond the source data range.

Figure 54 presents the harvesting cost profiles over the MTV range for each regime modelled. This chart shows a close to continuous relationship with MTV. There is overlap in MTV's between the harvesting options (see Figure 47 to Figure 50); for example, the largest MTV in T3 also appears in the 28, 30 and 34 year old clear fell cost profile, but with four different costs. Similarly, the largest MTV in T1 is just smaller than the smallest MTV in T2. However, there is a considerable gap between the largest MTV in T2 and the smallest MTV in T3. While use of specific operation harvesting rates (e.g. for a T1) is possible, a single cost-function addressing the full range of MTV's (0.10 m to 2.00 GMT/stem) is possible.

Relevant harvesting costs for all MTVs from 0.10 in 0.10 GMT/stem increments were compiled; equivalent to yields from 85 to 600 GMT/ha. The data set was used to generate a single function of harvesting costs by MTV; this is presented in Figure 54 (with an R^2 of 90.4%). This combined function allows a single cost model to be applied to all operations with MTVs from 0.05 to 1.9 GMT/stem.

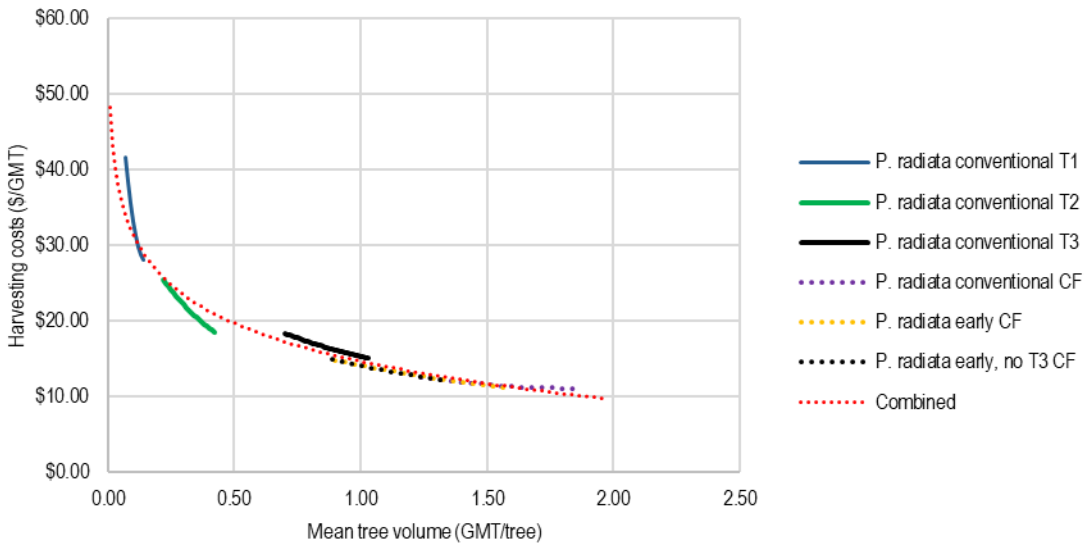

Figure 54: A compilation of softwood harvesting costs for MTV regimes in the GT and a generated combined single cost function.

Hardwood harvesting costs

Conventional whole tree chipping clear falling

Most *E. globulus* plantations are harvested at age 12 years using WTC clear fell with trees harvested by a feller-buncher aggregating complete trees (with branches and bark) into bunches. The bunches are removed using a grapple skidder, and fed into a chain-flail de-limber-de-barker-chipper (with no segregation), with the output woodchip direct-loaded into a waiting woodchip truck (usually a B double). The branches, leaves and bark removed by the flail are stockpiled by a grapple excavator and usually carried back into the cut-over area by the grapple skidder and spread over the site. The woodchips are delivered to the Port of Portland for export to China and/or Japan. Most hardwood plantations are established at 4.5 m x 2.2 m spacing with a stocking of 1,000 trees/ha. At clear fell age c.950 trees/ha have usually survived. Average clear fell yield is 205 GMT/ha with an MTV of the removed trees of 0.2158 GMT/stem. The average cost for WTC for woodchips loaded on-truck is $33.50/GMT. Based on a modified contract formula applied in softwood harvesting, the applicable cost of a range of yields from 105 to 305 GMT/ha have been calculated (Figure 55); this is +/- 49% of the average yield of 205 GMT/ha.

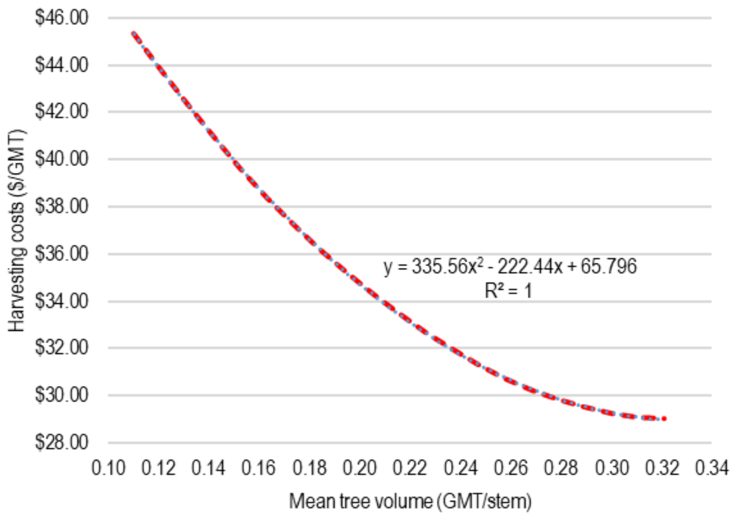

Figure 55: Harvesting costs for hardwood plantations harvested with a WTC system.

Conventional cut-to-length clear falling

Some *E. globulus* plantations are harvested at age 12 years by CTL clear fell operations where the logs are to be delivered to a static woodchip facility, for small plantations not suited to large WTC operations, or where logs are to be sorted for different customers. The trees are cut using a single-grip harvester felling, de-limbing and debarking the tree, using the harvesting head, and cutting stems into required-length logs. This is all undertaken at the stump. The de-barked logs are removed from the site using a forwarder and stockpiled at roadside, usually for subsequent loading and delivery to a mill door. An alternative is roadside-chipping with a mobile chipper (without flail) and direct loading into a woodchip truck. With an average yield of 205 GMT/ha, the MTV of the removed trees is 0.2158 GMT/tree. The average harvesting cost for CTL including on-truck loading (but not chipping) is $23.80/GMT. Harvesting costs were determined based on the modified contract formula for yields from 105 to 305 GMT/ha (Figure 56); this is +/- 49% of the average yield of 205 GMT/ha.

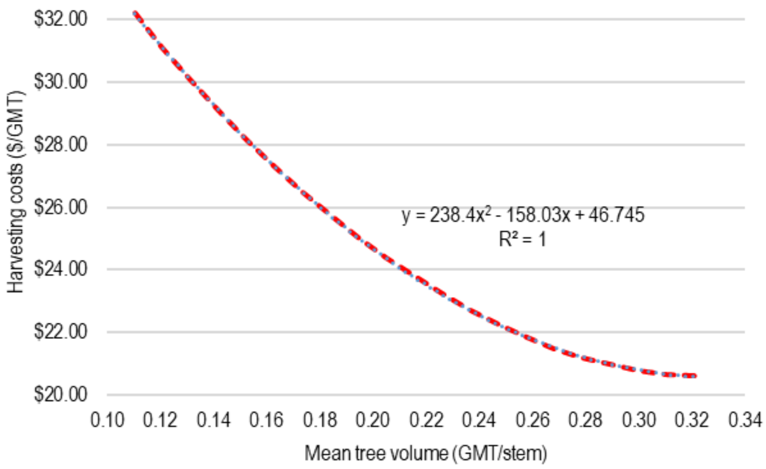

Figure 56: Harvesting costs by MTV for hardwood plantations harvested with a CTL system.

Conventional roadside chipping of cut-to-length pulp logs

The de-barked logs recovered from a *E. globulus* stand harvested at age 12 years using CTL clear fell can be chipped at the roadside using a mobile chipper, without a chain flail de-barker, with the woodchips direct loaded into a woodchip truck. This process will produce similar quality woodchips to the whole tree chipping method. Chipper productivity will depend on the quantity of de-barked pulp logs stockpiled at any one site minimising shifting the chipper. Further, chipping larger logs is more productive than chipping small logs. Therefore, chipping costs are linked to the yield per hectare by harvesting, as well as MTV of the standing trees at harvest. As a result, chipping costs are adjusted based on yield per hectare and MTV of a stand. With an average yield of 205 GMT/ha, the MTV of the removed trees is 0.2158 GMT/tree. The average chipping cost for CTL pulp logs is $13.90/GMT. Applying the modified contract formula, on-site chipping costs have been calculated for yields from 105 to 305 GMT/ha (Figure 57); +/- 49% of the yield of 205 GMT/ha. To produce woodchips to 'on-truck' using CTL debarked pulp logs to roadside and then mobile chipping, at 205 GMT/ha with an MTV 0.2158 GMT/tree, would cost $23.80/GMT for harvesting and $13.90/GMT for chipping at a total of $37.70/GMT. Applying a WTC method in a similar size stand it would cost $33.50 making CTL and mobile chipping a more expensive option. Transporting CTL debarked pulp log to a static chipper, with lower chipping cost, is a better option.

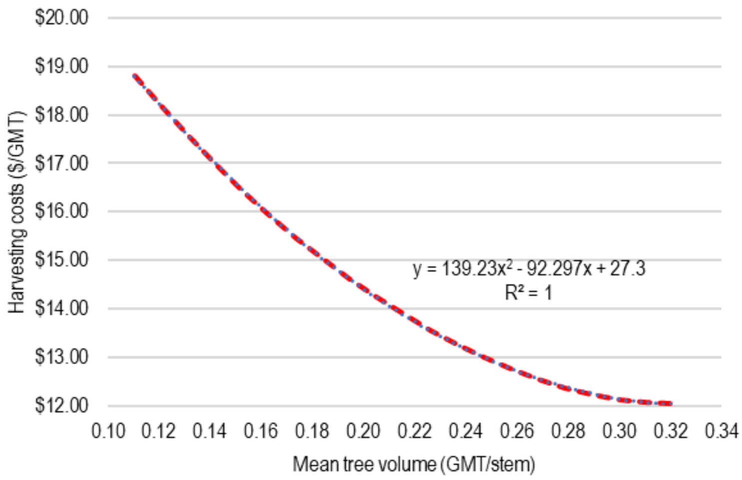

Figure 57: Roadside chipping costs by MTV for CTL clear fell hardwood de-barked logs.

An alternative regime of cut-to-length pulp log to roadside from thinning at age 8

While not a current regime, an extended hardwood rotation, with a thinning at age 8 years and clear fell at age 18 is considered. Hardwood plantations are normally planted at 4.5 m x 2.2 m resulting in a stocking of 1,000 trees/ha. With normal losses, a well-managed plantation will be at c.950 trees/ha at final harvest age. Thinning at age 8 years would reduce stocking from 950 to 400 trees/ha. A final stocking of 400 trees/ha will create optimum spacing between the retained trees and allow diameter increment prior to clear fell at age 18 years. Use of a WTC system would be impractical; skidding of bunched trees could damage the residual trees and lead to quality degrade. Skidding in thinning is very difficult, even in low stocked stands. A CTL system is more appropriate, with a small single-grip harvester and a small (less than 3 m wide) forwarder to recover the pulp logs. With rows 4.5 m apart, the harvester and forwarder will be able to move between the rows to harvest the trees to be removed. A maximum harvester reach would be able to reach one row either side requiring travel down each alternate row, thinning the trees on either side. Thinning to 400 trees/ha will remove 550 trees/ha, or 58% of stems which is a selection rate of three trees in five. Trees could be selected by the harvester operator, removing smaller and poorly formed trees and achieving a reasonable spacing of retained trees. For a stand with an MAI of 17 GMT/ha/year at age 10 years, prior to thinning at age 8 years, the stand would be standing at 136 GMT/ha. Removing 58% of stems (without selection) would recover 79 GMT/ha. However, as the smaller trees would be removed, an estimated yield of 75 GMT/ha is more realistic. At 75 GMT/ha the MTV of the removed trees would be 0.1364 GMT/tree. The average harvesting cost for this type of CTL thinning producing debarked logs at the roadside and loading on-truck, is estimated to be $32.77/GMT. Applying the modified contract formula calculated harvesting costs for yields from 30 to 120 GMT/ha (+/- 53% of the average yield of 75 GMT/ha) as presented in Figure 58. It is unlikely that yields below 30 GMT/ha would be economic.

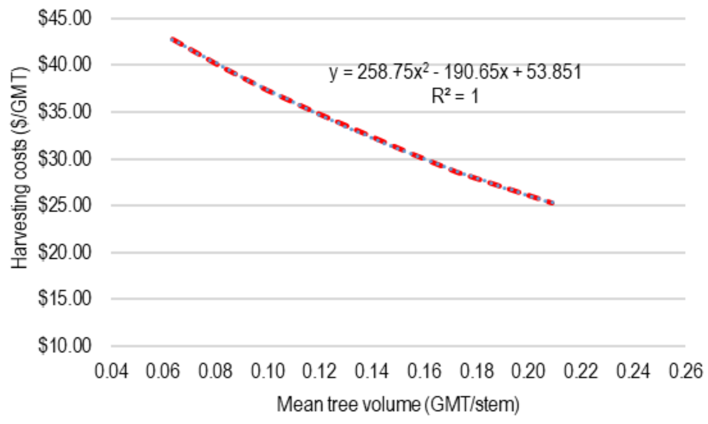

Figure 58: Harvesting cost profile for a hardwood plantation T1 CTL operation.

An alternative cut-to-length sawlog and pulp log to roadside from clear fell at age 18 after thinning

An extended hardwood rotation with a thinning at age-8 years has a clear fell at age-18 years. After thinning to 400 trees/ha a stand will grow on to age 18 years prior to clear fell. An objective is to produce larger logs for alternative markets, hence this clear fell would be by CTL, so that larger logs and pulp log (from the smaller parts of the trees) can be extracted, sorted, stacked and loaded for transport to different processors. The total average yield for a stand at age 18 years with an MAI of 17 GMT/ha/year would be 306 GMT/ha. Thinning removed 75 GMT/ha; hence the final harvest yield would be 231 GMT/ha with an MTV of the removed stems of c.0.5875 GMT/tree. The average harvesting cost for this type of CTL clear fell to debarked logs loaded onto a truck is estimated to be $18.43/GMT derived from 70% sawlog and 30% pulpwood with a $1.50/GMT premium for sawlog. Applying the modified contract formula, harvesting costs for 130 to 330 GMT/ha (+/- 38% about the average yield of 235 GMT/ha) are presented in Figure 59. This clear fell cost profile provides an interesting comparison with the age 12 hardwood CTL clear fell. At age 12 years, a yield of 235 GMT/ha (MTV of 0.2474 GMT/tree) has a harvesting cost of $22.33/GMT. At age 18 years and after thinning, the same yield per hectare has an MTV of 0.5875 GMT/tree with a harvesting cost of $18.43. This is $3.90/GMT (17%) lower driven by the increased MTV. Conversely, at age 12 years, a yield of 305 GMT/ha has an MTV of 0.3211 GMT/tree with a harvesting cost of $20.61/GMT. At age 18 years with thinning, a yield of 135 GMT/ha with a similar MTV (0.3375 GMT/tree) has a harvesting cost of $24.12/GMT which is $3.51/GMT (17%) higher. The increased harvesting cost is due to the lower yield at age 18 years. This reinforces that both yield/ha and MTV are important, but for similar yields/ha the thinned stands will always be significantly cheaper due to the higher MTV.

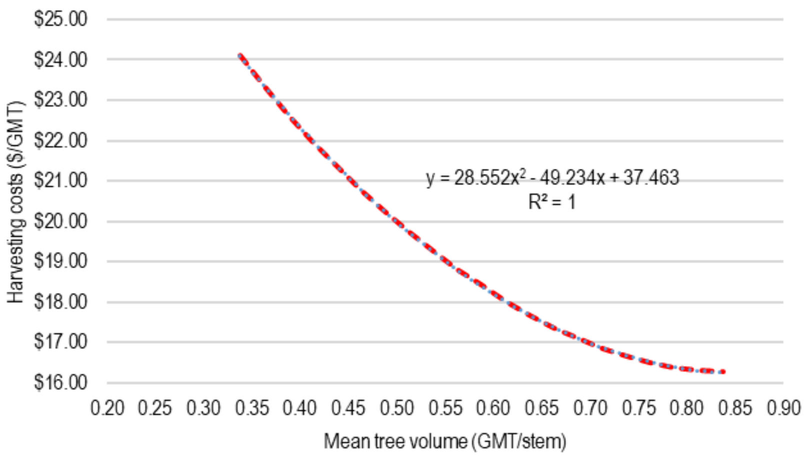

Figure 59: Harvesting costs for a thinned hardwood plantations clear fallen with a CTL system at age 18 years.

Development of a single hardwood harvest cost function

For comparison, the harvesting cost profiles presented in Figure 55 to Figure 59 are presented in Figure 60 and the impact of MTV is apparent. For MTV of c.01 to 0.34 GMT/tree, the impact of operation type is evident. The cost of thinning hardwood plantations approaches the lower cost of clear falling at the upper end of the MTV range. The subsequent clear fall of thinned stands is cheaper per unit of wood removed due to the larger tree size (driven by age and thinning combined). The most expensive operation is a CTL clear fall followed by roadside chipping of the debarked logs. If the intent was to supply woodchips, then WTC is a cheaper option. A composite function for CTL trees was developed combing routing clear fall, T1 and CTL after thinning. This function has an R^2 of 90.4% applied for an MTV range of 0.09 to 0.82 GMT/stem.

Harvest cost functions

Individual harvesting regimes

The data presented in the individual charts was used to generate a polynomial harvesting cots function based on MTV (see Equation 2). The constants generated are presented in Table 27 (softwoods) and Table 28 (hardwoods). Indeed, these models were used to generate Figure 54 and Figure 60. Such models can be applied in financial analysis of the different silvicultural and harvesting options across the range of MTV by operation included.

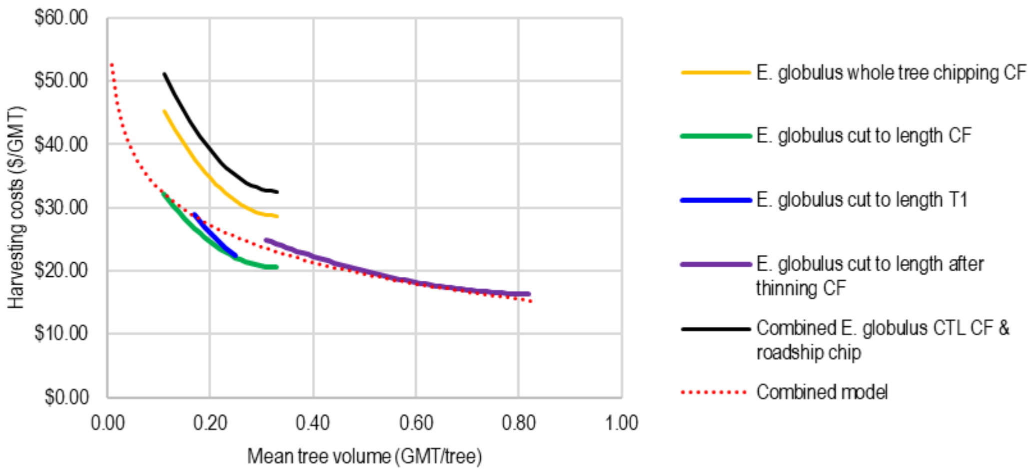

Figure 60: A compilation of hardwood plantation harvesting costs for the operations shown over the MTV indicated. A composite harvest cost function is included as the combined model.

Equation 2: The generic polynomial function for harvesting costs based on MTV.	$HC = (a\ x\ MTV^2) + (b\ x\ MTV) + c$
HC	Harvesting costs in $/GMT
MTV	Mean tree volume in GMT/stem
a	Constant 'a'
b	Constant 'b'
c	Constant 'c'

Table 27: The function constants for a polynomial softwood harvest cost function.

	P. radiata conventional T1	*P. radiata* conventional T2	*P. radiata* conventional T3	*P. radiata* conventional CF	*P. radiata* early CF	*P. radiata* early, no T3 CF	*P. radiata* composite T1 to CF
a	2,208.000	52.857	8.987	4.270	2.449	4.2695	1.770
b	-656.600	-68.461	-25.390	-15.704	-11.392	-15.704	-9.294
c	76.715	37.941	31.730	25.557	23.097	25.557	21.570
R^2	0.997	0.9992	0.9992	0.9992	0.9992	0.9992	0.9992

Table 28: The function constants for a polynomial hardwood harvest cost function.

