An Australian Government Initiative

Joint Venture Agroforestry Program

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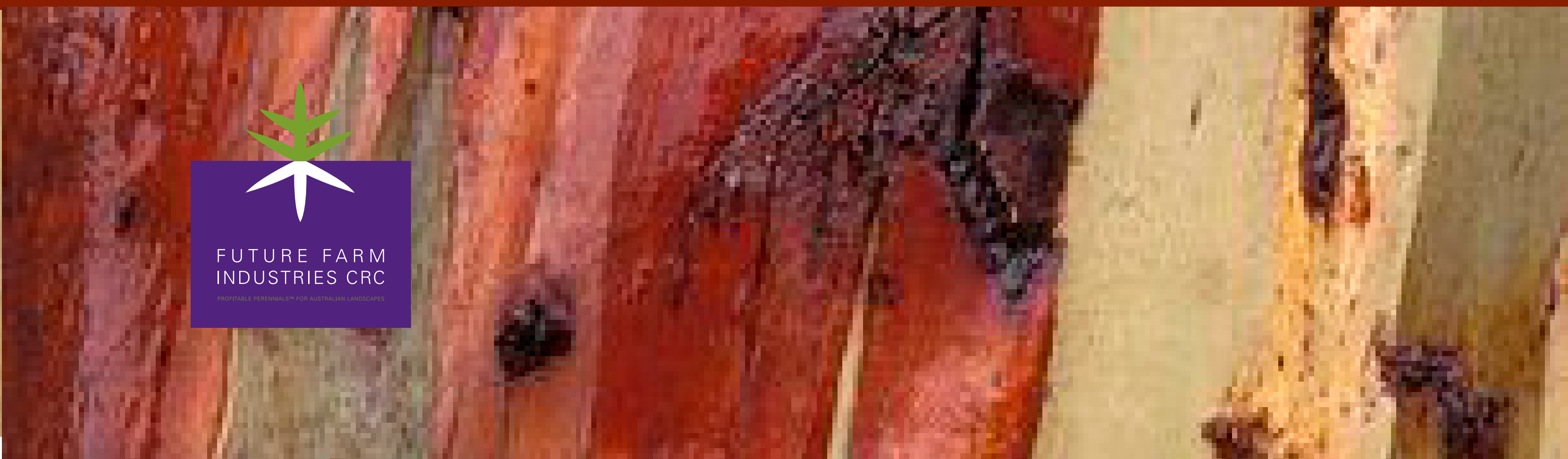
Forest & Wood Products Australia

Land & Water Australia

Evaluating agroforestry species and industries for lower rainfall regions of southeastern Australia

FLORASEARCH 1A



FUTURE FARM INDUSTRIES CRC

PROFITABLE PERENNIALS™ FOR AUSTRALIAN LANDSCAPES

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FUTURE FARM INDUSTRIES CRC

A report for the RIRDC / L&WA / FWPA / MDBC Joint Venture Agroforestry Program

by Mike Bennell, Trevor J. Hobbs and Mark Ellis

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* CRC for Plant-based Management of Dryland Salinity officially concluded operations on 30 June 2007. Its successor the Future Farm Industries Cooperative Research Centre continued to manage CRC PBMDS research projects until 30 June 2008.

Foreword

The FloraSearch project has the goal of providing a focus to the development of broad scale woody crops for southern Australia. Potential products are reviewed and taxa from southeastern Australia have been selected, sampled and tested for suitability for ongoing development as new crops. The project focuses on selecting species that can be developed to supply feedstock for the large-scale markets of wood and energy products. FloraSearch is a successor to WA Search and Acacia Search projects and draws strongly upon their philosophy and methodology. The first phase of the FloraSearch project has produced three reports:

a) Evaluating agroforestry species and industries for lower rainfall regions of southeastern Australia (FloraSearch 1a)

b) Agroforestry species profiles for lower rainfall regions of southeastern Australia (FloraSearch 1b)

c) Review of wood products, tannins and exotic species for agroforestry regions of southern Australia (FloraSearch 1c).

This report provides the methods and results of the initial evaluation process, including species screening, preliminary industry identification and product ranking, species productivity evaluations and use of the data for an exploratory regional industry potential analysis. The results indicate that farm based production of biomass to support several existing and new product types can be profitable. The report gives the rationale for ongoing work, which will further evaluate the target species selected from the screening process.