	E. globulus whole tree chipping CF	*E. globulus* cut to length CF	*E. globulus* cut to length T1	*E. globulus* cut to length after thinning CF	*E. globulus* roadside chipping of CTL CF
a	333.56	238.4	258.75	28.552	139.23
b	-222.44	-158.03	-190.65	-49.234	-92.297
c	65.796	46.745	53.851	37.463	27.3
R^2	1.0000	1.0000	1.0000	1.0000	1.0000

Composite harvesting functions

The outcome of the combined harvesting function is presented in Equation 3 as applied to *P. radiata* and *E. globulus* plantations in the GT. The value of the constants for the *E. globulus* and *P. radiata* models are presented in Table 29.

Equation 3: The generic natural log function for harvesting costs based on MTV.		$HC = a\ x\ In(MTV) + b$
HC	Harvesting costs in $/GMT	
MTV	Mean tree volume in GMT/stem	
a	Constant 'a'	
b	Constant 'b'	

Table 29: The combined harvest function constants for a natural log function.

	E. globulus CTL	*P. radiata*
a	-8.463	-7.275
b	13.67	14.679
R^2	90.5%	95.4%

Transport costs

Haulage systems in the Green Triangle

Various sizes of trucks are used to transport log and chip products from plantations to the local processors or to the export facility at Portland. Trucks vary from triaxle semi-trailers (load capacity c.26 GMT and a loaded weight of 43 tonnes), B-doubles (a prime mover towing two semitrailers with a load capacity c.45 GMT and a loaded weight of 68 tonnes) and A-doubles (a road train with two trailers, with a load capacity c.63 GMT and a loaded weight of 91 tonnes). Generally, the larger the truck capacity, the cheaper the haulage costs per tonne per kilometre ($/GMT/km). Woodchips are transported in specialist closed sided trucks.

Truck type

Most log transport in the GT utilises B-doubles. In general, the most common cost is for logs up to 6.1 m in length for most sawlogs and pulp logs. The cost for transporting short-log (less than 3.0 m; primarily preservation material), is 15% above the sawlog haulage costs. A-double transport is about 3.0% to 6.0% lower than B-double costs, with the upper reduction for long distance hauls. While not a major financial saving, the attraction of A-doubles is that a contractor requires less drivers to shift a given volume of logs. Currently, sourcing enough skilled drivers is a major challenge for the industry. Only a small volume of log is transported on single triaxle trailers, but they can be more popular from small private plantations where total volume is low or where roading is insufficient for B-doubles. Broadly, the cost for singles is 9% higher than B doubles.

Woodchip transport costs for B-double are between 6.3% and 3.3% above log B-doubles, due to the additional capital cost of chip trailers. However, woodchip transport costs include costs dictated by unloading method. The tipping platform unloaders at the Port of Portland unload A-doubles and B-doubles in one lift, enabling the trailers to be 'simple' boxes, requiring less capital cost. In contrast, some woodchip yards require walking floor unloading due to limited unloading facilities. A walking floor adds weight and capital cost to the trailers affecting transport costs. The cost reduction from B-double to A-double woodchip haulage is similar to logs, and the price premium for single trailers above B-doubles is similar to that of logs.

Variation in transport costs

There is a wide range of transport costs in the GT, reflecting the range of wood-types and products and truck configurations (B-double, A-double and single trailers) for each product. As well, for each product and truck type, haulage costs vary between contractors. Hence, providing average transport costs for the GT is reasonably difficult. Consultation with major forest owners sought to determine individual 'average haulage costs' and compared them with industry knowledge based on a range of individual contracts. Therefore, the costs presented in Figure 61 to Figure 63 are 'averages' hence individual situations may find their costs are at variance to these averages. Therefore, the actual costs for any specific type of transport may be quite different.

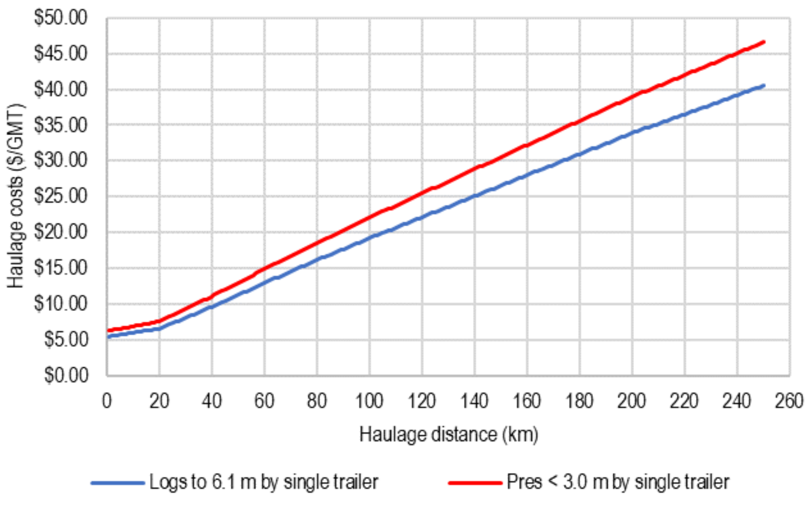

Figure 61: Plantation log haulage costs for single trailer log trucks in the GT.

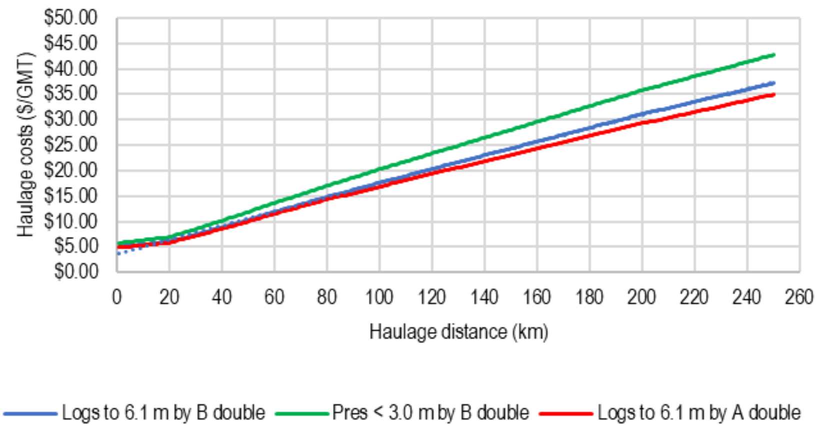

Figure 62: Plantation log haulage costs for B double and A-double log trucks in the GT.

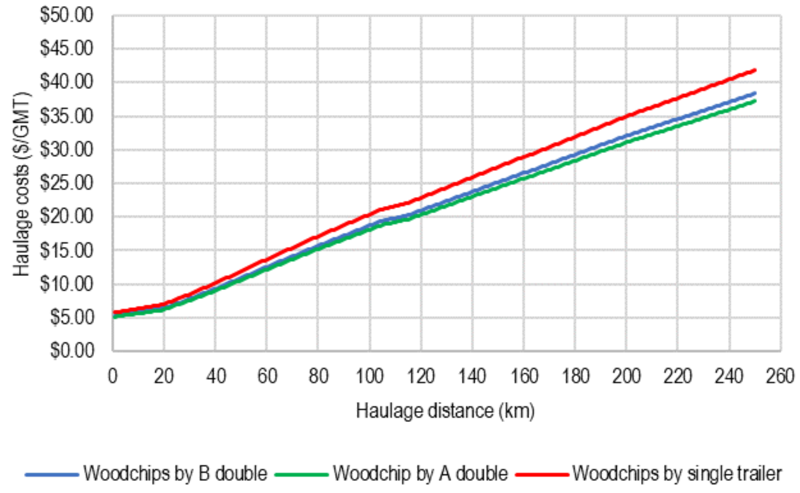

Figure 63: Woodchip haulage costs for singles, B double and A double woodchip trucks in the GT.

Haulage cost models

The data presented in Figure 61 to Figure 63 was used to generate haulage cost functions based on Equation 4 and the constants are presented in Table 30. This set of models can be applied to financial analysis of the silvicultural regimes under consideration.

Equation 4: The generic haulage cost polynomial function.	$TC = (a \ x \ D^2) + (b \ x \ D) + c$
TC	Log transport costs in $/GMT for distance D
D	Distance in kilometres one way.
a	Constant 'a'
b	Constant 'b'
c	Constant 'c'

Table 30: The polynomial haulage cost model constants for log and woodchip transport in the GT.

Log type	Logs to 6.1m	Pres < 3.0m	Logs to 6.1m	Logs to 6.1m	Pres < 3.0m	Woodchips	Woodchips	Woodchips
Truck type	B-double	B-double	A-double	Single trailer	Single trailer	B-double	A-double	Single trailer
a	-0.00003	-0.000034	-0.000041	-0.000032	-0.000037	-0.000037	-0.000036	-0.000041
b	0.142836	0.1645262	0.136486	0.155692	0.179045	0.147546	0.142987	0.160825
c	3.540247	4.071284	3.515951	3.858869	4.4377	3.946746	3.824791	4.301953
R^2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Appendix 5: Stocking and wood quality

<u>Project 1: Research new shorter rotation silvicultural models for pine plantations and longer rotations for blue gum plantations. Sub-report title: The interaction between radial variation in basic density and stem diameter on log value: A synopsis.</u>

Prepared by

Geoff Downes

Operating environment

Historically plantation and processing capacity were owned by the same party (e.g. the South Australian Woods and Forests Department owned both the plantations and sawmilling capacity). With a change in approach, some integrated supply chains were disaggregated and plantations divested. Hence, over recent decades the plantation forest value chain has not been integrated. That is, forest growers generate income from the sale of logs to forest processors rather than growing and processing their own trees. Because of the difficulty and expense of measuring wood quality in standing trees, log wood supply agreements (sales) have typically been based on merchantable volume; stem diameter and tree height are cost effective to measure. Previously, when wood properties have been measured (typically using increment cores) and usually a single value per tree, and often a single value per plot, have been used to provide an indicative wood quality metric. In contrast, log processors typically derive value from a combination of volume and quality of product, the latter being a consequence of the wood properties and their variation within logs.

Emergence and application of technology

With the recent uptake of the resistance drilling tool (IML PD series power drills; Resi), many forest growers and processors are using the technology to assess wood quality pre-harvest or in log stacks, and finding the approach provides sufficiently accurate, low-cost measures of wood density and volume. Typically, a single measure of wood quality per tree is used and combined into a site or compartment value. While the Resi data can quickly be processed to provide single summary value, it also offers the potential to explore radial variation patterns that can have a profound effect on log value.

The impact of initial stocking on wood basic density

Several recent studies have used this capability to explore the effect of initial stand spacing (333 to 2,222 stems/ha) on growth and radial wood property variation in mid-rotation (age 16 y) *P. radiata* stands in New South Wales (e.g. Downes *et al.*, 2022). It is recognised that differences between growing regions are likely, hence this information is to present trends and insights. In a high-level analysis of treatment effects, mean breast-height basic density values indicated no significant effect of stocking, while effects on breast-height diameter were significant. Figure 64 shows a typical pattern of radial variation where density increased from around 380 kg/m^3 near the pith, to 460-490 kg/m^3 at age 16 near the bark.

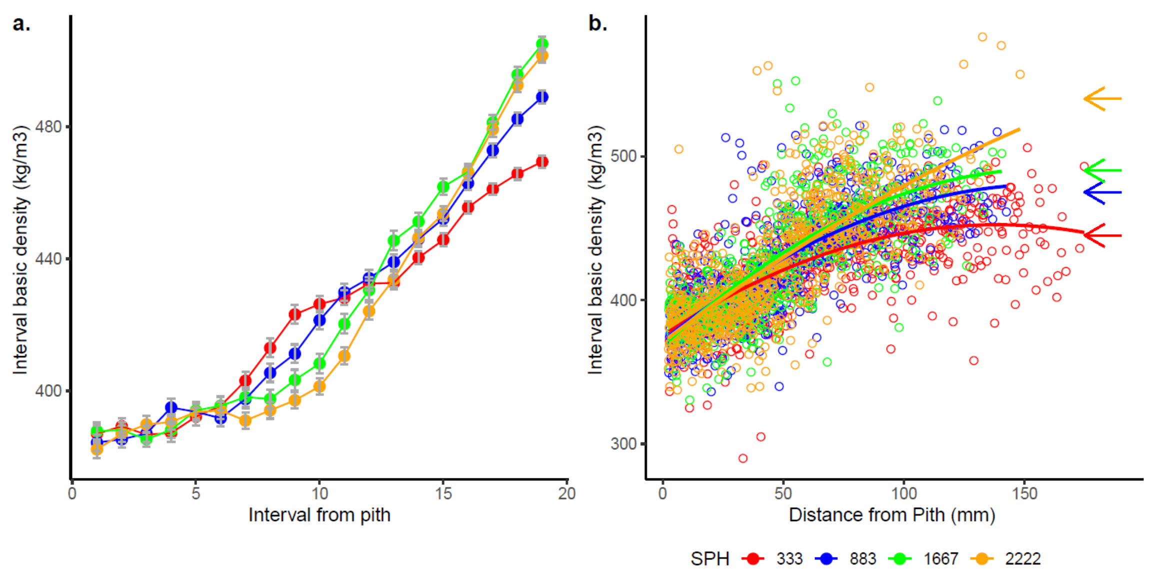

Figure 64. (a.) Mean basic density of the 5% intervals from pith to bark between four stocking treatments. (b) The same data expressed as a function of the distance of the interval from the pith, with curves indicating the mean (smoothed) radial trajectory within each treatment population. Vertical bars denote standard errors. Based on Downes *et al*., (2022).

When the radial variation pattern is considered, several treatment effects become evident. At age 16 years, basic density is only starting to plateau into what would be called mature wood. The magnitude of the mature wood plateau varies between treatments (arrows) with the low stocking treatment producing lower mature wood basic density. In Figure 64a, the effect of diameter is standardised between treatments where variation is expressed as a percentage of the radius. In Figure 64b, the same data is expressed with each value plotted as a function of its actual radial position. Here, the variation in mature wood basic density trajectories can be clearly seen from the smoothed curves fitted to the data. These different trajectories will impact markedly on the stiffness grades of the boards cut from different positions along the radius.

Implications for processor

Figure 65 illustrates this difference using seven individual Resi traces taken from seven individual trees from the same data set of 900 individual trees. In this illustration, under-bark stem (log) diameter has been kept approximately constant to better illustrate the effect of the radial variation pattern. The Resi traces have been converted into an MoE trace and processed through a simple virtual sawmill (part of the web platform used to process Resi traces) to produce a virtual log end. Based on set threshold values, the regions of the 'log' corresponding to different structural grades of timber on processing has been estimated. This approach allows the effect of log diameter interacting with the radial variation in basic density (and stiffness) to be estimated to generate a more informed view of log value. Based on this approach, a major consequence of silvicultural practices such as that implemented at the wide spaced woodlot (see Appendix 6: A wide spaced *P. radiata* woodlot

would be the production of too many logs, where the radial pattern is mostly represented by the left-hand side of Figure 65.

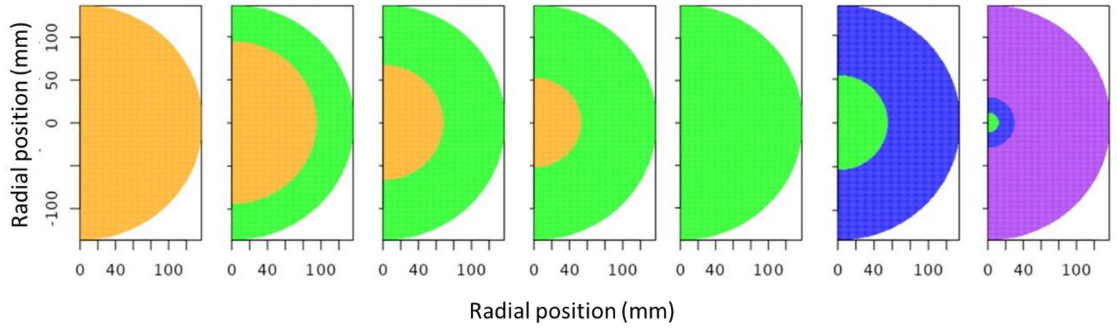

Figure 65. The effect of different radial trajectories on the non-structural core (orange) is illustrated in seven contrasting images derived from actual Resi samples. The cross-sectional area of below MGP10 (orange), MGP10 (green), MGP12 (blue) and MGP15 (purple) can vary markedly between individual trees and spacing treatments.

References

Downes, G.M., Watt, D., Kenna, R., Harrington, J.J., Lausberg, M. & Lee, D.L. (2022). MS3c FCNSW Gurnang Spacing Trial. Report contributes to MS3c. 04 November, 2022.

Appendix 6: A wide spaced *P. radiata* woodlot

Project 1: Research new shorter rotation silvicultural models for pine plantations and longer rotations for blue gum plantations. Sub-report title: Growth and wood properties of a 28-year-old wide spaced *Pinus radiata* stand in the Green Triangle.

Prepared by

Braden Jenkin, Geoff Downes, Dan Campbell and Aleisha Campbell

Summary

A wide-spaced and high pruned (to 6 m) 3 ha 28-year-old (planted in 1995) woodlot of *Pinus radiata* was assessed by routine inventory and with an IML PD400 (Resi) power drill. The woodlot was planted with an initial spacing of 8.5 x 3.5 m with an average initial stocking of 326 stems/ha in 1995 with an objective to produce 'higher value' pruned logs. The woodlot is currently standing at an average of 326 stems/ha (98% survival) with a modelled standing biological volume over bark of 345 m^3 /ha. The volume of pruned and above pruned log volume over bark was estimated to be 219 m^3/ha (58%) and 158 m^3/ha (42%) respectively. This standing volume as the total volume produced by the site (there has been no thinning) is below the yield what would be expected for a routine plantation. The internal stem wood properties (basic density and modulus of elasticity) were estimated and found to be less than those required by a structural sawmill. Currently in the GT there is no market (with a price premium) for pruned logs. Such logs if of the required size, could be purchased by non-structural mills.

Introduction

While conventional softwood silviculture seeks to control a site by maintaining fully-stocked stands for age and condition, agroforestry systems can seek to maintain pasture with trees. The definition of agroforestry varies. The World Agroforestry Centre defines agroforestry as 'agriculture with trees'[1] where as a broader Australian definition is that agroforestry is *'the productive use of trees on farms'* (Able *et al*., 1997, p.5). Some trees into farming legal definitions place a level of importance on the nature of a tree planting and its design. In South Australia under Water Allocation Plans (WAPs), the definition of trees into farming includes an absolute (area) and relative limitation (percentage of a title) to define farm

[1] Accessed from https://www.worldagroforestry.org/about/agroforestry on the 10/06/2023.

forestry (Box 5). Hence trees can be planted in blocks primarily for wood production or wider spaced to maintain grazing. Tree planting systems promoted in the 1980s and 1990s (e.g. England, 1998, p.1) include conducting agriculture and plantation enterprises on the same unit of land. This is distinct to a woodlot which is a small plantation at normal plantation stocking rates. Depending on the spacing of the trees and the nature of the pasture, pasture production can decline with tree age. While grazing benefits reduce, the over storey of trees can provide shade and shelter for livestock. The potential benefits of wide spaced trees are noted in Box 6 and include faster returns as trees reach a commercial size sooner, as well as price premiums for pruned logs.

Some processors are beginning to use IML PD series power drill (Resi) technology to check out potential stands; a price setting tool and/or yes/no to taking logs. The commercial uptake of the Resi, used in conjunction with the web processing application (e.g. https://forestquality.shinyapps.io/FWPA-4/) has been significant over the past 4-5 years within Australian industry. Over 30 individual instruments have been purchased by both (softwood and hardwood) forest growers, processors and tree breeders, to routinely measure wood basic density and assess wood stiffness variation. The full commercial ramifications of the generated data are still being established, but current and likely applications will be around informing plantation value to log processors, managing harvest and supply to mills, informing silvicultural interventions, selection of superior genetic stock for breeding and negotiating log supply contracts. This uptake has been based on the clear potential to precisely measure wood density in individual standing trees and logs at low cost (less than $1 per tree). These two points provide the basis of this analysis's research questions presented in Box 7.