This project was funded by the Joint Venture Agroforestry Program (JVAP), which was supported by three R&D corporations – Rural Industries Research and Development Corporation (RIRDC), Land & Water Australia (LWA), and Forest and Wood Products Research and Development Corporation (FWPRDC)[1], together with the Murray-Darling Basin Commission (MDBC). The R&D corporations were funded principally by the Australian Government. State and Australian governments contributed funds to the MDBC. Significant financial and in-kind contributions were also made by project partners within the Cooperative Research Centre for Plant-based Management of Dryland Salinity[2] including: SA Department of Water, Land and Biodiversity Conservation; CSIRO Forestry and Forest Products; NSW Department of Primary Industries; Victorian Department of Sustainability and Environment; and the University of Adelaide.

This report is an addition to RIRDC's diverse range of over 1800 research publications. It forms part of our Agroforestry and Farm Forestry R&D program, which aims to integrate sustainable and productive agroforestry within Australian farming systems. The JVAP, under this program, is managed by RIRDC.

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1 Now Forest & Wood Products Australia (FWPA)

2 Now Future Farm Industries CRC (FFI CRC)

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The authors acknowledge the Joint Venture Agroforestry Program and Murray-Darling Basin Commission for funding this project. Significant financial and in-kind contributions were also made by project partners in the Cooperative Research Centre for the Plant-based Management of Dryland Salinity including: SA Department of Water, Land and Biodiversity Conservation; Ensis/CSIRO Forestry and Forest Products; NSW Department of Primary Industries; Victorian Department of Sustainability and Environment; University of Adelaide; and WA Department of Environment and Conservation.

The input and helpful advice of project collaborators and members of the FloraSearch Steering Committee is gratefully acknowledged. This includes John Bartle, Graham Olsen, Ian Nuberg, Peter Milthorpe, George Freischmidt, Des Stackpole and John Doran. Thanks to Joe Landsberg for advice on plant productivity modelling; State and National Herbarium staff – especially Tim Entwisle, Barry Conn, and Gary Chapple – for access to Australia's Virtual Herbarium; and Martin O'Leary for plant identifications. We appreciate Don McGuire and Mick Underdown (Forestry SA), and Don Cooper and Rick Giles (WA DEC) for their advice on a range of forestry issues, and Julian Morison for his review of our economic analysis and models. The high quality of field surveys, databases, computing and photography would not have been possible without the technical support of Julie Dean, Ben Shepherd, Brett Bartel, Brett Honeysett, Sue Wakefield, Darcy Peters and Kim Tomkinson.

We thank Rob Preston, Joe Landsberg, Russell Haines and Rosemary Lott for useful review comments on earlier versions of this report.

Abbreviations

ABC	Acid Buffering Capacity
AER	Annual Equivalent Return
ATSC	Australian Tree Seed Centre
BBC	Base Buffering Capacity
BDU	Bone Dry Unit
CP	Crude Protein
CRC PBMDS	Cooperative Research Centre for Plant-based Management of Dryland Salinity
DCF	Discounted Cash Flow
DDM	Digestible Dry Matter
DNRE	Department of Natural Resources and Environment
FWPA	Forest & Wood Products Australia
JVAP	Joint Venture Agroforestry Program
L&WA	Land & Water Australia
LVL	Laminated Veneer Lumber
MDBC	Murray-Darling Basin Commission
MDF	Medium Density Fibreboard
ME	Metabolisable Energy
MRET	Mandatory Renewable Energy Target
NHT	National Heritage Trust
NPV	Net Present Value
NSW NPWS	New South Wales National Parks and Wildlife Service
OSB	Orientated Strandboard
RIPA	Regional Industry Potential Analysis
RIRDC	Rural Industries Research and Development Corporation
SA DEH	South Australian Department of Environment and Heritage
SARDI	South Australian Research and Development Institute
SFMCA	Stock Feed Manufacturers' Council of Australia
WBC	Wood Buffering Capacity

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Executive Summary

What the report is about

This report details the outcomes of an agroforestry species selection and evaluation process aimed at identifying Australian native species with potential for development as broad scale commercial woody biomass crops in the lower rainfall regions of southeastern Australia. It also reviews and prioritises a range of potential industry types that could utilise large volumes of plant biomass grown in the 250-650 mm rainfall zone from short-cycle woody crops. Spatial models of plantation productivity, existing and potential industry infrastructure, and expected landholder economic returns have been used to identify regions and industries with the greatest potential for new agroforestry development.