Box 5: The legal definition of trees into farming in South Australian WAPs (SENRMB, no date).
'The Plan defines 'farm forestry' to mean a commercial forest that is situated on a farm and where the net planted area does not exceed: *(i) 10% of the land described in a Certificate of Title or Crown Lease; or* *(ii) 20 hectares – whichever is greater.* *In a practical sense, farm forestry is a forestry activity that is integrated with other farming activities, such as cropping or livestock production. Farm forestry can take many forms, including plantations on farms, woodlots, timber belts, alleys, wide spaced tree plantings and sustainably managed private native forests.'*

Box 6: The claimed advantages of wide-spaced agroforestry (England, 1998, p.1).
'In wide-spaced agroforests the trees are planted at lower stockings. This allows individual trees to grow rapidly, reducing the wait for financial return as each tree reaches a commercial size at an earlier age. The wider spacing allows stock to be grazed under the trees. Pruning of the lower branches is essential but this yields high quality "clearwood" logs for the top end of the market.'

Box 7: The research questions addressed by this analysis.
Research question 1: *What is the impact of wide spaced trees on total volume production and yield of logs?* Research question 2: *What is the impact of wide spacing on the properties of the wood grown?* Research question 3: *What is potential and most likely log product mix?* Research question 4: *What are the financial implications of an expectation for a pruned log premium and the over cost of producing of logs?*

The woodlot site

A *P. radiata* woodlot was established in the Mount Schank region (South Australia) in 1995 as part of a 220 ha farming enterprise (Figure 66). Mount Schank receives around 740 mm/y of rainfall. The site planted was a sandy rise with the trees covering 3 ha planted in a belt (Figure 67). The farmer purchased planting stock cuttings with improved genetics to promote finer branches. The trees were planted nominally at 8.5 m between rows and 3.5 m between trees within the rows; a stocking of 289 to 343 stems/ha. The woodlot is 11 rows wide. At this spacing, the farmer cut hay between the rows of trees after establishing the trees as part of site management. The trees were pruned to 6 m with above this height remaining un-pruned. There has been no thinning of the woodlot (Figure 68). The farmer has also planted conventional P. radiata stands (initial stocking c.1,600 stems/ha and with routine thinning), *E. globulus* and a range of other species. The farmer has managed the harvest of the conventional stands. Logs have been sold on the stump (a stumpage) after seeking two quotes. Products recovered have included preservation logs and pulpwood. The routine *P. radiata* stand first thinning (T1) was cash-positive, after investment in internal road infrastructure. A subsequent second thinning operation was more cash-positive than the T1. The farmer's strategy for the wide spaced *P. radiata* harvesting will depend on markets for pruned logs. In absence of a premium, the farmer intends to 'keep the trees' (Jenkin, 2022, p.14-16).

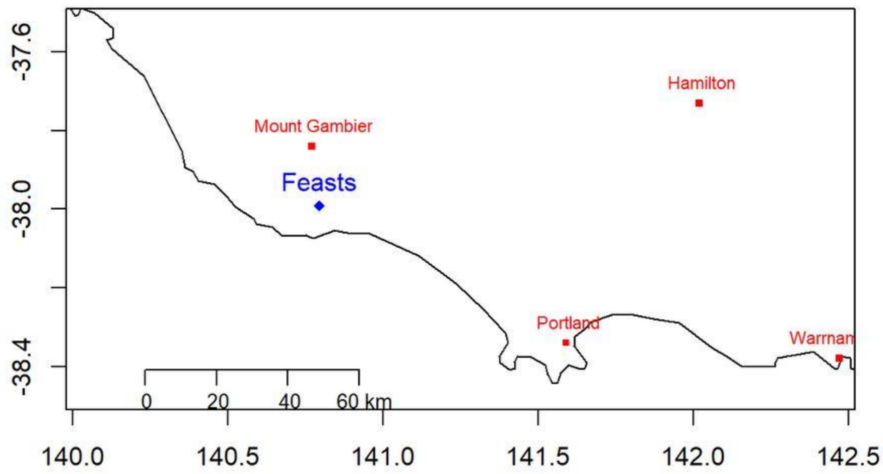

Figure 66: The location of the woodlot site.

Figure 67: An aerial view of the wide-spaced *P. radiata* woodlot adjacent to an *E. globulus* plantation and near a number of centre pivots.

Figure 68: The wide spaced woodlot in December 2021. (Sylva Systems©.)

Methods and materials

Overview

A combined routine inventory and Resi assessment was undertaken of the trees in May 2023 by Campbell Forestry. Five temporary plots were installed located evenly along the length of the woodlot. The plots were installed in the centre of woodlot to reduce edge effects and were four rows wide (34 m) and six trees (21 to 23 m) long to give c.0.09 ha plots. The plot dimensions were measured and the area was calculated for each plot. Each tree was measured for DBHOB using a standard tree measuring diameter tape and the data captured in field sheets. A sample of tree total heights was taken in each plot. Each tree was assessed with the Resi at breast height (1.3 m) and the trace recorded.

Routine inventory and analysis

The inventory data was entered into the Sylva woodlot assessment tool and woodlot attributes calculated mean; DBHOB, mean tree basal area, initial and current stocking and survival. This data was used to calculate mean tree biological volume based on mean tree DBHOB and total height (Equation 5). Woodlot volume was calculated by multiplying mean tree volume by stocking (Equation 6). Based on simple trigonometry, stump (Equation 7), pruned log and above pruned log volume to a small end diameter (SED) of 10 cm over bark was estimated (Equation 8). The log volume function was based on Smalian's formula (Philips, 1994, p.56). The residual stem volume was estimated based on total volume less stump, less the pruned log and less above the pruned log volumes. A simple diameter for height function was developed and applied (Equation 10). It is recognised that this ignores the nuances of tree shape.

Equation 5: Stem biological volume over bark calculation.	$V_{STEM} = Ht\ X\ (\frac{DBHOB}{200})^2\ \text{X}\ \frac{22}{7} X\ \frac{1}{3}$
V_{STEM}	Volume of the tree stem (m^3/stem)
Ht	Total height of the tree (m)
DBHOB	Diameter at breast height over bark (cm)

Equation 6: Woodlot biological volume over bark calculation.	$V_{WOODLOT} = V_{STEM}\ X\ S$
$V_{WOODLOT}$	Volume of the woodlot (m^3/ha)
V_{STEM}	Volume of the stems (m^3/stem)
S	Stocking of the woodlot (stems/ha)

Equation 7: Stump volume over-bark calculation.	$V_{STUMP} = H_{STUMP}\ x\ (\frac{D_{STUMP}}{200})^2\ X\ \frac{22}{7}$
V_{STUMP}	Volume of the tree stump (m^3/stump)
D_{STUMP}	The stump diameter (cm)
H_{STUMP}	The stump height (m)

Equation 8: Stem section volume over-bark calculation.	$V_{SS} = L\ X\ (\frac{SED+LED}{400})^2\ X\ \frac{22}{7}$
V_{ss}	Volume of stem section (m^3/section)
L	Log length (m)
SED	Log small end diameter (cm)
LED	Log large end diameter (cm)

Equation 9: Above SED volume over-bark calculation.	$V_{S>SED} = V_{STEM} - V_{SS} - V_{STUMP}$
$V_{>SED}$	Volume last section above SED (m^3/section)
V_{STEM}	Total volume of the stem (m^3/stem)
V_{ss}	Volume of stem section (m^3/section)
V_{STUMP}	Volume of the stump (m^3/stem)

Equation 10: A simple stem diameter at a specific- height function.	$D_H = (H_D - BH)\ X\ (\frac{DBHOB}{H_T})$
D_H	Diameter (cm) at height
H_D	Height (m) at the point where diameter is required
BH	Breast height at 1.3 m
DBHOB	Diameter at breast height over bark (cm)
H_T	Total tree height (m)

Resistance drilling wood quality assessment

Resi traces were collected from every tree in each plot. The TreeID field in the Resi was used to identify trees by plot number and tree number within the plot. This allows cross-referencing to other data captured in regard to each tree. Each Resi trace was taken at around breast height and from the north-south aspect, except where stem features (e.g. knots and stem defects) required changes to the sample point to be more likely clearwood. A total of 119 Resi traces were captured, downloaded, and processed through the web platform located at https://forestquality.shinyapps.io/FQResi. Each trace was reviewed to determine that it had been processed correctly and manually corrected as required. The pith location (centre of a stem section) was manually checked and adjusted as necessary. Each trace consists of two radii (entry and exit) corresponding approximately to the north and south aspects. All analyses and reporting were undertaken in R (Team, 2020a) using RMarkdown (Allaire *et al.*, 2020) within the RStudio environment (Team, 2020b). Summary metrics were collected from each trace.

Results

Plot and woodlot attributes

Table 31 presents a summary of the plot data and analysis outcomes. The average woodlot stocking (319 stems/ha) remains close to the initial planted rate (326 stems/ha) with average survival of 98%. It is not known whether the woodlot was refilled to take account of any initial losses. Average woodlot DBHOB was 40.4 cm (an average increment of 1.4 cm/y) and average woodlot basal area was 41.4 m^2/ha (an increment of 1.5 m^2/ha/y). Estimated woodlot over-bark biological volume ranged from 298 to 379 m^3/ha with a mean of 345 m^3/ha. Stocking was combined with standing volume to generate a mean tree volume (MTV) of 1.1 m^3 and with a conversion factor of 1.0000 GMT/m^3, an MTV of 1.1 GMT/stem. This value drives harvesting costs which are a significant contributor to woodlot financial viability.

Diameter at breast height over bark

Figure 69 presents a DBHOB frequency distribution for the five individual plots, with variation between the plots and with an overall general pattern of minimal outlier trees. There is a concentration of trees between a DBHOB of 35 to 46 cm. This pattern is more evident in Figure 70 which combines all plots. This distribution has implications for the product mix at harvest with products defined by log small end diameters (SED). This DBHOB distribution was converted to a cumulative distribution to indicate the percentage of logs of a specific DBHOB or less (Figure 71).

Table 31: A summary of the inventory outcomes and calculated woodlot attributes. (SD = standard deviation; MAI = mean annual increment; Ob = over bark; MTV = mean tree volume).

			Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Min	Average	Max
Age		(y)	27.9	27.9	27.9	27.9	27.9			
Initial stocking		(stems/ha)	289	343	343	343	313	289	326	343
Stocking		(stems/ha)	267	343	343	343	300	267	319	343
Survival		(%)	92.4%	100.0 %	100.0 %	100.0 %	96.0 %	92%	98%	100 %
DBHOB	Average	(cm)	41.2	40.4	39.1	40.9	40.4	39.1	40.4	41.2
	SD	(cm)	4.0	5.2	5.2	3.9	5.4	3.9	4.7	5.4
	Increment	(cm/y)	1.5	1.4	1.4	1.5	1.4	1.4	1.4	1.5
BA	Woodlot	(m^2/plot)	3.2	3.1	2.9	3.2	3.1	2.9	3.1	3.2
		(m^2/ha)	35.8	44.7	41.8	45.5	39.2	35.8	41.4	45.5
	Increment	(m^2/ha/y)	1.28	1.60	1.50	1.63	1.40	1.3	1.5	1.6
Height	Average	(m)	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Volume	Standing OB	(m^2/ha)	298.3	372.5	348.3	379.2	326.7	298.3	345.0	379.2
	MAI OB	(m^2/ha/y)	10.7	13.3	12.5	13.6	11.7	10.7	12.4	13.6
	MTV	(m^2/stem)	1.1	1.1	1.0	1.1	1.1	1.0	1.1	1.1
	Conversion factor	(GMT/m^3)	1.0	1.0	1.0	1.0	1.0			
	MTV	(GMT/stem)	1.10	1.10	1.00	1.10	1.10	1.0	1.1	1.1
Slenderness		(cm/m)	1.65	1.62	1.56	1.64	1.62	1.6	1.6	1.7

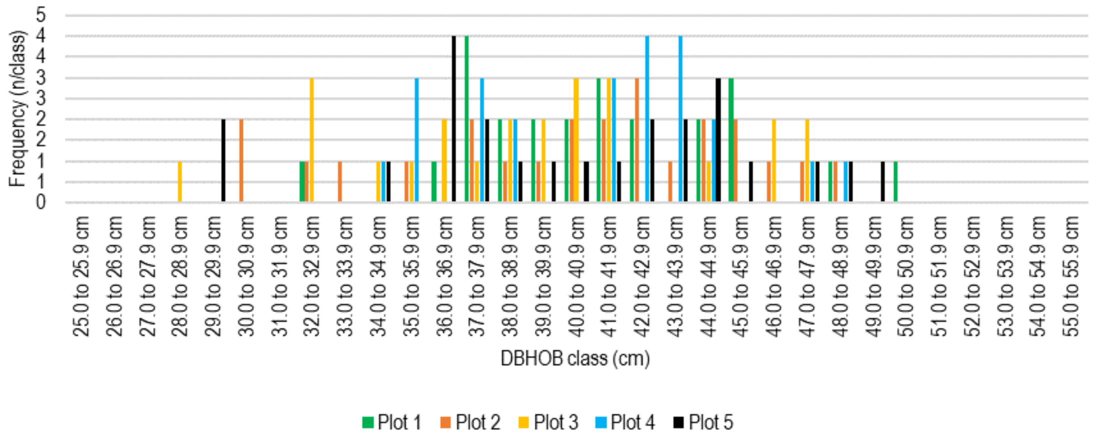

Figure 69: Individual plot DBHOB frequency distribution.

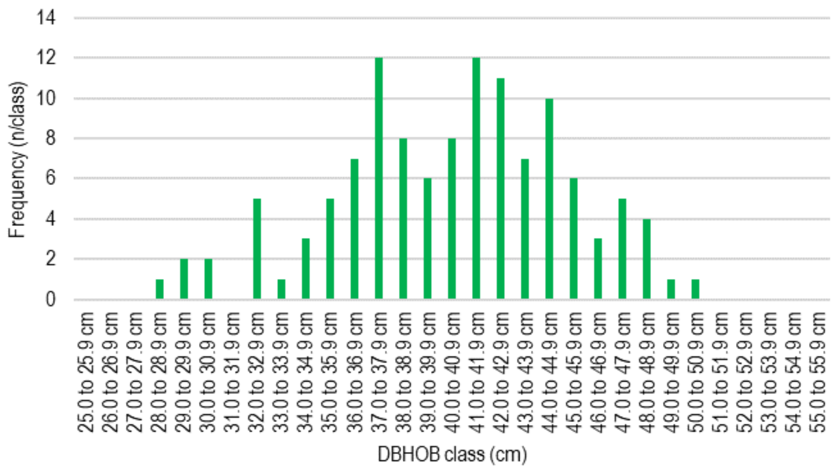

Figure 70: Combined BDHOB data for all 5 plots presented as a single frequency distribution.

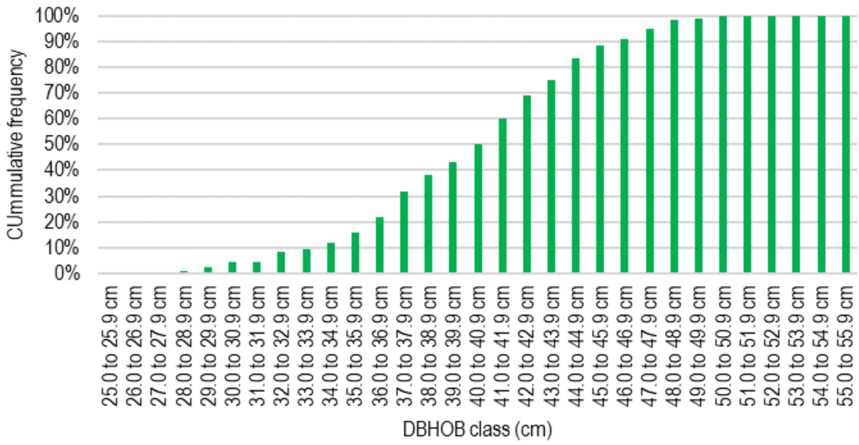

Figure 71: A cumulative DBHOB by size class distribution for the combined data for all 5 plots.

Standing volume and log types

Figure 72 and Figure 73 present modelled standing over-bark volume segmented into stumps (assumed 20 cm high), 6 m length pruned logs to the height of pruning, un-pruned logs to an SED of 10 cm over-bark and above SED residual stemwood. The model used to generate this data applied simple trigonometry and is highly indicative; it assumes no losses due to stem defects and indeed assumes stem perfection. The analysis assumed that all stumps would be 20 cm and that all pruned stem sections would produce a 6 m long log above the height of the stump. Therefore, the breakdown of the biological volume per stem into products assumed consistent proportions. Of note is that merchantable volume to 10 cm SED is estimated to be 326 m^3/ha (95.7%); if the SED is increased to 20 cm, this reduces to 299 m^3/ha (87.7 %). The modelled pruned log volume was estimated to be 219 m^3/ha which is 58.0% of the standing biological volume based on log length rather than any SED limits. A product mix of 60% pruned logs and 40% un-pruned logs results.

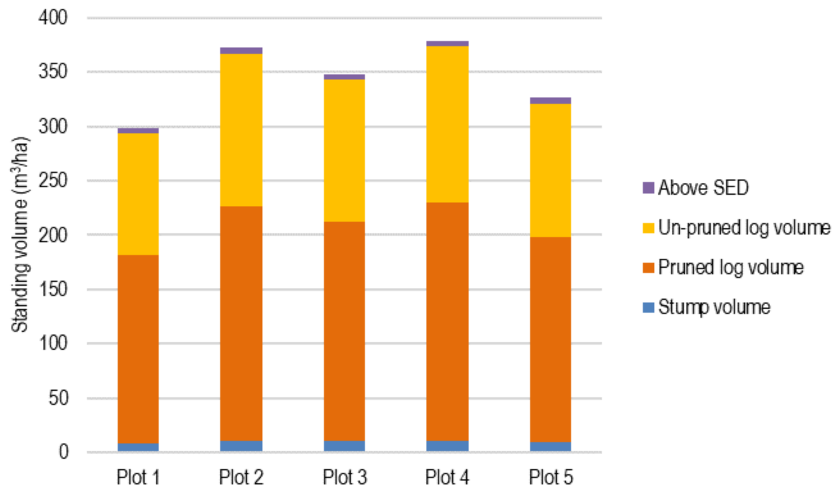

Figure 72: Modelled plot standing volume over-bark by stem components.

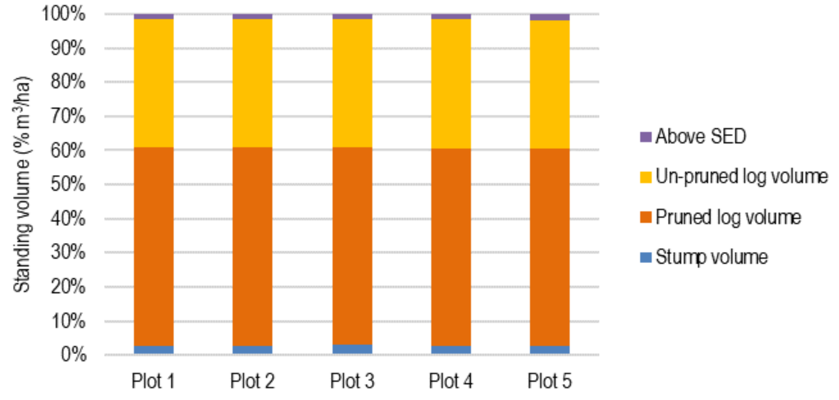

Figure 73: Modelled plot standing volume by estimated stem components presented as a percentage of total plot volume.

Woodlot wood properties

Table 32 presents a summary of the Resi derived plot attributes. Figure 74 presents the outcome of the Resi-tool derived wood radial density variation from pith to bark. It is recognised that wide spacing is the driver of change in growth patterns of the individual trees which has a potential impact on wood properties.

Table 32: A summary of the Resi assessment of woodlot wood properties. (Core density = the density of the radial sample; Disc density is the weighted average density of the sample disc; PrMoE = predicted modulus of elasticity.)

	Tree count	Stem diameter			Basic density		
		DBHOB	DBHUB	Bark thickness	Core density	Disc density	PrMoE
	(n)	(mm)	(mm)	(mm)	(kg/m^3)	(kg/m^3)	
Plot 1	24	389.4	351.7	18.9	392.0	407.0	7.79
Plot 2	24	385.2	348.9	18.6	397.3	414.1	7.94
Plot 3	24	377.9	342.7	17.5	394.6	414.0	7.83
Plot 4	24	383.0	346.8	18.5	395.0	419.8	7.84
Plot 5	23	380.7	346.5	17.0	396.3	418.3	7.92

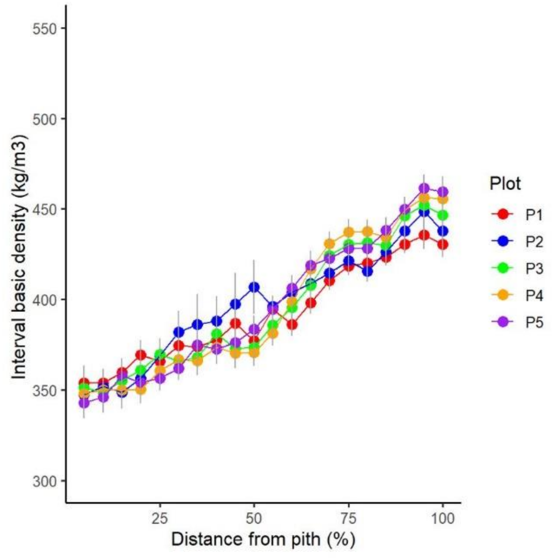

Figure 74: Plot interval breast height basic density for each of the 5 plots.