Who is the report targeted at?

This report is intended to allow rural landholders, large-scale biomass industries, government agencies and research managers to make informed decisions about appropriate species and industry selections for agroforestry development in the lower rainfall regions of southeastern Australia. It aims to influence decision makers at all levels involved in developing sustainable and productive agroforestry within Australian low rainfall farming systems.

Background

FloraSearch was initiated in 2002 with financial support from the Joint Venture Agroforestry Program and the Murray-Darling Basin Commission to provide a focus to the development of broad scale woody crops in short-cycle agroforestry systems for the wheat-sheep zone of southern Australia. The FloraSearch study area contains the dryland wheat-sheep zone of southeastern Australia bounded by the low rainfall limit of cropping and the 650 mm rainfall isohyet, and extending north to the upper extent of the annual, winter dominated rainfall region.

The scale of perennial plant cover necessary to control salinity is immense, and new approaches to land management and sustainability in regions affected by salinity are proposed. This includes development of a mosaic of land uses, including tree crops driven by large-scale industrial markets and new agroforestry systems that derive higher-value products from perennial vegetation, herbaceous perennial crops together with traditional annual grain and pasture species. New agroforestry designs include short-cycle woody crops based on belts or plantations of coppice and phase crops suited to local hydrological systems. FloraSearch endeavours to select and develop woody perennial species suited to the concept of developing commercially viable industries, which can also meet natural resource management goals.

Aims and Objectives

The initial phase of the FloraSearch project has three major components:

- Investigation of potential products for the study area. This provides a ranking of industry types with the greatest potential for development and can include the expansion of existing industries and the development of new industries based on emerging technology.
- Species sampling and evaluation. This will provide species that can provide a product meeting industry specification and are productive and suited to cultivation as a crop.
- Regional analysis of industry potential. There will be a matrix of species, products and infrastructure resources that will lead to particular industry options having the greatest chance of success in particular regions. This component of the project aims to provide a systematic process to consider regional suitability.

Methods Used

An investigation of potential products was considered with reference to two basic criteria:

- Market size and potential for utilising large volumes of industrial feedstocks from short-cycle woody crop systems in the target zone
- Feasibility of making products of adequate quality at the required scale and at a competitive price from feedstock grown in the target zone.

Information from collations of published and expert opinion in these aspects of potential industries was used to rank options for southern Australia.

Species selection and evaluation required sifting prospective species from a genetic pool of approximately 10,000 taxa. Information on plant taxa occurring in southeastern Australia was collated into an extensive database that included herbaria and survey records from NSW, Victoria and SA, information from published sources, and knowledge by individuals with native plant expertise. These species were sorted on attribute information and prioritised for sample collection from as many taxa as resources permitted. Species and germplasm identified and prioritised were chosen for preliminary sampling, lifeform and productivity measurements, product testing and regional suitability mapping. Laboratory analysis of wood, leaf and biomass properties including fodder value, provided insight to likely yields from each species for each industry type. Information gathered in this process was then methodically reviewed and the suitability for FloraSearch products and markets evaluated. Results were fed back into the plant databases to permit more detailed analyses of germplasm suitability and potential for development.

Basic wood density is a key characteristic for wood processing with a maximum acceptable limit of 650 kg/m^3 for pulp and paper production and 600 kg/m^3 for composite wood products. For the sorting process undertaken in this work a slightly higher limit of 700 kg/m^3 was used to allow for likely improvements in feedstock quality emerging from genetic improvement and silvicultural development. Suitability for pulp and paper is further defined by pulp yield where a yield greater than 45% was taken as a minimum value.

The Regional Industry Potential Analysis (RIPA) is a methodology that integrates a geographic information system with species, environmental, industry and economic information to assist in the evaluation, prioritisation and selection of woody germplasm and appropriate industries in the FloraSearch region. Developments will be focussed on locations where the maximum economic, environmental and community benefits can be gained. Product groups and industries often have a number of common criteria relevant to their development. We have identified some of these criteria, such as feedstock requirements, transport infrastructure and minimum economic plant size, and gathered relevant datasets for spatial analysis.