Analysis and discussion of the assessment outcomes

Yield and growth

Addressing Research question 1, the following considers the yield outcomes of this regime. The modelled volume outcomes for the plots at age 27.9 years (Figure 72) were graphed against GT expected total yields for *P. radiata* plantations; recall that this woodlot has not been thinned hence current standing volume is the total site yield. The ABARES data is based on Legg *et al*. (2021, p.71) assumes clear fell at age 30 years. The other three regimes are based on the lower end of productivity reported (see Appendix 4: Harvest and transport costs in the Green Triangle) with conventional clear fell assumed at age 34 years and an early clear fell regime assumed clear-felled at age 30 years. Such stands were assumed to have been planted at 1,600 stems/ha rather than 326 stems/ha. The regime data was converted into mean annual increment (MAI) and compared to the wide-spaced treatment. This difference is due to the understocked management regime and the lower number of planted trees not making full use of all available site resources. The response to Research question 1 is that this regime resulted in a reduction in yield.

Wood properties, product mix and markets

Addressing Research question 2, the following are comments in regard to wood property outcomes. There are two broad log products or types based on usual log grades potentially available from this woodlot. The first is nominally 6 m long pruned logs and the second is un-pruned logs, many of which have current live green branches (Figure 68). Based on wood properties (see Table 32), it is questionable whether a structural timber sawmill would seek to purchase such logs; the wood basic density and expected percentage recovery of MGP10 or greater boards is low. If wood quality is not an issue, then such logs, with an average modelled SED of 30.7 cm, would meet industry requirements.

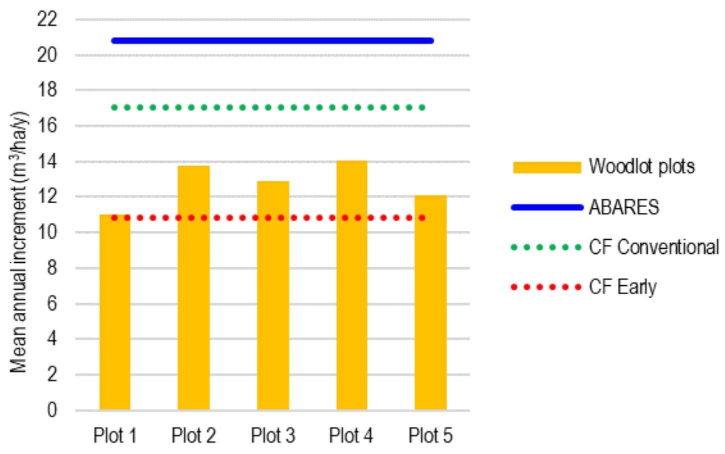

Figure 75: The estimated mean annual increment of the woodlots compared to expected lower total harvest volumes for the regimes presented.

Addressing Research question 3, the following considers the likely product mix. That is, potential products compared to actual and current markets. While there is variation in tree DBHOB (see Figure 70), the cumulative frequency of trees by diameter class (Figure 71) suggests that a very small number, if any trees (based on DBHOB), will have a pruned log SED of less than 15 cm. In regard to the pruned logs, a price premium currently is not on offer for such logs in the GT (see Appendix 3: Log products and prices in the Green Triangle). The simple analysis indicated a volume of 200 m^3/ha. With an area of 3 ha, a potential volume of 600 m^3 is available. It is possible for a local processor to purchase such logs or for an external party to seek to buy these logs. This would require a specific arrangement. The upper stem logs will require specific attention. The length of this section is c.18 m hence three 6 m logs could be recovered down to a 10 cm SED. It is likely that such logs would be classed as industrial logs. Specific consideration would be required of the size of the branch knots with a positive aspect that the knots will be green. Failing supply as industrial logs, these logs could be supplied as pulp logs (SED limit of 10 cm and a LED of 30 cm) or into a future pellet plant. Market access considerations include compliance with voluntary third-party certification requirements. Geddes and Parsons (2023) suggest that the cost an independent audit as part of supplying logs to a certified processor can be higher for smaller parcels of logs; this process is a fixed cost divided by logs sold. The response to Research question 3 is that based on current active markets, the pruned logs are mostly likely to be purchased by a non-structure sawmill and the above pruned height logs could be sold as industry logs or for woodchips or for energy pellet production (if such a plant is constructed).

Financial considerations

Addressing Research question 4, the following considers the financial aspects of the regime. Net harvest revenues will be driven by log mill door price less haulage costs, less harvesting costs, less any internal roading (limited in this case) and any harvest administration costs. This revenue will be determined by the log types sold by log product price. A key point will be whether all stemwood can be sold to a reasonable stem SED. While there are establishment cost savings (e.g. fewer plants needed), a woodlot planted at final stocking rates generates income at final harvest (at rotation) rather than over the rotation. With the time value of money, this places pressure in financial performance. This can be in part offset by farm enterprise benefits and to make an informed decision, the quantum of such benefits require analysis. The initial saving in planting stock costs (from $670/ha to $137/ha or $535/ha) results in an additional cost of pruning. With multiple lifts at a cost of $4.50/stem, this equates to a cost of $1,467 /ha. To recover this cost will require a pruned log price premium as well as a premium to cover the foregone productivity (see Figure 75) to result in the same returns per hectare as a more routine plantation. In effect this regime has created high-cost rather than high value trees. The response to Research question 4 is that the investment in pruning to produce pruned logs is unlikely to generate sufficient returns to justify this regime.

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Appendix 7: *Eucalyptus globulus* stem analysis

Project 1: Research new shorter rotation silvicultural models for pine plantations and longer rotations for blue gum plantations. Sub-report title: Development of a one-way volume function for a 15-year-old trial of *Eucalyptus globulus* in the Green Triangle.

Prepared by

Braden Jenkin, Geoff Downes, Dan Campbell and Aleisha Campbell

Summary

An Australian Bluegum Plantations (ABP) *Eucalyptus globulus* spacing trial, established in 2008 in western Victoria was to determine optimal stocking to maximise site potential (volume) and maximise harvest efficiency at final harvest. Making use of this trial, 24 trees were selected (one per plot treatment replicate) based on mean DBHOB and variation around that mean, and were fallen. The sample trees DBHOB ranged from 17.0 cm to 30.5 cm. The tree stems were measured for over bark diameter at a set series of stem points and bark thickness measured at each point. The volume of each stem was estimated using a model that summed the volume of the individual sections. A dataset of 24 trees with DBHOB and volume (over and under-bark) was used to test one-way volume functions. A polynomial function had the best fit with separate constants (a, b and c) for the over and under-bark functions. Given the nature of polynomial functions, caution is required when applying this function to trees outside of this DBHOB range. The analysis estimated that the percentage of bark based on over-bark volume ranged from 14.5% to 25.4% with a mean of 20.6%. This is an important attribute given payment for *E. globulus* wood grown and harvested, based on the weight of under-bark wood delivered to a mill gate.

Introduction

Individual shape, volume and growth are important metrics with which to understand the attributes of trees. When combined with stocking, they can define the attributes of a stand (see Carron, 1968; Philips, 1994). This is assisted by understanding the relationship between an easily measured tree attribute and relating this to the attributes of a stem. A two-way volume function can combine tree total height and diameter at breast height over-bark (DBHOB at 1.3 m) to estimate tree and stand volume (e.g. Wong *et al*., 2000). While there are well established techniques for estimating tree total height, even with laser- based equipment, this can be slow and where tree growth tips are difficult to see (e.g. with dense crowns) or are moving due to wind, this process can be inaccurate. Estimation of DBHOB is a simple and easily captured stem attribute. A conventional calibrated diameter tape or more recently, the IML PD series power drill (Resi) technology can be used. While a Resi assessment is a marginally slower process per tree (under favourable conditions, around 600 to 800 stems per eight-hour day can be assessed) the additional data captured in regard to stem wood properties is important. The impact of bark thickness is critical as hardwood logs are generally sold after debarking whereas measurement of DBHOB by diameter tape is over-bark. Hence, development of a one-way stem volume function for volume under and over-bark based on DBHOB is an important contribution to development of tree and stand metrics. This report addresses the research questions presented in Box 7.

Box 8: The following research questions were addressed by this analysis.
Research question 5: *What is the form and constants for a one-way volume function based on DBHOB for plantation grown* E. globulus*?* Research question 6: *What is the quantum of bark for plantation grown* E. globulus*?*

The site

Trial purposes and site

An Australian Bluegum Plantations (ABP) *Eucalyptus globulus* spacing trial, was established in 2008 at the Wilderness plantation, Victoria (Figure 76; 38.00929oS 141.94084oE and Figure 77) as part of Timbercorp Project number 146 (see Agars *et al*., 2008). The broad aim of the trial was to determine the optimal stocking to maximise site potential (volume) as well as maximise harvest efficiency at final harvest. The trial research questions were as follows.

1. *What is the optimal stocking at the chosen sites that will maximise yield and piece size?*
2. *Can non-commercial thinning be used to optimise yield and piece size and therefore maximise harvest efficiency?*
3. *What is the cost: benefit (volume vs improved access) of manipulating row spacing (4.0 vs 4.5 m)?*
4. *Is non-commercial thinning a valuable means of genetic selection?*

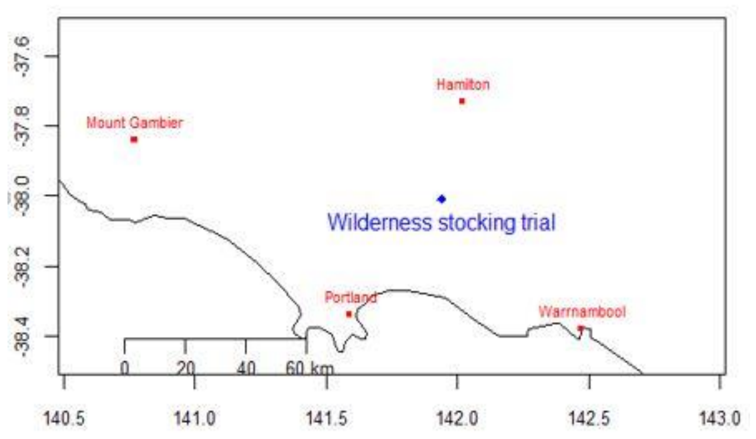

Figure 76: The location of the trial site in western Victoria.

Figure 77: An aerial view of the site with the trial indicated by the red dotted line.

The trial consists of three initial stocking treatments (1,250, 1,000 and 833 stems/ha un-thinned), and an established at 1,250 stems/ha treatment thinned to waste and 833 stems/ha at around age 3 years) as presented in Figure 67. These treatments were applied in two row spacing treatments, with 4.0 or 4.5 m between rows. The plots are 35 metres long and eight internal rows wide (nine measured rows including peg line). Row spacing and hectares for each of these plot types are as follows.

- 4.5 m row spacing: 9 rows (40.5 m wide x 35 m long) = 0.14 ha.
- 4.0 m row spacing: 9 rows (36.0 m wide x 35 m long) = 0.13 ha.

The effect of the between row spacing was that within the rows, trees were slightly closer together with the wider spacing to give the same stocking per hectare.

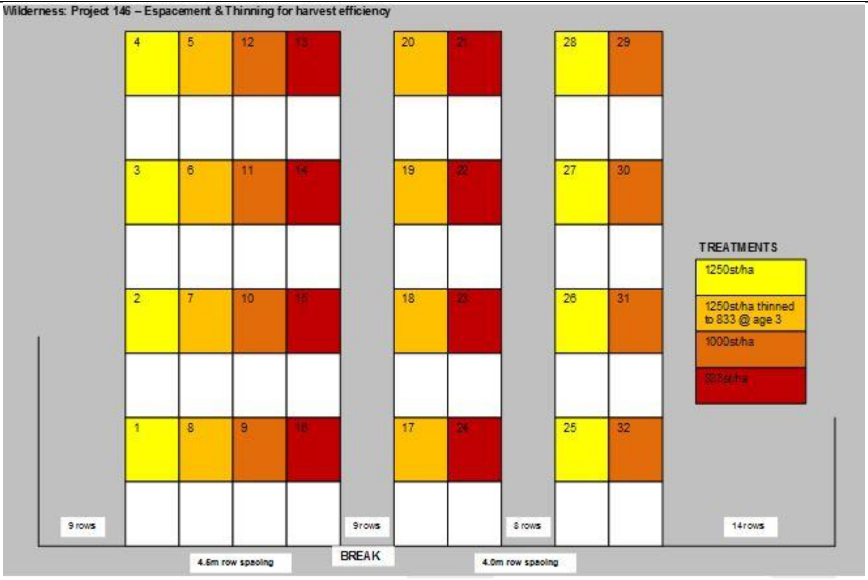

Figure 78: The trial layout and treatments.

The resulting trial was age 15 years at the time of assessment with no understorey and very limited grass (Figure 68). As part of trial management, ABP has conducted an annual routine inventory and the data for the 2023 inventory was provided.

Figure 79: The stand in April 2023 with no understorey. (Sylva Systems©.)

Methods

Inventory data

The ABP routine inventory data for 2023 was provided and was entered into the Sylva woodlot assessment tool. This model generates a range of stand metrics and can be applied to individual treatments in a trial. In effect each treatment is treated as an individual woodlot. This tool presents the data as a treatment map allowing navigation and finding specific individual trees. The mean DBHOB for each treatment per replicate was calculated and as was the standard deviation around each mean.

Tree selection

The assessment objective was to fall 24 sample trees from eight replicates of the four treatments (as time allowed rather than 32 sample trees). Candidate sample trees were selected to reflect trees that had potential for beyond pulpwood products based on stem size. Sample trees were selected within each treatment based on tree DBHOB data for each plot; select as close as possible to the mean tree, the tree with the closest DBHOB less one standard deviation or the tree with the closest DBHOB plus one standard deviation. Each candidate sample tree was located in the field, inspected and suitability determined based on form. A field datasheet was prepared for each sample tree. Box 9 presents a summary of the data captured in the field for each tree.

Box 9: A summary of the individual tree-data captured from each stem.

- Stump height: The height of the stump from the ground to the felling bottom cut.
- Total tree height: The total tree height above ground to the tip of the green foliage. This was used to calculate the percentage total height measurement points.
- Height to first green branch: The height of the tree from the ground to the first green (live) branch.
- DBHOB: The DBHOB (1.3 m above the ground) of the stem.
- DOB: The DOB at each measurement point.
- Bark thickness: The thickness of the stem bark at each measurement point on the south and north side of the stem.

Sample tree falling and measurement

Sample trees were fallen using a chainsaw with felling direction aimed to reduce potential for hang-ups (Figure 80). The fallen stems were de-limbed either by chainsaw or by use of a small axe. This was to allow access to the tree stem. Once fallen, the location of the north and south facing tree sides were determined using a field compass. Tree stump height was directly measured using a 30 m tape and the height recorded in metres (Figure 81). The measuring tape was then pinned to the log-end taking account of the stump height, the tape was run-out along the stem and total height measured and recorded in metres (Figure 82). The height to the first green branch was recorded in metres. The measuring tape was left along the tree stem to define measuring and sample points. There were two sets of sampling point at which measurements were taken. The first was to measure at the stump, DBHOB, and at every metre of stem height above ground. The last measurement was taken at the point where the stem became more branchlike or where the stem diameter was 6 cm of less over bark at the last metre section point. The second set of sampling points were calculated at 2% (P0), 10% (P1), 30% (P3), 50% (P5) and 70% (P7) of total tree height as per Downes *et al*. (1997, p.26, Figure 3.3). A steel diameter tape was used to measure diameter over bark at all sample points along the stem (Figure 83). Where access was limited (e.g. the measuring point was on the ground), a shovel was used to provide access or a crow-bar used to lift the stem. Diameter data was recorded on the field sheet in centimetres. At each point, bark-thickness was measured using a bark gauge on the north and south side of the stem. To under-bark bark thickness measurement, the bark gauge was tapped with a nylon hammer to ensure that the full depth to the cambium layer was measured (Figure 84). Bark-thickness data was recorded on the field sheet in centimetres.

Figure 80: Directional falling of sample trees making use of wedges. (Sylva Systems©.)

Figure 81: A sample tree stem with a 30 m fibre glass measuring tape in place to define measurement points. (Sylva Systems©.)

Figure 82: The end of the 30 m fibre glass measuring tape attached to the stem end to take account of stump height. (Sylva Systems©.)

Figure 83: Measurement of stem diameter over bark at a measurement point. (Sylva Systems©.)

Figure 84: Measurement of stem bark thickness at a measurement point. (Sylva Systems©.)

Stem volume calculation

The field data was entered into the Sylva stem analysis Excel® spreadsheet model each night while in the field to allow checking. The model calculates over and under-bark stem volume based on the sum of the volume of each section of stem (Equation 11). The first section is the stump with the volume was calculated based on Equation 12 using stump height and diameter measurements. The over-bark volume of each subsequent section was calculated as per the formula in Equation 13 based on Smalian's formula (Philips, 1994, p.56). The length of the section was based on the distance between the sample points. The diameter over-bark of each end was based on the diameter at each measurement point. The volume of the section above the last stem diameter was based on the volume of the cone (Equation 14). The under-bark volume was calculated based on the diameter at each sample point, less two times the average bark-thickness at each point. The percentage of stem bark by volume was calculated as the difference between over and under-bark stem volume as a percentage of total over-bark volume.

Equation 11: Stem biological volume calculation.	$V_{STEM} = \sum_{i=0}^{n} V_{STUMP} \; + V_{S1} \ldots\ldots + V_{Sn-1} + V_{TOP}$
V_{STEM}	Volume of the stem (m^3/stem).
V_{STUMP}	Volume of the stump (m^3/stump).
V_{S1}	Volume first section (m^3/section).
V_{n-1}	Volume second last section (m^3/section).
V_{TOP}	Volume last section above SED (m^3/section).

Equation 12: Stump volume calculation.	$V_{Sn} = H_{STUMP}\ x\ (\frac{D_{STUMP}}{200})^2 \times \frac{22}{7}$
V_{STUMP}	Volume of stump over or under-bark (m^3/stump).
H_{STUMP}	Stump height (m).
D_{STUMP}	Stump diameter over or under-bark (cm).

Equation 13: Stem section volume calculation.	$V_{Sn} = L\ X\ (\frac{SEDOB+LEDOB}{400})^2 \times \frac{22}{7}$
V_{sn}	Volume of stem section n (m^3/section).
Ln	Section n length (m).
SEDOB	Section n small end diameter (cm).
LEDOB	Section n large end diameter (cm).

Equation 14: Above SED volume calculation.	$V_{S>SED} = L_{SECTION}\ x\ (\frac{D_{SED}}{200})^2\ \text{X}\ \frac{22}{7}\ \text{X}\ \frac{1}{3}$
$V_{>SED}$	Volume last section above SED (m^3/section).
$L_{SECTION}$	Section length (m).
D_{SED}	Stem SED (cm).

A one-way stem volume function

A one-way tree volume function was developed with DBHOB as the determinate. The individual data for the 24 sample trees was prepared in a summary table; tree height, height to the first green branch, DBHOB, over-bark volume and under-bark volume for the stump, main stem and above the tree SED. Making use of Excel®, a range of function formats were tested with the R^2 of the relationships used to selected the most robust form. A polynomial volume function was selected (Equation 15).

Equation 15: The polynomial volume function format.	$V_{BIOLOGICAL} = a.DBHOB^2 + b.DBHOB + c$
$V_{BIOLOGICAL}$	Stem total biological volume (m^3/stem).
DBHOB	DBHOB (cm).
a	Constant a
b	Constant b
c	Constant c

Results

Tree height for DBHOB

Tree total height and height to first green branch data are presented in Figure 75. While there is a general relationship between DBHOB and total height (R^2=55%) for this sample of trees, there is a very week relationship. There was a very poor relationship between DBHOB and the height to first green branch (R^2=6%).

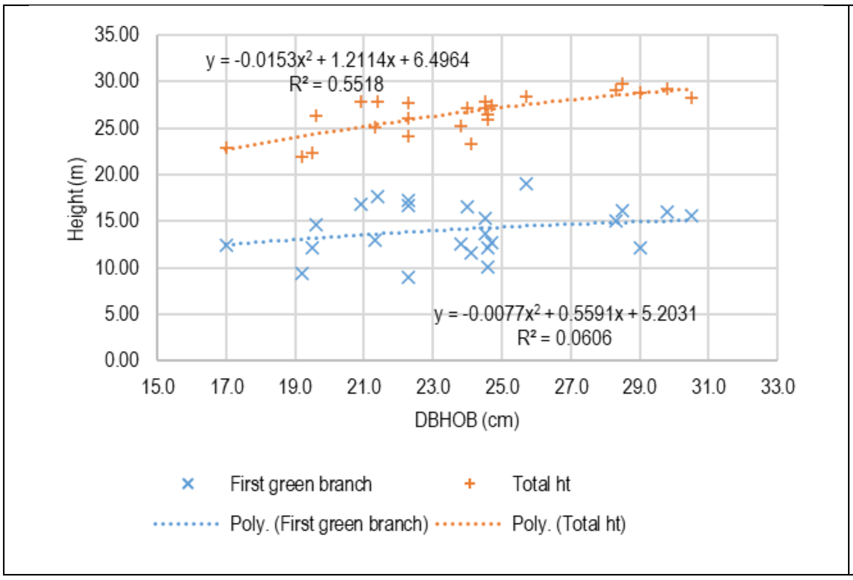

Figure 85: Tree total height and height to first green branch for DBHOB.

Individual stem volume

The outcome of the calculated individual tree stem volume over bark is presented in Figure 72 and in Figure 87, for the under-bark volumes. The stem volumes ranged from 0.22 to 0.83 m^3/stem with DBHOB from 17.0 to 30.5 cm. The volume of the stumps is a minor component of the stem volumes driven by minimising stump height; in the treatments and based on actual falling stump, height ranged from 10.0 to 20.0 cm. The impact of over and under-bark treatment on volume is apparent.

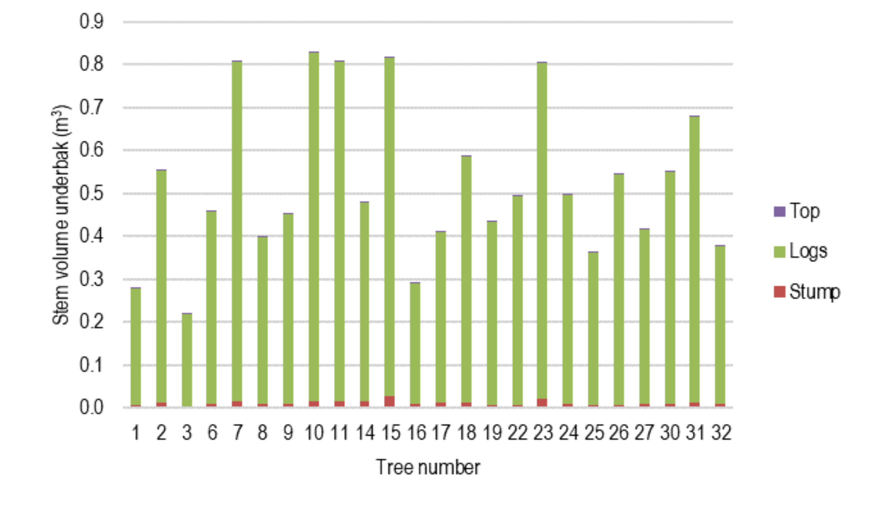

Figure 86: The over-bark volumes of the individual stems split into stump, logs and above SED (top).

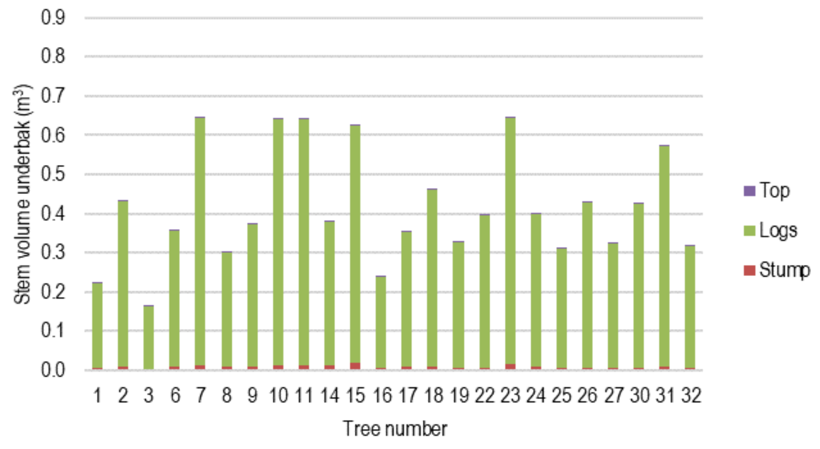

Figure 87: The under-bark volumes of the individual stems split into stump, logs and above SED (top).

Bark volume

Figure 88 presents the modelled under-bark stem volume and the volume of bark. This data is expressed on a percentage of total over bark stem volume in Figure 89. The percentage of bark ranged from 14.5% to 25.4% with a mean of 20.6%. There was a weak correlation between bark percentage and over-bark whole stem volume (Figure 90). This lack of relationship reinforces the need for separate functions for under and over-bark volumes based on DBHOB.

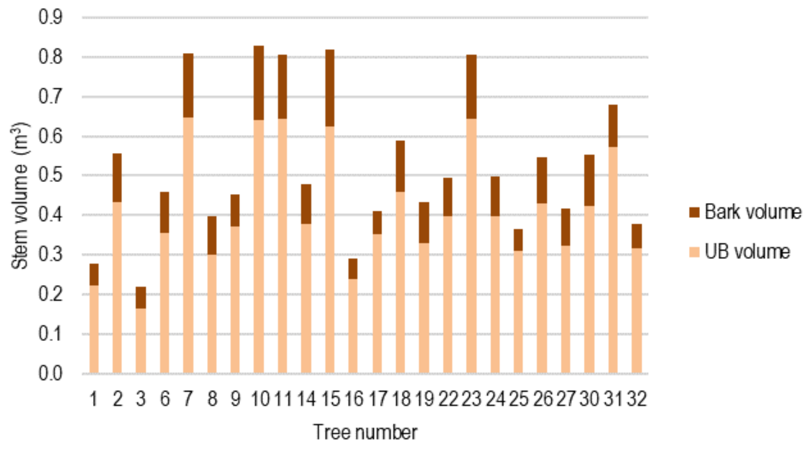

Figure 88: Modelled stem volume under-bark and bark volume.

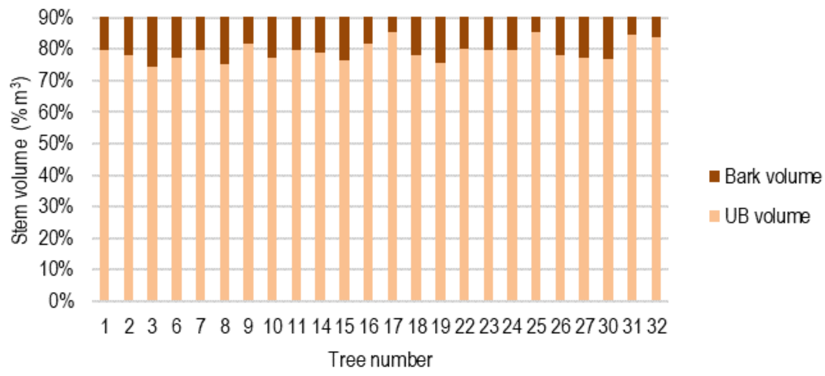

Figure 89: Modelled stem volume under-bark and bark volume as percentage of total volume over-bark.

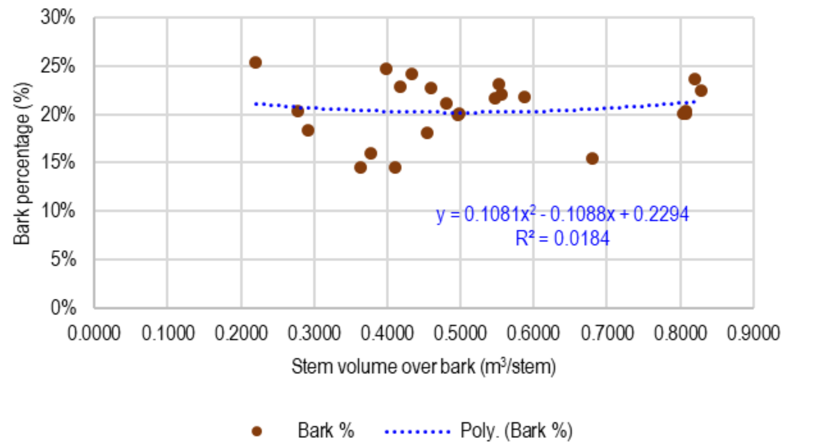

Figure 90: Modelled bark percentage for stem volume over-bark.

Volume functions

Four volume functions (based on Equation 15) have been generated; total and above stump volume functions for over and under-bark volume. The underlying data and resulting models are presented in Figure 91 (whole stem biological volume) and Figure 92 (above stump volume). Each chart presents over and under-bark functions. The constants for each model are presented in Table 33. The resulting volume function is presented in Figure 93.

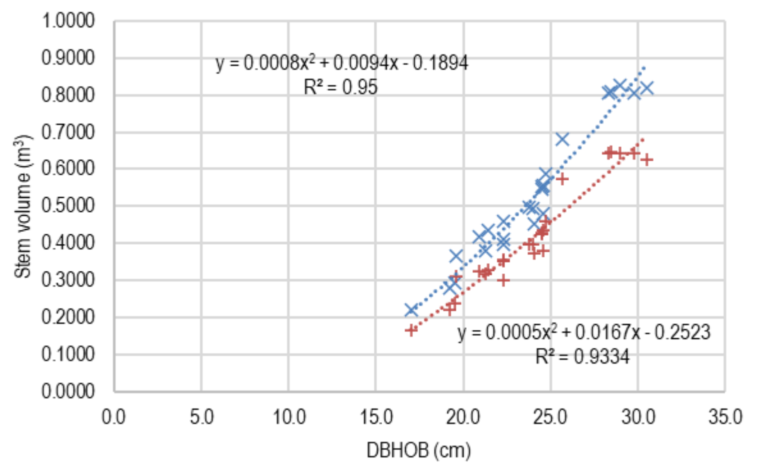

Figure 91: Tree over-bark and under-bark total stem volume.

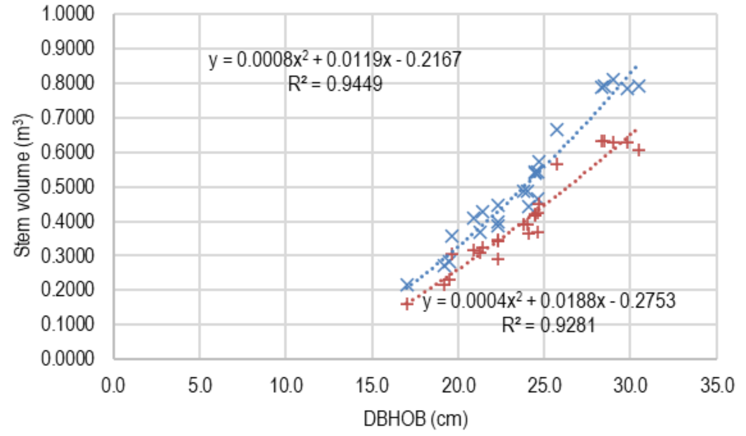

Figure 92: Tree under-bark and under-bark stem volume above the stump.

Table 33: The polynomial volume function variable for use with Equation 20.

Basis	Constants	OB	UB
Full stem	a	0.0008	0.0005
	b	0.0094	0.0167
	c	-0.1894	-0.2523
	R^2	95%	93%
Above stump	a	0.0008	0.0004
	b	0.0119	0.0188
	c	-0.2167	-0.2753
	R^2	95%	93%

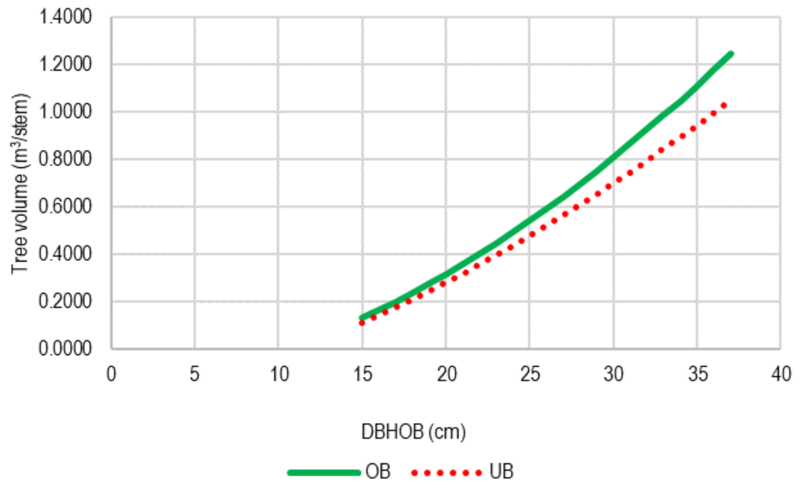

Figure 93: Modelled stem biological volume over and under-bark.

Analysis and discussions

A one-way tree volume function

Research question 1 has been addressed. A robust polynomial one-way volume function has been developed for *E. globulus* growing at the Wilderness site; see Equation 15, Table

33 and Figure 93. This function is based on trees with a DBHOB ranging from 17.0 to 30.5 cm, hence given the nature of polynomial functions, caution is required where applying this function to trees outside of this range.

Bark percentage

Research question 2 has been addressed. The analysis of the trees sampled estimated the percentage of bark based on over bark volume ranged from 14.5% to 25.4% with a mean of 20.6%. This is an important attribute given that payment for *E. globulus* wood grown and harvested is based on the weight of under-bark wood delivered to a mill gate and as determined based on weigh bridge weights.

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Appendix 8: *Eucalyptus globulus* wood disc analysis

Project 1: Research new shorter rotation silvicultural models for pine plantations and longer rotations for blue gum plantations. Sub-report title: Effect of initial stocking on disc basic density and NIR-predicted breast height strips in 24 *E. globulus* trees sampled across four spacing treatments.

Prepared by

Braden Jenkin and Geoff Downes

Summary

Wood moisture content, density (green and basic), expected pulp yield and cellulose content were determined for a sample of 24 *Eucalyptus globulus* trees fallen at age 15 years in a trial located in western Victoria. The trial explored the impact of three initial planting densities (833, 1,000 and 1,250 stems/ha) and with a sub-treatment of 1,250 stems/ha initial stocking thinned to waste to 833 stems/ha at age 3 years. Wood samples were recovered at 2% (P0), 10% (P1), 30% (P3), 50% (P5) and 70% (P7) of total tree height and at 1.3 m or breast height. It was found that wood moisture content on a green basis reduced with height in the tree stems. While green density was consistent with height, basic density was consistent to P1 and then increased with height in the trees stem. The impact of initial stocking treatment was considered and it was found that trees subject to a non-commercial thinning at age had a lower and statistically significant basic density. Near infrared analysis of breast height samples indicated that kraft pulp yield was consistent after a lower value at the stem pith but then increased from around 50% of the stem radius; that is the outer stem-wood had higher pulp yield.

Introduction

The properties of wood from Australia's natural forests have been a subject of interest (e.g. Baker, 1919; Baker & Smith, 1924; Boas, 1947). A number of more pivotal references have been prepared on eucalypts as a source of wood products (e.g. Hillis & Brown, 1984) while Bootle (1996) presents a comprehensive overview of the utilisation of wood in general. Wood consists of solid material (pulp fibres, lignin and extractives), moisture and air voids when 'dry' (Figure 94). The importance of each element is driven by the intended use of the wood grown. Sawn timber production makes use of wood as a whole and may seek to control wood moisture content, whereas paper makers target wood fibres used in paper making, and potentially utilise the energy in wood (made available as by-product of pulping and chemical recovery). Wood moisture content varies within trees and also will vary with time, handling and conditions (i.e. it is not constant). Wood moisture content can be defined as weight of water as a percentage of the green weight of wood or weight of water as a percentage of dry weight of wood. Wood basic density is the bone-dry weight of solid wood per green wood volume (Bootle, 1996, p.145). Basic density varies within trees (Washusen, 1998), between trees (Dean, *et al.,* 1990), with age (Whiteman, 1997) and growth rates and patterns (Downes et al., 1997; Downes et al., 2006). Basic density can be selected for and improved by tree breeding (Downes et al., 1997). This report addressed the research questions presented in Box 7.

Box 10: The following research questions were addressed by this analysis.
Research question 7: *What is the impact of initial stocking on the wood properties of plantation grown* E. globulus *trees?* Research question 8: *What is the radial variation in wood properties within individual plantation grown* E. globulus *trees?*

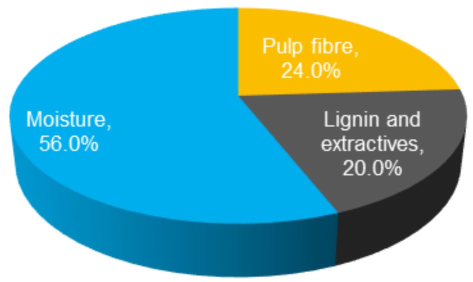

Figure 94: The composition of 8-year-old *E. globulus* wood (after Dean *et al.*, 1990, Figure 2).

Methods

Trial purposes and site

An Australian Bluegum Plantations (ABP) *Eucalyptus globulus* spacing trial was established in 2008 in the Wilderness plantation, located in western Victoria (38.00929oS 141.94084oE; Figure 95 and Figure 96) as part of Timbercorp Project number 146 (see Agars *et al*., 2008). The broad aim of the trial was to determine the optimal stocking to maximise site potential (volume) as well as to maximise harvest efficiency at final harvest. The trial research questions were as follows.

5. *What is the optimal stocking at the chosen sites that will maximise yield and piece size?*
6. *Can non-commercial thinning be used to optimise yield and piece size and therefore maximise harvest efficiency?*
7. *What is the cost: benefit (volume vs improved access) of manipulating row spacing (4.0 vs 4.5 m)?*
8. *Is non-commercial thinning a valuable means of genetic selection?*

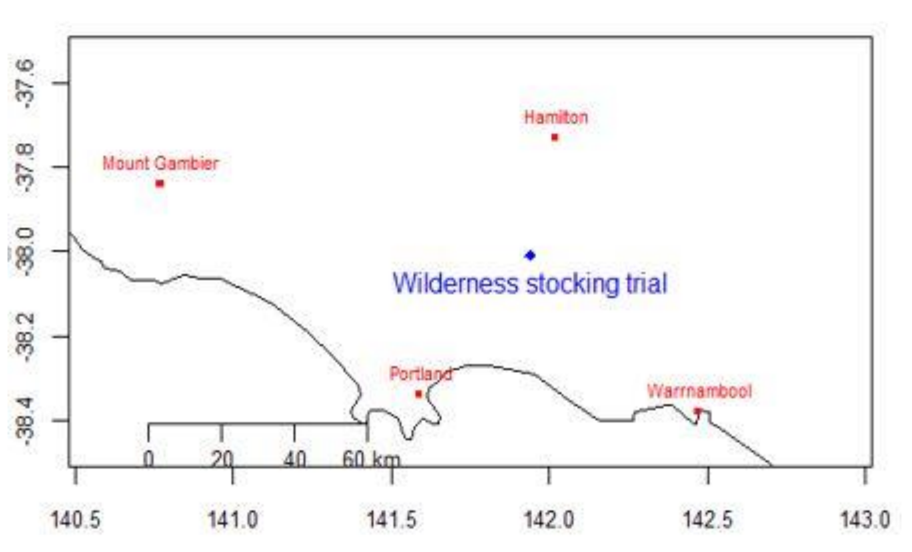

Figure 95: The location of the trial site in western Victoria.

Figure 96: An aerial view of the site with the trial indicated by the red dotted line.

The trial consists of three initial stocking treatments (1,250, 1,000 and 833 stems/ha un-thinned) and 1,250 stems/ha thinned to waste to 833 stems/ha at around age 3 years as presented in Figure 97. These stocking treatments were applied in two row spacing treatments with 4.0 or 4.5 m between rows. The plots are 35 metres long and eight internal rows wide (nine measured rows including the peg line). Row spacing and hectares for each of these plots are as follows.

- <u>4.5 m row spacing</u>: 9 rows (40.5 m wide x 35 m long) = 0.14 ha.