The work reported here is an exploratory analysis of the RIPA process and utilises current industry knowledge, preliminary models of regional productivity and economic analyses for short-cycle woody crops. These analyses will gain in predictive power as more data becomes available from species trials and through more detailed examinations of prospective products and industries.

Results / Key findings

Products and Markets: This process followed closely on the product selection process undertaken by the WA Search project where composite wood panels (particleboard and medium density fibreboard), pulp and paper, and bioenergy were considered to have high potential in the study region. In FloraSearch the solid wood only products were given a low rating and were not evaluated further. Oriented strand products and wood plastics were considered favourably, but given a lower rating, as stranding requires special processing requiring non-chipped wood feedstocks and wood plastics have small existing markets.

In situ fodder systems, based on perennial species, were highly ranked and further work on this topic has been developed as a separate "Enrich" project with JVAP. These systems were identified as having the potential to provide high rates of return partly attributable to green out-of-season feed (summer/ autumn) being more valuable than the same feed in spring, due to higher market prices for livestock produced out-of-season. Industrial scale cineole production was also considered prospective if technology to allow in-field processing could be developed. Wood product often requires separation of foliage and bark, and species selection can ensure that these secondary feedstock streams can be utilised for valuable product such as essential oil from leaf or tannin and gum from the bark. The most prospective FloraSearch industries, which utilise short rotation woody crops and are predominantly based on "chip-in-field" harvest technologies, include:

- Pulp and paper (Australian production and woodchip export)
- Composite woods (e.g. MDF and other fibreboards, particleboard)
- Bioenergy (co-firing and renewables)
- Extractives (oil and tannin)
- Livestock fodder (in situ and processed).

Species selection: From the 392 prioritised species about 140 were subsequently sampled and tested to obtain data on several characteristics to indicate suitability for pulp and paper, fibreboard, bioenergy and fodder. Virtually all of the oil producing species sampled to date have been previously tested for oil yield and composition and these results have been incorporated into the FloraSearch databases. FloraSearch will test untested oil species, and variants of previously sampled species, in the future.

Identified priority species were also evaluated for their growth and yield potential in the study area from preliminary growth measurements and laboratory results, and bioclimatic modelling employed to describe where they may be successfully cultivated. Matching these species to suitable climate and soil conditions within the FloraSearch region is a crucial following step. Natural distributions of the species provide information on climate and soil affiliations which have been utilised in bioclimatic modelling, giving strong indications as to where these species are most likely to perform. A group of the most prospective species that emerged from this initial process are listed in product groups together with attribute data in Table 1.

Regional Industry Potential Analysis: Industry facilities for separate product types already exist in some industry ventures identified above including pulp and paper, composite wood products and bioenergy including co-located plants such as energy generation adjacent to sawmills or pulp mills that utilise waste stream for bioenergy benefits. Integrated tree processing plants, such as the one constructed for oil mallees in WA, can produce multiple products to increase profitability (e.g. oils, bioenergy and charcoal).

The viability of each of these industries in the FloraSearch study area depends on the degree of matching between existing resources and industries, commercially viable primary production and access to markets. The RIPA provides a wealth of information on many key components that influence the potential for commercial agroforestry development in the region, including:

- Industry infrastructure and non-biomass resources
- Existing industries and their facilities
- Primary production of total biomass (and fractions) using a representative species
- Generalised cost-benefit analysis for primary producers
- Evaluations of returns to primary producers to supply to existing industries
- Potential location for the investment in new facilities.

Table 1. Species with greatest potential for agroforestry development in the FloraSearch region.