- 4.0 m row spacing: 9 rows (36.0 m wide x 35 m long) = 0.13 ha.

The effect of the between row spacing differences was that within the rows, trees were slightly closer together with the wider spacing for the same stocking. The resulting stand was age 15 years at the time of this assessment with no understorey and very limited grass (Figure 98). As part of trial management, ABP has conducted an annual routine inventory and the data for the 2023 inventory was provided.

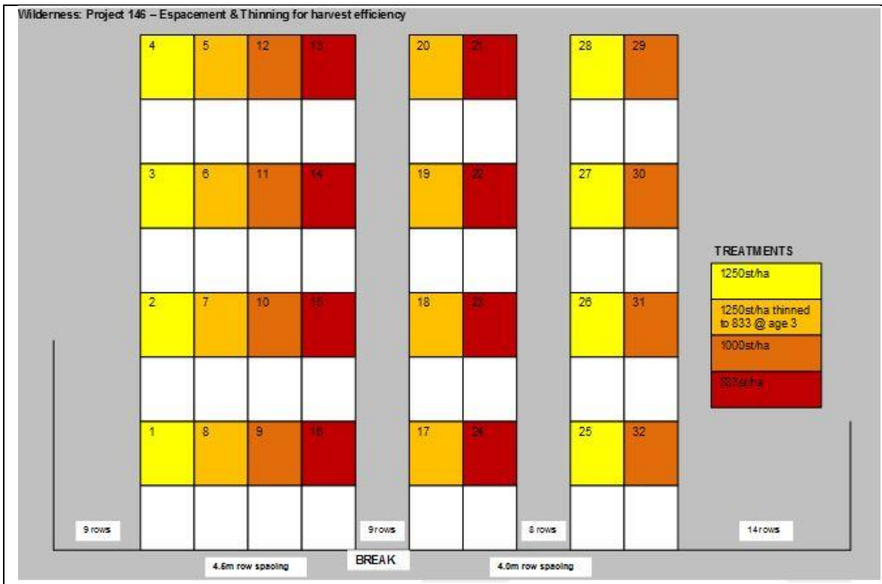

Figure 97: The trial layout and treatments.

Figure 98: The stand in April 2023 with no understorey. (Sylva Systems©.)

Inventory data

The ABP routine inventory data for 2023 was entered into the Sylva woodlot assessment tool. This tool was developed to assist with inventory of small-scale and odd shaped woodlots. This model generates a range of stand metrics and was applied to individual treatments in a trial. This tool presents the data as a plot map allowing navigation and to find specific individual trees. The mean diameter at breast height over bark (DBHOB) for each treatment per replicate was calculated, as was the standard deviation around each mean.

Tree selection and falling

The assessment objective was to fell 24 sample trees from a possible 36 treatments eight replicates of the four treatments limited by time. Candidate sample trees were selected to reflect trees that had potential for beyond pulpwood products based on stem size. Sample trees were selected within each treatment based on tree DBHOB data for each plot; select as close as possible to the mean tree, the tree with the closest DBHOB less one standard deviation or the tree with the closest DBHOB plus one standard deviation. Each candidate sample tree was located in the field, inspected and suitability determined based on form. A field datasheet was prepared for each sample tree.

Sample collection

Sample trees were felled by a skilled faller using a chainsaw with wedges to assist in directional falling between residual trees. Felled stems were de-limbed for ease of access. Total stem height was measured and adjusted to take account of stump height. North and south facing aspects were marked on the stem. Sections of the stem relating to 2% (P0), 10% (P1), 30% (P3), 50% (P5) and 70% (P7) of total tree height were calculated and marked on the stem with tree marking paint along with tree breast height (at 1.3 m). A sample disc of 3 to 6 cm thickness was recovered at each sample point (Figure 99 and Figure 100) and stored in hessian bags.

Figure 99: Recovering a sample disc from a tree stem. (Sylva Systems©.)

Figure 100: The sample discs sitting proud of the stem at the sampling point. (Sylva Systems©.)

Sample preparation

Sample preparation was undertaken onsite and mostly on the day of sample collection to minimise moist losses. Each disc was cut in half using a compound mitre radial-arm saw (Figure 101) and labelled. The cut was aligned with IML PD series power drills Resi sample drill holes and to cut through the centre of the disc. The disc centre was defined as the pith with the first growth. The first disc-half was to be used to determine wood properties (green moisture content, green density and basic density). The second disc had a 1.5 cm wide strip recovered from bark to bark as a single radial sample through the centre of the disc. The disc for density analysis was passed to the field laboratory and the near infrared (NIR) sample was labelled and bagged to maintain moisture content (Figure 102).

Figure 101: A compound mitre radial arm saw used to cut discs in half and to recover NIR analysis sample strips. (Sylva Systems©.)

Figure 102: A set of sample half-discs from four trees and bagged NIR samples (one tree per bag). (Sylva Systems©.)

Wood moisture content and density half disc samples

Wood moisture content can be defined as the weight of water as a percentage of green weight of wood (Equation 16) or weight of water as a percentage of dry weight of wood (Equation 17). Determination of wood moisture content is set by ISO 3130:1975 (Wood – Determination of moisture content for physical and mechanical tests).

Equation 16: Wood moisture content on a green wood basis.	$MC_{GREEN}\,\% = \frac{(M_{WATER})}{(M_{OVEN\ DRY\ WOOD} + M_{WATER})}\ X\ 100$
MC GREEN	Moisture content on a green basis (%).
M WATER	The mass of water (g).
M BONE DRY WOOD	Mass of oven dry wood (g)

Equation 17: Wood moisture content on a bone-dry wood basis.	$MC_{DRY\ BASIS}\,\% = \frac{(M_{WATER})}{(M_{OVEN\ DRY\ WOOD})}\ X\ 100$
MC DRY BASIS %	Moisture content on a dry basis (%).
M WATER	The mass of water (g).
M OVEN DRY WOOD	Mass of oven dry wood (g).

The determination of green density is by Equation 18. The determination of basic density is set by AS/NZS 1080.3:2000 (Timber – Methods of test: Method 3: density); see Equation 19 (Bootle, 1996, p.145). Green volume can be estimated by measuring the dimension of a wood sample, by volume displacement or by application of Archimedes' principles; this assessment made use of Archimedes' principles.

Equation 18: Wood green density calculation.	$$D_{GREEN} = \frac{M_{GREEN}}{V_{GREEN\ VOLUME}}$$
D GREEN	Wood green density in kilograms per green cubic metre.
M OVEN DRY WOOD	Mass oven dry wood in kilograms.
V GREEN **WOOD**	Wood green volume in cubic metres.

Equation 19: Wood basic density calculation.	$$BD = \frac{(M_{oven\ dry\ wood})}{(V_{green\ wood})}$$
BD	Basic density in kilograms per green cubic metre.
M OVEN DRY WOOD	Mass oven dry wood in kilograms.
V GREEM WOOD	Volume green wood in cubic metres.

A field laboratory was established in the back of a work vehicle (Figure 103). The bark was removed from each half-disc and weighed using as set of electronic scales (maximum weight capacity of 40 kg). Green volume was measured using Archimedes Principle (physical law of buoyancy) and water displacement. A five-litre measuring jug of water was placed on a set of scales and the scales tared. The disc was suspended in the water jug by a screw driver inserted in the disc and clamped into a series of builder's clamps. The disc was submerged to just being covered with minimal length of the screw driver shaft in the water (Figure 103). The weight of the arrangement was recorded and based on 1 mL of water equals 1 g, the weight in grams was converted to millilitres (mL). The samples were then re-bagged in the hessian bags and stored safely. The samples were air-dried, prior to oven drying to a constant weight at 103ºC to generate oven dry weights. For each sample, green density and moisture content at time of harvest was calculated, as was basic density.

Figure 103: The scale and measuring jug setup with the overhead frame from which the samples were suspended. (Forest Quality©.)

Near infrared analysis of wood strips

The NIR samples were packaged in sealed plastic bags in cardboard boxes and posted to Tasmania. The breast height sample (bark-to-bark strip) was subject to NIR analyses using a radial scanning method (see Downes, et al. 2010; Downes, *et al.,* 2012; Downes, *et al*., 2014). Full diameter strips were air-dried in aluminium U-channel sections to minimise distortion during drying. Once air-dried the bark-to-bark radial longitudinal surface was trimmed using a radial-arm saw to provide a clean-cut flat surface. The NIR spectra were collected every millimetre from bark-to-bark. Predictions of sample wood properties (see Box 11) were made using existing calibrations developed for plantation grown *E. globulus* and *E. nitens* in Tasmania.

Box 11: The wood properties determined by NIR analysis.

- Kraft pulp yield
- Diglyme cellulose content
- SilviScan-derived
  - air-dry density
  - Microfibril angle
  - dynamic MoE

Results and outcomes

The data set

The data set from the wood discs was pooled based on position in the tree and as a single dataset. The consistency of the data set was checked. Figure 104 presents the individual data on a green volume for green weight basis and the dataset shows no anomalies. Figure 105 presents the individual data on a green weight for bone dry weight and the dataset shows no anomalies.

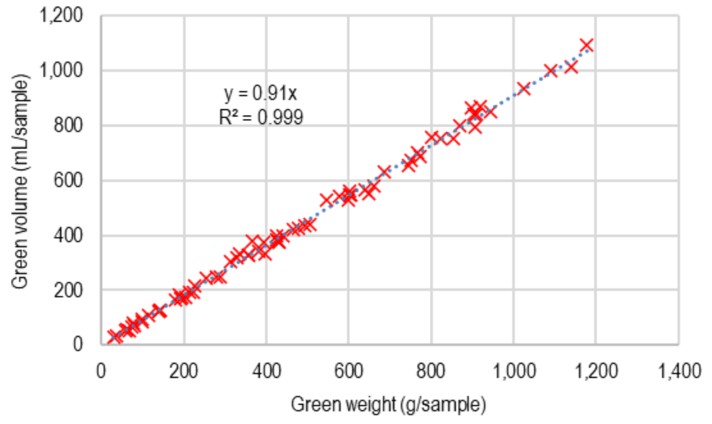

Figure 104: Individual sample green weight for volume as a check of data consistency.

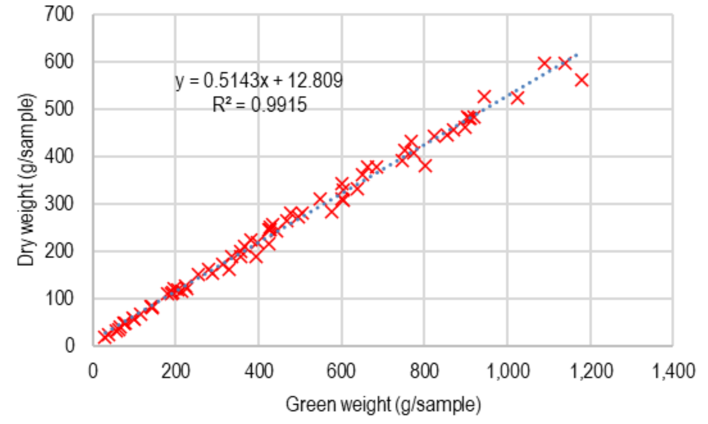

Figure 105: Individual sample green for bone dry weight as a check of data consistency.

Wood moisture content

The sample data was used to calculate wood green moisture content based on Equation 16. The results of the average wood moisture content for the pooled sample set and based on position in the tree is presented in Figure 110. A range from 39.2% to 47.1% to is evident. The data indicates a relatively consistent wood moisture up to P1 (sample point at 10% of tree total height) after which wood green moisture content decreases with increasing height in the tree. These results are consistent with Lausberg *et al*. (1995, Figure 4) for *E. nitens* grown in New Zealand.

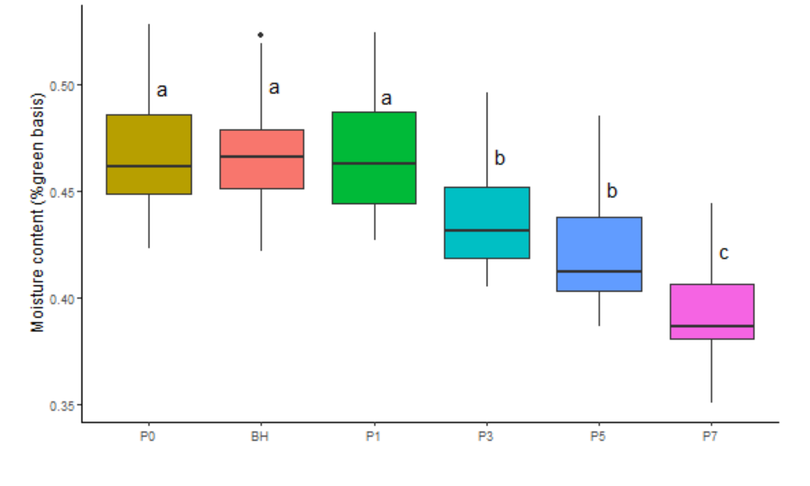

Figure 106: The mean wood green moisture content for the dataset pool based on position in the tree.

Wood density

The sample data was used to calculate wood green density based on Equation 18 and the results are presented in Figure 107. The data indicates a consistent wood green density with the average density ranging from 1,097 to 1,130 kg/m^3. The sample data was used to calculate wood basic density based on Equation 19 and the results are presented in Figure 108. The data indicates a relatively constant wood basic density to around 10% tree height, averaging around 580 to 600 kg/m^3 after which it increases with to around 650 to 670 kg/m^3. This variation is greater than the variation for green density due to the differences in wood moisture content (see Figure 106). This outcome is broadly consistent with Lausberg *et al.* (1995, Figure 6) for wood properties of *E. nitens* grown in New Zealand.

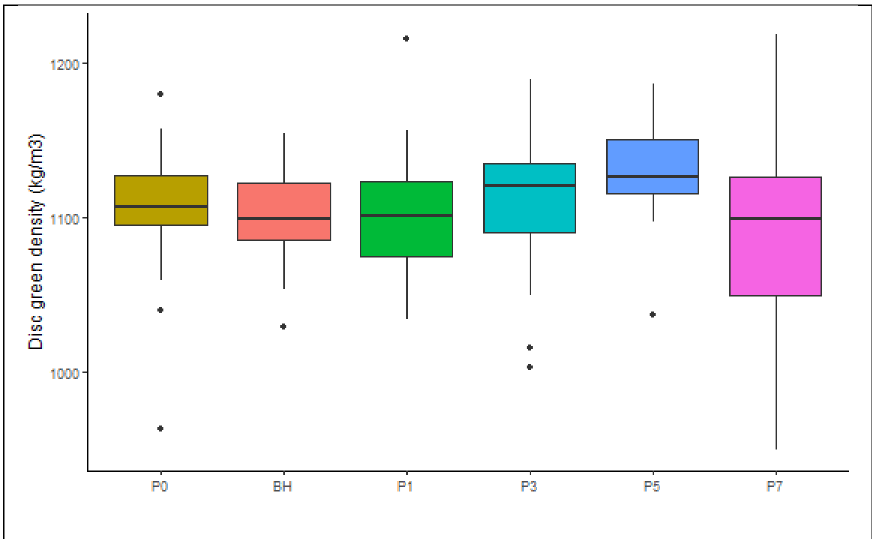

Figure 107: Wood green density +/- 1 SD for the pooled dataset.

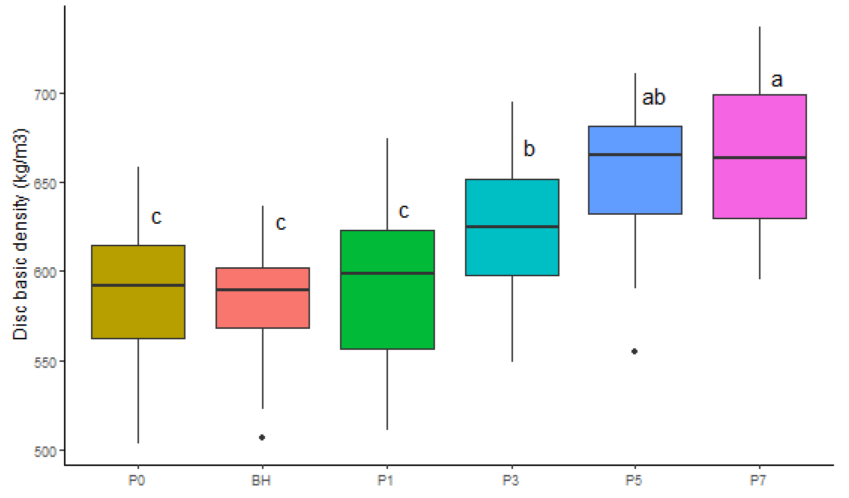

Figure 108: Wood basic density +/- 1 SD for the pooled dataset.

The relationship between basic density and moisture content

The outcome of the full dataset moisture content for wood basic density is presented in Figure 109, with a good relationship between these two attributes (R^2 = 75.2%). The height position average moisture content for height position wood basic density is presented in Figure 110. There is a general decrease in wood moisture content with increasing basic density. This suggests more solid wood with reduced voids holding moisture.

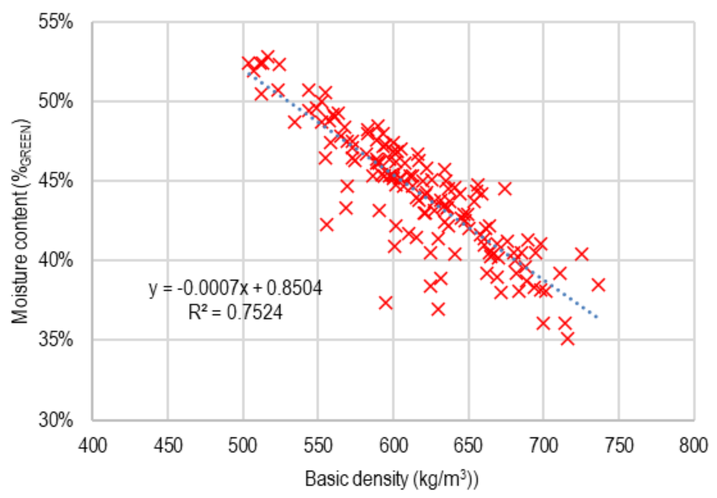

Figure 109: Dataset variation in wood moisture content for basic density.

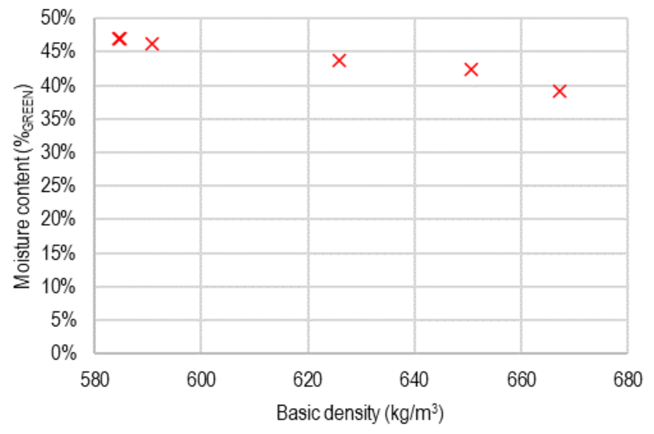

Figure 110: Sample mean moisture content for mean basic density pooled by position in the stem.

Breast height disc basic density and initial stocking

The breast height disc basic density was considered in regard to the four stocking treatments and the outcomes are presented in Figure 111. The analysis indicates that there was no interaction between row spacing and stocking, and density (p=0.76), no significant effect of row spacing and density (p=0.60) and no significant effect of stocking (p=0.65). The pattern presented in Figure 111a indicates that establishment at 1,250 stems/ha followed by a thinning to 833 stems/ha tended to have the lowest disc basic density. The data presented in Figure 111b indicates that the trees from within the rows with wider spacing had a lower average basic density, albeit non-significantly.

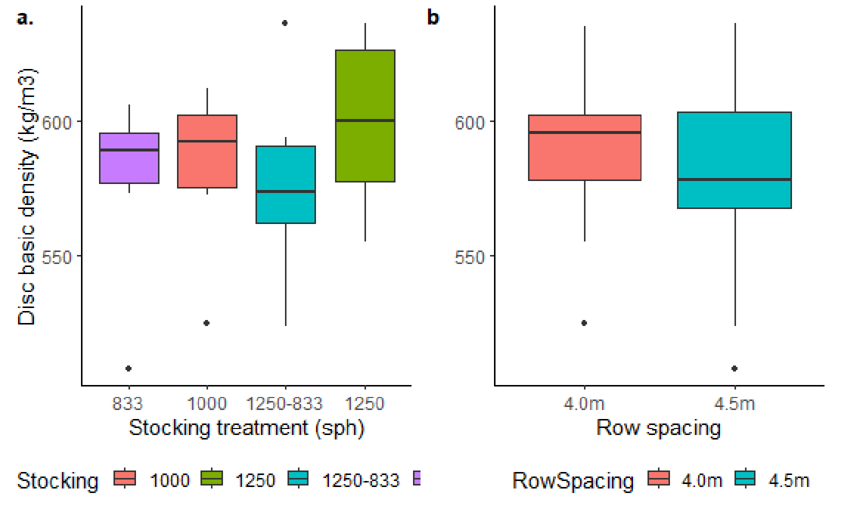

Figure 111: Results of the analysis of disc basic density by initial stocking treatment.

Basic density variation with tree height

Figure 112 presents the disc basic density data pooled by the different height sample points for each stocking treatment. This analysis found that there is a significant effect of height on basic density with values at or above 10% (P1) height significantly greater than below this point. This is generally consistent with the conical symmetry pattern noted in Downes *et al*. (1997, p.21). Trees planted at 1,250 stems/ha followed by a thinning to 833 stems/ha tended to have the lowest disc basic density at each height (Figure 112). Trees planted at 833 stems/ha have the lowest basic density for the lower sections and with height, the density relative to the other stockings increases.

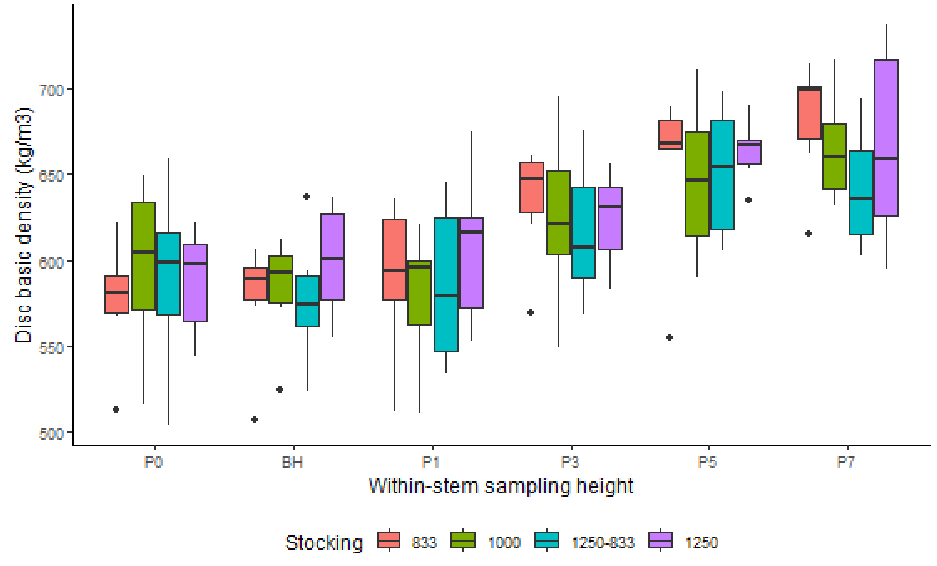

Figure 112: Results of the analysis of disc basic density by initial stocking treatment at each sampling height.

Breast height scanning NIR analyses

The main value of the NIR analysis applied is to demonstrate the radial patterns of variation in wood chemistry and consequently the physiological effects associated with tree age, site and silviculture on mean tree properties. Table 34 compares the treatments with respect to the mean predicted Kraft pulp yield (KPY) and cellulose content based on the mean values from each radial strip. There were no significant stocking effects on these properties, or any interaction with, or effect of, row spacing.

Table 34 Treatment means of NIR predicted wood properties from breast height bark-to-bark radial strips

Stocking	Predicted kraft pulp yield	Kraft pulp yield	Predicted cellulose content	Cellulose
(stems/ha)	(%)	(%)	(%)	(%)
1,000	49.30	0.53	39.08	0.48
1,250	49.44	0.47	39.20	0.52
1,250 to 833	50.76	0.39	40.51	0.40
833	49.10	0.89	38.83	0.95

Figure 113a presents the kraft pulp yield as a function of relative radial position. As has been found in other studies (e.g. Downes, Harwood *et al*., 2012) pulp yield tends to remain relatively constant over the first half of the radius (possibly reflecting wood produced within the live crown), before increasing towards the bark. Interestingly the decline in kraft pulp yield from 85% to 100% of radius is similar to the decline in density observed in the Resi traces (see Appendix 9: *Eucalyptus globulus* trial; DBHOB and basic density assessment). Figure 113b presents the same data but shows the expected kraft pulp yield of the disc if the tree had been sampled at different diameters, measured as radial percentage distance from the pith. The increasing benefit of tree age on average kraft pulp yield is evident. No significant differences between treatments were evident, however the 1,250 stems/ha stocking treatment thinned to 833 stems/ha at age 3 years was consistently higher throughout the rotation. It is hard to explain this, especially given the lack of similar effect in the Resi density trends (see Appendix 9: *Eucalyptus globulus* trial; DBHOB and basic density assessment). If the effect is real, it may be indicative of some effect on green crown depth and the distance from breast height to the green crown impacting on cambial chemistry. Analysis of the samples taken at other heights in the tree may inform the consistency of the patterns.

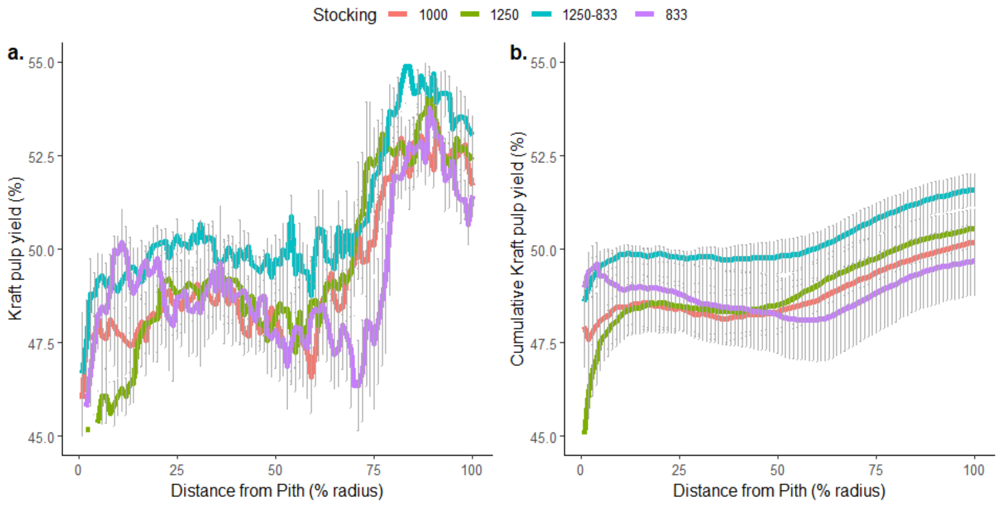

Figure 113. The opposing radii in each strip were separated, converted to a percentage scale and a mean radial transect determined. These in turn were added together within the spacing treatments (n=6) to produce a treatment mean transect. (a) shows the radial pattern of variation in kraft pulp yield and (b) shows the same data expressed as a cumulative sum. That is, the kraft pulp yield value associated with each radial percentage indicates the expected mean value of the disc if sampled when the tree was that diameter. Vertical bars represent +/- 1 standard error.

Effects on dimensional stability

Previous studied have explored the application of radial NIR scanning to detect tension wood in *E. globulus* as an indicator of non-recoverable collapse (e.g. Wentzel-Vietheer, *et* *al.,* 2013; Downes, *et al.,* 2014). Figure 114 presents the alignment of the NIR predicted cellulose, SilviScan modulus of elasticity (ssMoE) and SilviScan micro fibril angle (ssMFA) values in a single sample with the image of the dried sample which demonstrated the greatest degree of collapse among all 24 samples. Compared with the reports cited above, there were no indications of significant tension wood presence (i.e. non-recoverable collapse) which would be indicated at points where cellulose content exceeded 50% and ssMoE exceeded 25 GPa. It should be noted that NIR predictions are based on statistically calibrated models developed from spectra collected from a set of samples covering a range of organic chemistries. The extremely high MFA values and low MoE values suggest that some portions of these samples have chemistries not well represented by the calibration data set. If the technique is pursued, additional calibration data should be sought to improve the calibration models.

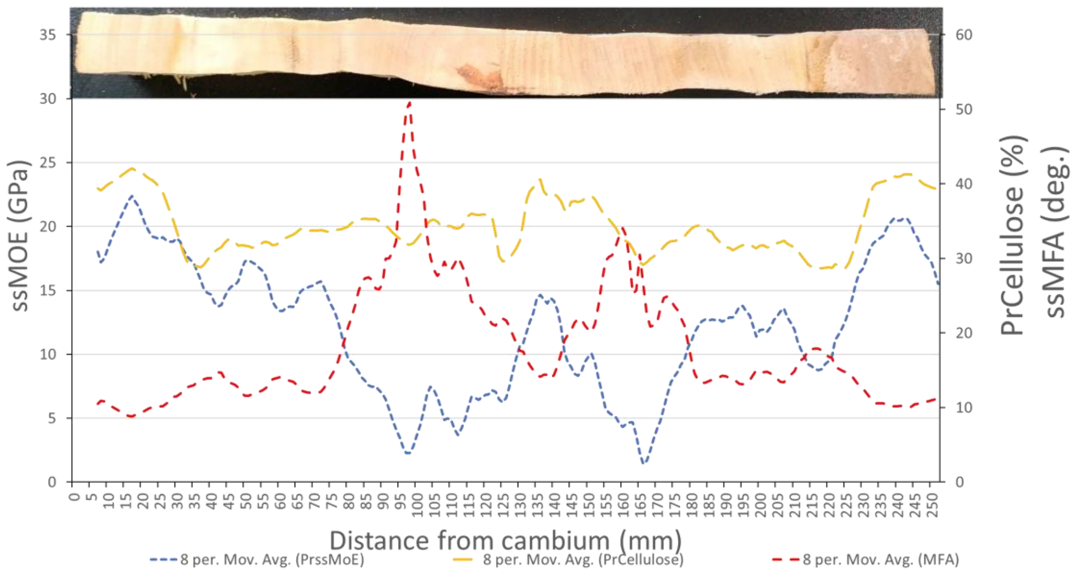

Figure 114. A single bark-to-bark strip is shown together with the variation in NIR-predicted properties obtained from it. This strip indicated the most collapse and distortion of any of the 24 breast height strips.

Application of basic density and wood moisture content

Conversion factors between cubic metres and green metric tonnes are important to resource manager and modelling of financial outcomes. Practically, trees are grown in cubic metres which can be estimated by inventory and are harvested, transported and sold in green metric tonnes. The quality of wood is estimated based on weigh bridge determined weight at the point of sale. The data for wood basic density and moisture content was combined to determine the conversion factors for the wood at the different sampling positions within a tree stem and the outcomes are presented in Figure 115. These factors ranged from 1.097 to 1.130 GMT/m^3 hence there is a need for a whole stem weighted by volume conversion factor.

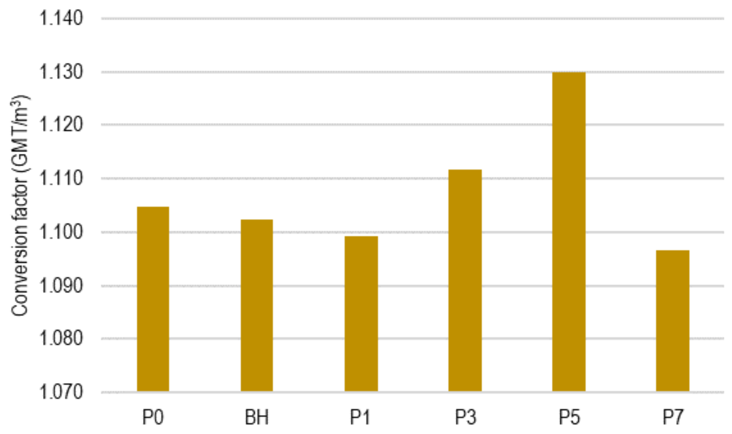

Figure 115: The calculated mean conversion factors for each sampling height for the pooled dataset.

Conclusions

The variation noted between initial stocking treatments has indicated the following.

- No effect of spacing treatment was observed on disc basic density.
- Disc basic density was significantly affected by within-tree height, with discs above 30% total tree height increasing in density compared to those below this height
- Moisture content was inversely related to basic density

Overall and based on the NIR analysis, spacing treatments had no observable effect on breast height kraft pulp yield or cellulose content. The kraft pulp yield and cellulose content increased markedly towards the bark from lower values close to the pith. This would reflect differences in the wood laid down with radial growth. There was no real evidence of a propensity for non-recoverable collapse observed in any of the 24 trees. The collapse evident should be recoverable by steam treatments. This suggests a broader potential range of uses for the wood from *E. globulus* grown under a range of initial stocking regimes.

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Appendix 9: *Eucalyptus globulus* trial; DBHOB and basic density assessment

Project 1: Research new shorter rotation silvicultural models for pine plantations and longer rotations for blue gum plantations. Sub-report title: Effect of spacing on Resi-predicted breast height diameter and basic density in *E. globulus*.

Prepared by

Braden Jenkin and Geoff Downes

Summary

A 15-year-old *E. globulus* initial spacing and thinning trial was assessed using a IML PD series power drill (Resi) technology. Tree wood basic density, diameter at breast height (DBH at 1.3 m height, over and under-bark; DBHOB and DBHUB) and bark thickness was determined as was treatment standing volume and treatment mean annual increment (MAI). There was no significant effect of row spacing on DBH, bark thickness or MAI. There were small but significant effects of row spacing on basic density. However, the row spacing treatment was confounded with spatial position within the site and the effect may be due to the greater exposure of the 4.0 m spacing to the prevailing wind interacting with site geography. There was a significant effect of stocking treatment on BHD, bark thickness but not MAI, with the lower stocking (833 stems/ha) resulting in significantly greater DBHOB and DBHUB than the other treatments. The higher stocking (1,250 stems/ha) also had significantly smaller diameter trees. No effect of stocking on basic density was observed. Radial patterns of Resi-derived basic density were very consistent between stocking treatments with typically a decrease in density from 20% to 50% of the radius, followed by a marked increase in density from 550 kg/m^3 at 50% radius to between 580 and 600 kg/m^3 at around 80% of radius. The lower-stocked 833 stems/ha treatment tended to have lower density between 75% and 100% of radius than other treatments. Combined with the greater rate of growth of trees in this treatment this may tend to make the effect of stocking on average basic density more significant over time.

Introduction

Estimation of diameter at breast height (DBHOB) is a simple and easily captured stem attribute (see Carron, 1968; Philips, 1994). A conventional calibrated diameter tape or more recently, the IML PD series power drill (Resi) technology can be used. While the Resi is a marginally slower process per tree (under favourable conditions, around 600 to 800 stems per eight-hour day can be assessed) the data captured in regard to stem wood properties is important. Wood properties are an important attribute. For example, wood basic density will influence wood properties relating to pulp quality (Bootle, 1996, p.135). An Australian Bluegum Plantation's (ABP) *Eucalyptus globulus* initial stocking and thinning trial was established in 2008 and was made available for assessment as part of a PIRSA project seeking to explore and develop alternative silvicultural regimes. This report explores any relationships between initial stand stocking with and with-out a thinning operation on tree DBHOB growth, and radial and disc average wood basic density.

Materials and Methods

The site and trial layout

The trial site is located in the Wilderness plantation near Macarthur in western Victoria (38.00929ºS 141.94084ºE; see Figure 116). The site was generally flat with no undergrowth (Figure 117). The trial was set-out in a systematic plot arrangement (Figure 118) (see Agars, *et al*., 2008). There was a slight ridge running from plot 9 -10 heading southeast through plots 19 and into plots 27-28. Consequently, the land sloped up from plot 32 towards plots 18 -19 then sloping down towards plot 12. As the prevailing winds tended from the south-west, the 4.0 m spacing treatment might be expected to be more exposed than the 4.5 m spacing. In essence these treatments are confounded with geography and differences may reflect this attribute, rather than the treatments.

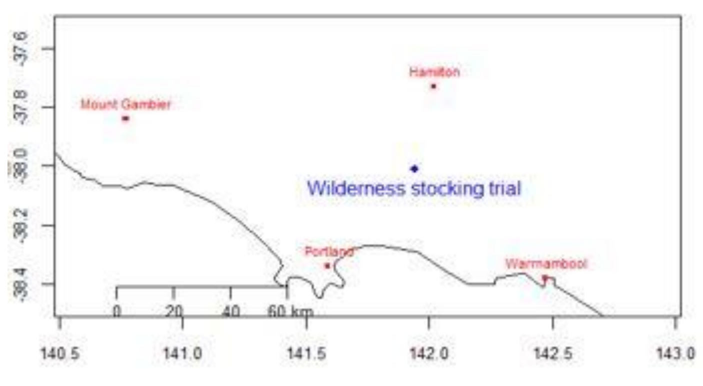

Figure 116: The location of the trial site in western Victoria.

Figure 117: The stand in April, 2023. The site was generally flat with no undergrowth. (Sylva Systems©.)

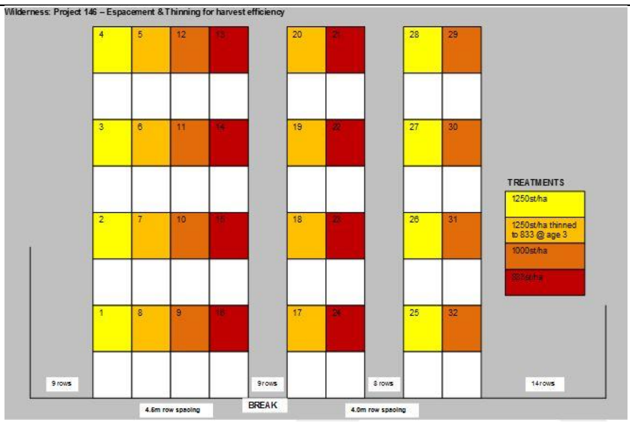

Figure 118: Site plots layout and treatments.

The trial treatments

The trial consists of three initial stocking un-thinned treatments (1,250, 1,000 and 833 stems/ha), and 1,250 stems/ha initial stocking thinned to 833 stems/ha around age 3 years as presented in Figure 118. The thinning was to waste by pushing out the selected trees. These treatments were applied in two row spacing treatments with 4.0 and 4.5 m between rows. All plots are 35 metres long and 8 internal rows wide (9 measured rows including peg line). Row spacing and hectares for each of these plots is as follows.

- <u>4.5 m row spacing</u>: 9 rows (40.5 m wide x 35 m long) = 0.14 ha.
- <u>4.0 m row spacing</u>: 9 rows (36.0 m wide x 35 m long) = 0.13 ha.

With the spacing within the rows, the trees were slightly closer together with the wider spacing. Essentially each column in Figure 118 represents a replicate, with plots 1, 8, 9 and 16 being the 4.5 m row spacing and 17, 24, 25, and 32 the 4 .0 m row spacing treatments.

Res-trace collection

Resi traces were collected from every tree in each plot assessed; this excluded plot 4, 5, 12, 13, 20 and 21 due to time constraints (Figure 119). The TreeID field in the Resi sampling was used to identify trees by plot number and tree number within the plot. This allows cross - referencing to other data captured in regard to each tree. Each Resi trace was taken at around breast height and from the north - south aspect, except where stem features (e.g. knots and stem defects) required changes to the sample point to be more likely clearwood. A total of 930 Resi traces were captured, downloaded, and processed through the web platform located at https://forestquality.shinyapps.io/FQResi. Each trace was reviewed to determine that it had been processed correctly and manually corrected as required. For example, the pith location (centre of a stem section) was manually checked and adjusted as necessary. Each trace consists of two radii (entry and exit) corresponding approximately to the north and south aspects. Each radius was divided into radial intervals representing 5% increments from pith to bark, resulting in 40 intervals from each Resi trace (20 from the entry radius and 20 from the exit radius) (see Figure 120). All analyses and reporting were undertaken in R (Team, 2020a) using RMarkdown (Allaire *et al.*, 2020) within the RStudio environment (Team, 2020b). Summary metrics were collected from each trace.

Figure 119: Collecting a Resi-trace at breast height (1.3 m above the ground). (Sylva Systems©.)