Taxa	Stemwood production [m³/ha/year@500mm]	Basic density [kg/m³]	Wood chip production [bdt/ha/year@500mm]	Pulp yield [%dm@Kappa 18]	Water Solubles [%dm]	pH	Oil Yield [%dm]	Crude Protein [%dm]	Digestibility [%dm]	Metabolisable Energy [MJ/kg dm]	Palatability [High Med Low Not]
Pulp, Fibre/Particleboards											
Eucalyptus viminalis ssp. *cygnetensis*	17.5	532	6.0	44.3	11.2	5.0	1.36				
Eucalyptus globulus ssp. *bicostata*	22.4	656	9.6	46.7	8.0	4.6	1.15				
Eucalyptus ovata	18.7	504	6.1	49.5	8.2	4.5	0.95				
Eucalyptus bridgesiana	13.8	539	5.8	46.2	8.8	4.4	0.58				
Eucalyptus porosa	6.4	641	3.0	49.9	7.7	5.1	2.10				
Codonocarpus cotinifolius	9.7	397	3.3	46.5							
Eucalyptus goniocalyx	9.5	660	4.9	46.4							
Eucalyptus botryoides	8.4	599	3.9	47.9							
Fibre/Particleboards, Pulp, Fodder											
Acacia retinodes	22.5	639	11.3	49.1	8.3	5.2		15.6	51.3	7.2	
Acacia salicina	14.1	648	7.1	45.3				14.3	62.3	8.9	L
Bioenergy											
Eucalyptus cladocalyx	22.0	753	12.1	49.6	8.4	4.3	0.05				
Acacia retinodes	22.5	639	11.4	49.1	8.3	5.2		15.6	51.3	7.2	
Eucalyptus leucoxylon	19.3	773	9.9	43.0	9.5	5.5	1.65				
Eucalyptus chloroclada	20.3	621	9.8	39.9	14.0	4.0					
Eucalyptus globulus ssp. *bicostata*	22.4	656	9.6	46.7	8.0	4.6	1.15				
Eucalyptus viminalis ssp. *cygnetensis*	17.5	532	6.0	44.3	11.2	5.0	1.36				
Eucalyptus camaldulensis	19.2	502	7.5	38.3	16.0	5.4	1.50				
Oil/Bioenergy											
Eucalyptus porosa	6.4	641	3.0	49.9	7.7	5.1	2.10				
Eucalyptus incrassata	5.0	768	3.1	48.6	4.6	5.9	2.80				
Eucalyptus aromaphloia ssp. *sabulosa*	25.5	540	7.8	44.5			2.95				
Eucalyptus dives	7.4	603	3.5	39.4			3.81				
Eucalyptus polybractea	2.5	770	1.5	54.0	7.4	4.4	2.35				

Table 1. Continued

Taxa	Stemwood production [m³/ha/year@500mm]	Basic density [kg/m³]	Wood chip production [bdt/ha/year@500mm]	Pulp yield [%dm@Kappa 18]	Water Solubles [%dm]	pH	Oil Yield [%dm]	Crude Protein [%dm]	Digestibility [%dm]	Metabolisable Energy [MJ/kg dm]	Palatability [High Med Low Not]
Fodder Only											
Atriplex nummularia	1.5	450	0.5					20.4	75.6	11.1	M
Eremophila longifolia	2.3	672	1.2	<38	8.8	5.2		13.2	75.4	11.0	H
Chenopodium nitrariaceum								20.8	78.6	11.5	M
Indigofera australis								20.9	70.2	10.2	H
Atriplex vesicaria	0.4							20.1	69.4	10.1	H
Maireana pyramidata								25.8	68.5	9.9	M
Rhagodia spinescens								20.8	67	9.7	M

Recommendations

- Of the initial group of 392 species selected a significant number remain to be fully evaluated. Although Hobbs et al. (2007) provide significant new data on product testing results, more detailed and conclusive results are still required for many species and provenances. For many species information on growth potential, product yields and expected adaptability to cultivation is still sparse. Most priority species still need to be tested for their composite wood product values and combustion characteristics for bioenergy.
- Technology development is required for harvest of short rotation woody crops and coppice crops. The focus on wood products for WA Search and FloraSearch has an underlying assumption of the development of continuous flow harvesting that produces chip-in-field off the stump and is capable of producing the quality needed for processing. The Future Farm Industries CRC plans to further investigate chip-in-field harvester technologies and will require future research and development support.
- Field trials of priority species over a range of rainfall zones and soil types are necessary to determine optimal species and provide data on productivity. This work has commenced as part of the Cooperative Research Centre for Plant-based Management of Dryland Salinity's "Field Evaluation of Woody Germplasm" and includes many of the selected FloraSearch species but will require future support for maintenance, measurements and analysis.
- The potential of FloraSearch species to contain interesting secondary plant compounds requires investigation particularly in the case of species selected for further development.
- All species selected for development, both indigenous and non-indigenous, will need to be assessed for weed risk potential.
- Genetic improvement and crop development research of selected species is being conducted as part of the ongoing FloraSearch project and will require future support as currently selected plant species progress towards domestication and other species are advanced for further development.

1. Introduction

The removal of perennial native vegetation and development of annual agricultural systems in the 250-650 mm winter dominated rainfall zone of southern Australia has lead to widespread land degradation, most pressingly dryland salinity and salinisation of waterways. The National Land and Water Audit (2001) found that 5.7 million hectares were at risk or affected by dryland salinity, and that in 50 years time this area could rise to 17 million hectares.

Revegetation has been promoted strongly over the past decade as part of the national endeavour to control salinity and generally improve the sustainability of agriculture in southern Australia. However, it has become apparent that the scale of perennial plant cover necessary to control salinity is very large and that it is not feasible to rely solely on revegetation for biodiversity to achieve salinity control. Stirzaker *et al*. (2000) proposed that a new approach be taken to management of the landscape in regions affected by salinity and other sustainability issues. Development of a mosaic of land uses including tree crops driven by large-scale industrial markets (such as biomass fuels), agricultural systems utilising annual and herbaceous perennial crops, and biodiversity resources was proposed. Stirzaker *et al*. (2002) concluded that, "as long as we obtain low-value products from trees grown in the drier area, they are unlikely to match the value of annual crops and pastures. To help fund revegetation, we must foster industries that derive higher-value products from perennial vegetation."

Through a good understanding of catchment scale hydrology, these options can be placed in the landscape in such a way as to optimise water use while maintaining productive capacity. Agroforestry designs based on new short production cycle woody crops, such as coppice and phase crops, has created the opportunity for commercially viable cropping of woody perennial species. The Western Australia experience of mallee as a multiple-product crop has demonstrated this potential with a feasibility study showing that it should be commercially viable (Enecon 2001, Bartle and Shea 2002, Olsen *et al*. 2003). Stirzaker *et al*. (2002) outline four alternative agroforestry designs:

- Plantations with short rotations on agricultural land in areas too dry for conventional forestry. In this system unused water in the soil profile can be "mined" to provide higher growth rates than expected from rainfall only
- Belts of trees to intercept sub-surface and surface flows on sloping sites
- Alley farming on flatter terrain where lateral flow is insignificant but where trees can extend their rooting systems to exploit soil water
- Agroforestry over shallow saline watertables where most forms of agriculture are unviable (this option is specifically excluded from FloraSearch).

There are three commercial cropping systems most likely to suit these agroforestry designs:

- Long-cycle crops: upright single trunk trees managed over a growth period of ten to 100 years
- Coppice crops: long-lived species that readily re-sprout from the cut stump after harvest and which could be harvested every two to five years
- Phase crops: part of an annual crop rotation, harvested at three to ten years after which the land reverts to annual crops or pasture.

Markets for environmental credits could enhance the competitiveness of new woody crop industries, but it appears they will be complex and have high transaction costs. It is more reliable to make woody crops competitive on their own account as much as possible.

There is a great diversity of native woody and exotic species potentially suited to the wheat-sheep belt of southern Australia. Like many eucalypt mallees these species have good potential for bulk low-cost biomass production which together with other product attributes such as fodder, gums, chemicals or food may open many landuse options. The development of native species to provide the woody crop component of new agricultural systems may have environmental advantages over introduced species, in particular, the diminished risk of becoming environmental weeds. Also the diverse flora of southern Australia has not been comprehensively assessed for product value in the past and represents a vast reserve of genetic variability that could be exploited by selection and breeding programs.

The FloraSearch project has undertaken an investigation to gather information on potential products, species attributes and a regional analysis of industry potential to provide a group of "best bet" species that will be the subject of crop development in the ongoing FloraSearch project. This is reported in the following chapters addressing different components of the study:

Chapter 2: Project Background – provides a short description of the FloraSearch project background including a summary of the findings of preceding WA Search and Acacia Search projects.

Chapter 3: FloraSearch Methodology – defines the approach taken by FloraSearch to identify, evaluate and review the industries and species with the greatest potential for development in the low rainfall regions of southern Australia.