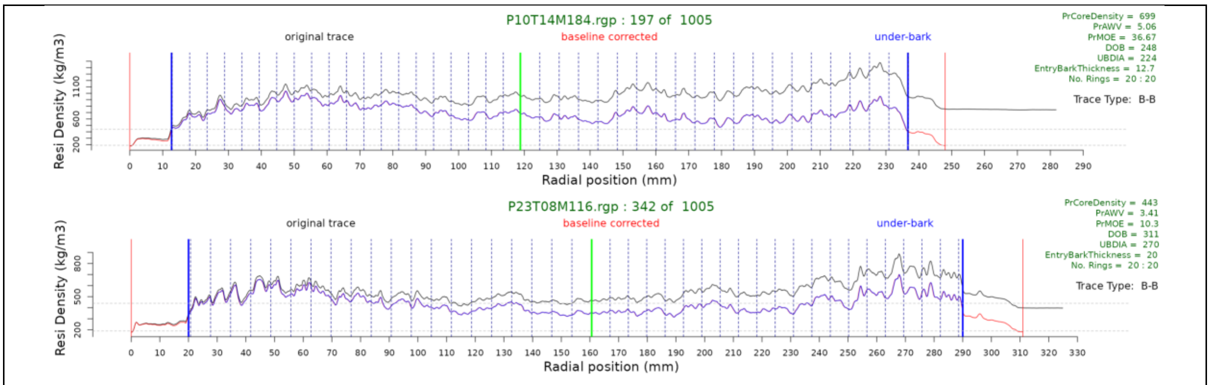

Figure 120: Two examples of typical Resi traces are presented, where the Resi needle has entered from the left (north) and exited on the right (south).

Results

Effects on tree growth and potential yield

Table 35 summarises the row spacing and stocking means of the Resi-derived metrics; bark thickness is the Resi determined thickness of the bark, core density is the density of the radial section (e.g. a strip), disc density is the calculated density of the disc based on geometry and the radial density variation, mean annual increment over (MAI.ob) and under-bark (MAI.ub). Using plot mean values, there is no significant interaction effect of stocking and row spacing on DBHOB. There is a significant stocking effect with the 833 stems/ha treatment having larger diameters than other stocking treatments (Figure 121a). The 1,000 and 1,250 thinned to 833 stems/ha treatments were not significantly different from each other, while the 1,250 stems/ha treatment was significantly smaller than all other treatments. The Resi trace allows the bark and wood to be distinguished, allowing a measure of under-bark as well as over-bark diameter. There was no significant interaction effect of stocking and row spacing on DBHUB (Figure 121b). A highly significant effect of stocking on DBHUB was evident with the 833 stems/ha treatment significantly larger than all other treatments. Like DBHOB the 1,000 and 1,250 thinned to 833 stems/ha treatments were not significantly different from each other, while the 1,250 stems/ha treatment was significantly smaller than all the others.

Table 35: A summary of the attribute means for each treatment (1,250-833 is the 1,250 initial stocking thinned to 833 stems/ha).

Row spacing	Stocking	DBHOB	DBHUB	Bark thickness	Core density	Disc density	Disc area	MAI.ob	MAI.ub
(m)	(stems/ha)	(mm)	(mm)	(mm)	(kg/m^3)	(kg/m^3)	(m^2)	(m^3/ha/y)	(m^3/ha/y)
4.5m	1,250	204	177	11.8	553	559	0.0255	21.6	19.05
4.5m	1,250-833	233	204	12.8	558	565	0.0336	24.1	21.15
4.5m	1,000	236	207	12.7	561	566	0.0350	26.9	23.6
4.5	833	255	222	14.3	564	567	0.0402	21.5	18.79
4.0	1,250-833	225	197	12.5	568	575	0.0312	26.8	23.68
4	833	248	216	14.2	558	563	0.0381	26.6	23.26
4	1,250	209	182	11.4	576	585	0.0272	26.9	23.72
4	1,000	230	200	13.2	569	576	0.0328	24.3	21.41

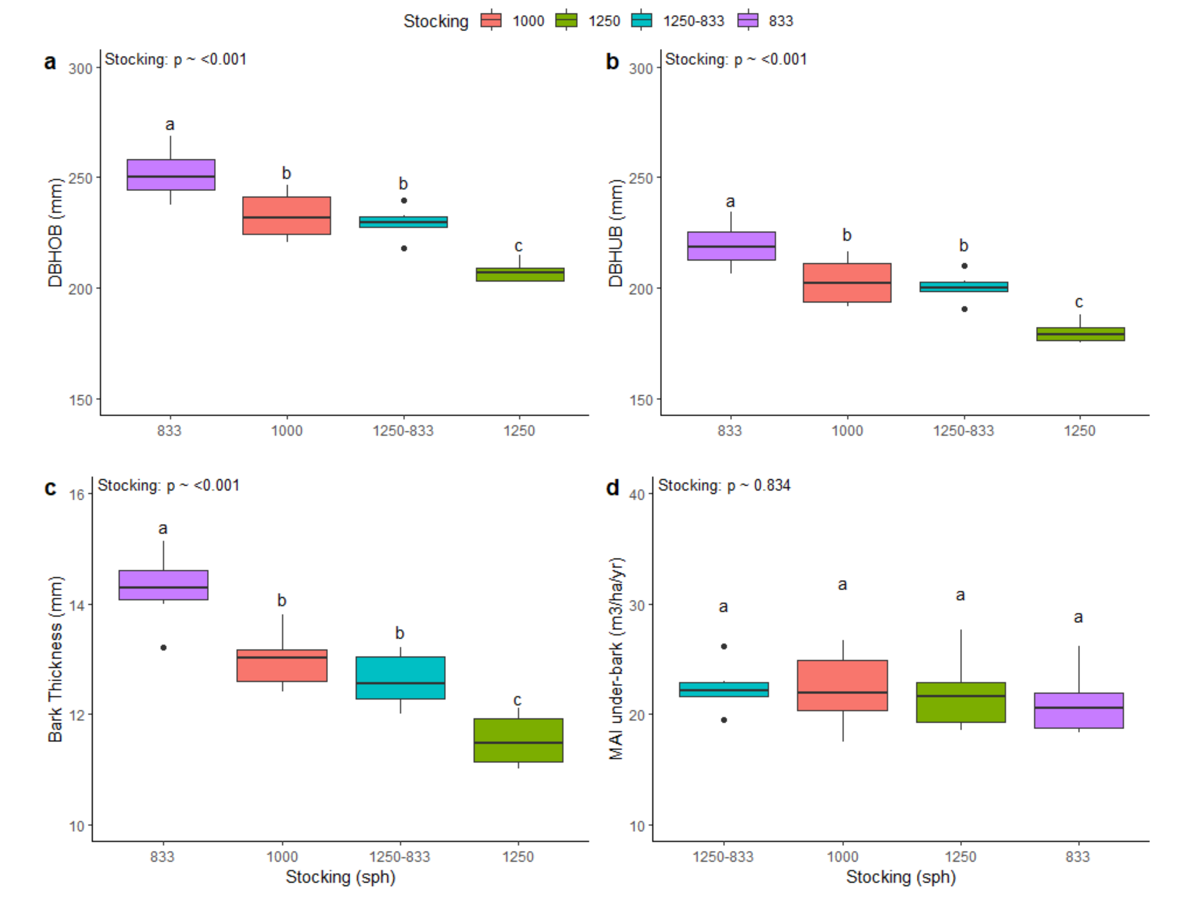

Figure 121: Effect of treatments on Resi-derived tree growth metrics and stand attributes.

Bark thickness

Figure 121c presents information on bark thickness. Bark thickness can be derived from the Resi trace due to its (usually) lower density than wood, but also due to the presence of the cambium layer between the wood and wood components, which is typically lower in density. Only the entry bark thickness was used as exit bark thickness is somewhat biased by the definition of when the Resi trace is flat enough and also flaking bark effects on the exit side. This often causes exit bark thickness to be over-estimated. While there was no significant interaction effect of stocking and row spacing on bark thickness, there was a highly significant effect of stocking on bark thickness. The bark of the 833 stems/ha treatment was significantly thicker than all other treatments. The 1,000 and 1,250 thinned to 833 stems/ha treatments were not significantly different from each other, while the 1,250 stems/ha treatment was significantly thinner than all other treatments Figure 121c).

Stand growth rates

Individual stem volumes of the sampled trees were calculated from the Resi-derived DBHOB by application of a derived one-way individual tree volume function (see Equation 15). The equation described a relationship developed based on the 24 trees destructively sampled on the site. These relationships are defined and described (see Appendix 7: *Eucalyptus globulus* stem analysis).

Equation 20: The polynomial one-way volume function format and constants.	$V_{BIOLOGICAL} = a.DBHOB^2 + b.DBHOB + c$
$V_{BIOLOGICAL}$	Stem biological volume (m^3/stem).
DBHOB	DBHOB (cm).
a	Constant a; 0.00008 OB & 0.00005 UB.
b	Constant b; 0.0091 OB & 0.00167 UB.
c	Constant c; -0.1859 OB & -0.2525 UB

Effects on wood density

In contrast to growth metrics, there was no significant effect of stocking on Resi-estimated wood density. There was no interaction effect of stocking and row spacing on radial density (Figure 122). However, there was a significant difference between the row spacing treatments with respect to basic density determined as the bark-to-bark average (Figure 122a) and as a cross-section (disc) average (Figure 122b). The 4.0 m spacing was significantly denser than 4.5 m spacing albeit the difference is 10 kg/m^3. There was a near significant interaction ($p = 0.094$) between stocking and row spacing on disc (area-weighted) density. In the experimental design, the row spacing treatment is confounded by geography, as the two treatments were not replicated but laid out side by side, hence site may possibly account for the density difference.

Comparison between Resi basic density and actual disc density

The predicted disc basic density for the breast-height, pre-felling Resi data for the 24 felled trees was compared with the actual breast height disc basic density (see Appendix 8: *Eucalyptus globulus* wood disc analysis) (Figure 123a) and found to correlate strongly (R^2 = 75%). Using the existing calibration for the Resi instrument (based on radiata pine samples), there was a slight tendency to under-estimate the actual values by approximately 16 kg/m^3. The bark-to-bark density (radial density) was slightly less well correlated as would be expected.

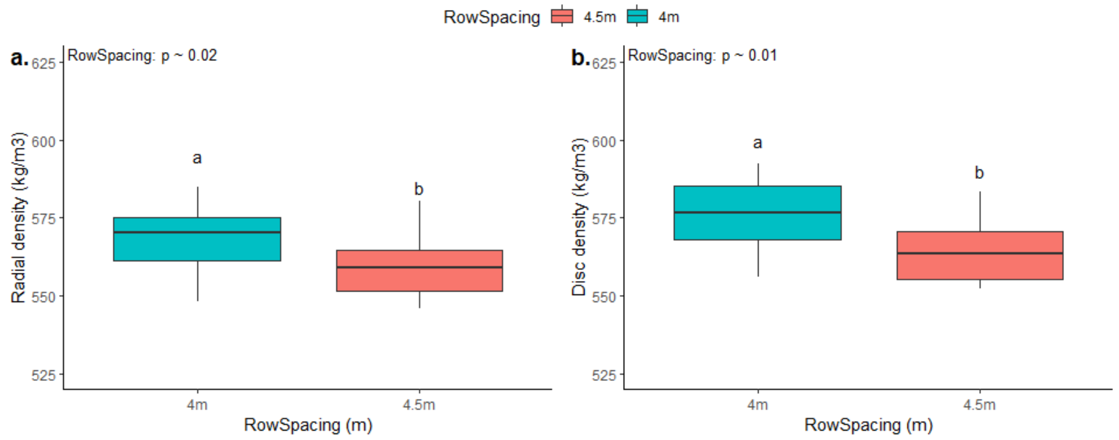

Figure 122: The effect of spacing treatments on Resi-derived metrics for radial and disc density.

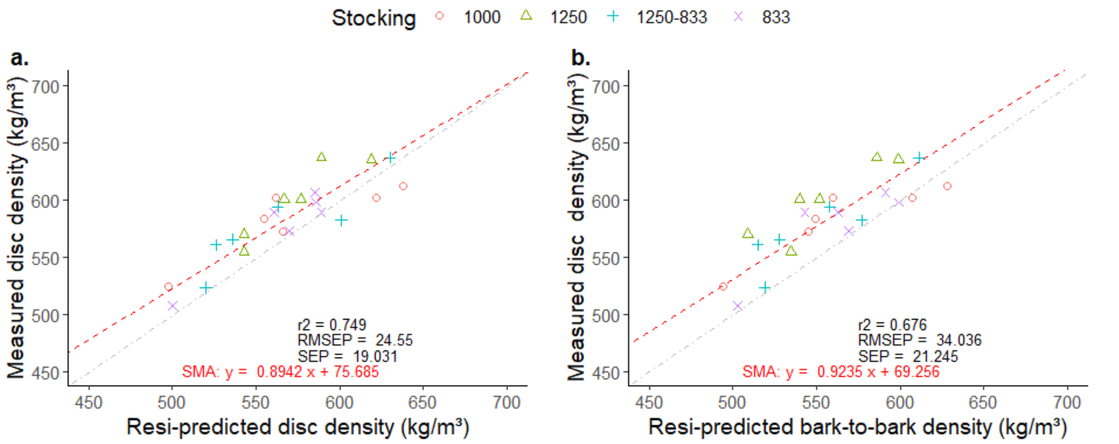

Figure 123: Resi predicted breast height disc basic density correlated with measured disc density in the 24 felled trees.

Radial variation patterns in density

Mean density measurement offers limited insights into the differences between treatments. It is well known that density varies radially (pith to bark) in stems with a tendency to increase towards the bark. This has implications for the utility of the resulting wood relative to a processor's needs. Examining the radial patterns offers insight into how density might be expected to be impacted into the future. Figure 124 presents the mean radial variation in Resi-derived basic density expressed as 5% interval means. By partitioning the radius into these percentage-based intervals, an equal number of data points is produced for each radius irrespective of the actual stem diameter. These can then be (a) converted into a mean radius for each tree in the plot (n varies between 30 and 60 trees) combining opposing radii, and then combined into a plot mean radius. As the trees are all growing under similar conditions, this approach assumes the radial growth pattern within each annual cycle is similar even if the actual growth increment (ring width) varies. From these 24 plot means, a stocking treatment mean (n=6) can be produced (Figure 124a) where the density is shown too initially increase then decrease before a marked increase to around interval 14 (70% radius) after which density plateaus. The radial patterns among the stocking treatments were markedly similar, which might be expected as all trees are experiencing similar growing conditions, and between stocking effects on density are not significant. It would be expected that the radial patterns would differ between different sites. Figure 124b expresses the same data but where the radial position of each interval is plotted on the x-axis. This illustrates the effect of the different growth rates among the stocking treatments. It is noted that the last increment has a markedly lower density, probably arising from an incomplete annual growth cycle. This may also be compounded by better growth over the last few seasons. As this markedly influences the fitted radial pattern of density variation, Figure 124c is the same data with the last 2 increments removed indicating a plateau density at around 580 to 600 kg/m^3.

Cumulative density pattern

An alternative approach to displaying the radial pattern of density growth is using a cumulative density measure (Figure 125). Here the density at any given radial position estimates the basic density of the stem cross section (disc) to that point, if the tree had been harvested at that time. It indicates that an earlier harvest would produce less dense wood reducing potential fibre yield on pulping, whereas a delayed harvest is likely to generate wood with a higher density, producing more green metric tonnes per cubic metre of stem volume.

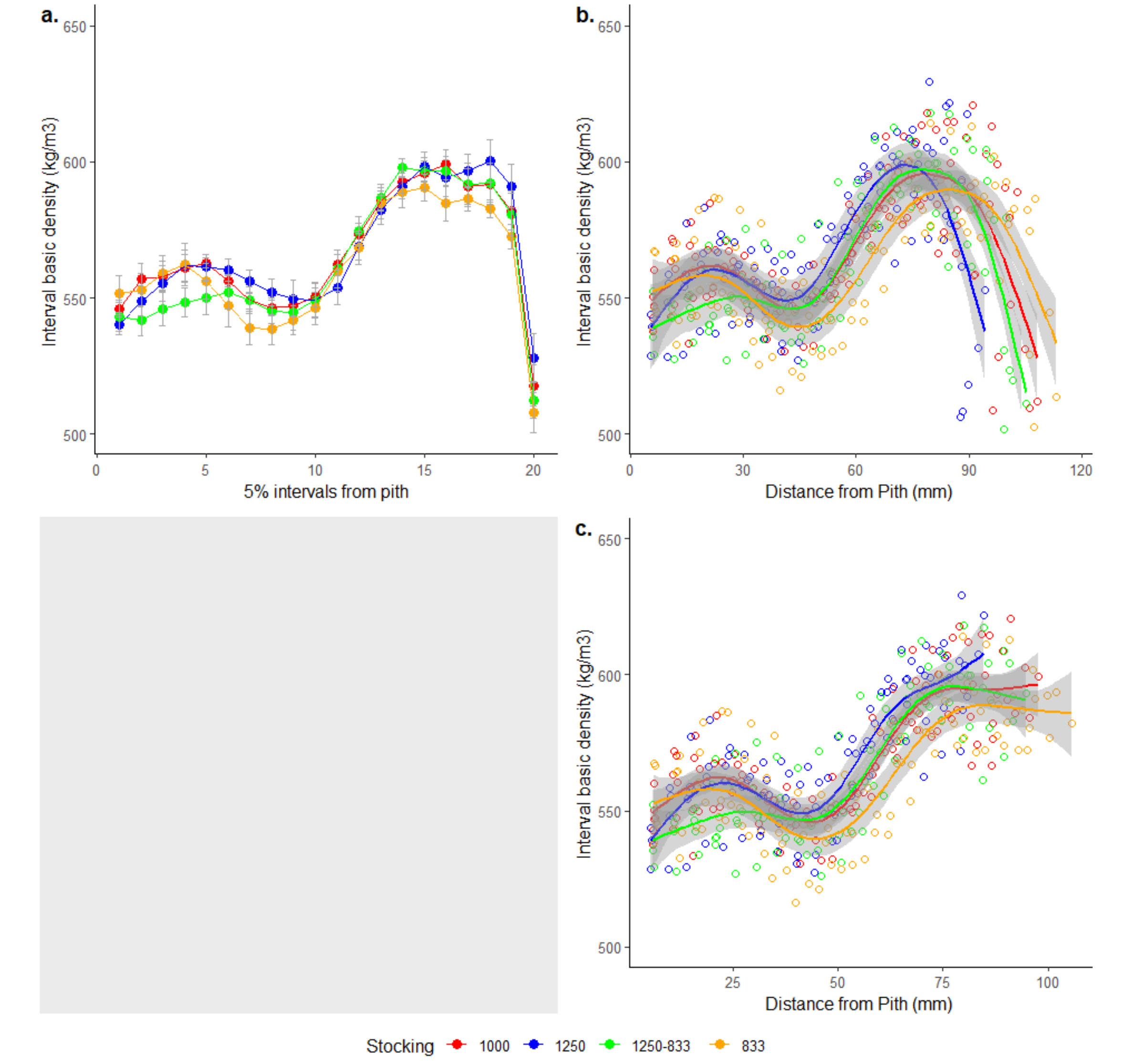

Figure 124: Effect of treatments on radial variation in Resi-derived breast height basic density.

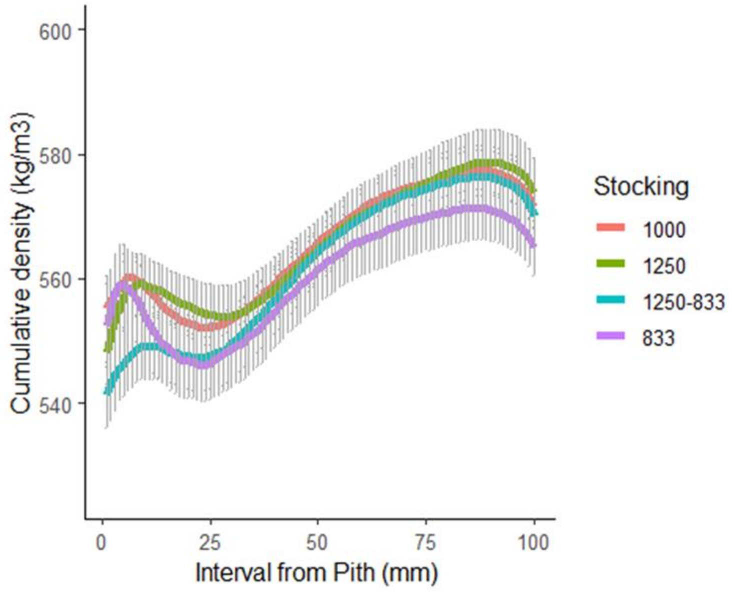

Figure 125: Effect of treatments on cumulative radial basic density variation from radius to pith.

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