Chapter 4: Products and Markets – details product information from preceding studies and reviews commissioned by FloraSearch is considered in reference to market size, technical feasibility and potential to compete with alternative feedstock sources.

Chapter 5: Species Selection – details the process where information on plant taxa occurring in the SE region of Australia is collated into an extensive database. This includes herbaria and survey records from NSW, Victoria and SA, information from published sources and knowledge of individuals with native plant expertise. These species were sorted on attribute information and prioritised for sample collection from as many taxa as resources permitted.

Chapter 6: Species Evaluation – describes how samples were subsequently tested to obtain data on several characteristics indicating suitability for products such as pulp and paper, medium density fibreboard, and fodder. Priority species were evaluated for their growth and yield potential in the study area and modelling employed to describe where they may be successfully cultivated.

Chapter 7: Regional Industry Potential Analysis (RIPA) – presents a methodology that integrates a geographic information system with species, environmental, industry and economic information to assist in the evaluation, prioritisation and selection of woody germplasm and appropriate industries in the FloraSearch region. It provides an exploratory analysis of prospective products and industries in the region based on current industry knowledge, indicative models of primary production and economic analyses for short-cycle woody crops.

Chapter 8: Conclusions and Future Directions – integrates information from the preceding chapters to provide groupings of species that are most likely to meet product feedstock requirements whilst optimising growth potential considering environmental constraints. These species will form the basis of ongoing crop development. This chapter concludes with an outline of future research directions required to fulfil the FloraSearch goals.

2. Project background

2.1 FloraSearch

FloraSearch was initiated in 2002 with financial support from the Joint Venture Agroforestry Program (JVAP) and the Murray-Darling Basin Commission (MDBC) to focus on the development of broad scale woody crops for the wheat-sheep zone of southern Australia. FloraSearch is a successor to WA Search and Acacia Search projects and draws strongly upon their philosophy and methodology. These projects have focused principally on selecting species for the large-scale markets of wood and energy products. In FloraSearch, taxa from southeastern Australia with potential to become large-scale crop plants and make a substantial contribution to natural resource management have been selected. Species screened in the WA Search and Acacia Search projects that also occur in the FloraSearch study zone have been identified and are included within the analysis to provide a more comprehensive determination of suitable species for the southeastern region. Data from these sources is clearly identified in the body of the report.

The FloraSearch study area (Figure 1) contains the dryland wheat-sheep zone of southeastern Australia. It is bounded by the low rainfall limit of cropping (approximated in part by the 250 mm rainfall isohyet) and the 650 mm rainfall isohyet and extends north to the upper extent of annual, winter dominated rainfall region. Bounded by the low rainfall limit of cropping, summer dominated rainfall areas, and the 650 mm annual rainfall isohyet.

This report describes the results of the initial phase of the FloraSearch concept collating information on the 10,000 or so plant taxa naturally occurring in the region and selecting those most worthy of detailed consideration. The following Phase 2 of FloraSearch will undertake new crop development based on innovative product options utilising the species selected here. This will include selection and development of genetically improved plant resources, and agronomic and production systems. Together with several interlinking projects, many of which are taking place within the CRC for Plant-based Management of Dryland Salinity, this work aims to develop commercially effective ways of using woody perennials to control the processes of dryland salinity and saline discharge to waterways.

2.2 Related Projects

2.2.1 CRC for Plant-based Management of Dryland Salinity

The growing acceptance of the need for broadscale integration of perennials into agriculture has led to the establishment of a number of related research and development projects and programs across the nation.

Figure 1. The FloraSearch study area (shaded) contains the low rainfall winter cereal growing areas of southeastern Australia.

The CRC for Plant-based Management of Dryland Salinity (CRC PBMDS) was established in 2001 as a major initiative to support development of plant based systems for prevention and amelioration of dryland salinity. The CRC focuses on the agronomic development and promotion of commercially viable crops based on herbaceous and woody perennials. Subprogram 4 "Woody Perennials" focuses specifically on the development of commercial woody perennial crops. The subprogram includes three projects; "Selection and development of multipurpose species for large-scale revegetation in the wheat-sheep belt of southern Australia" (FloraSearch); "Quantifying differences in performance among tree species/genotypes on salt-affected land"; and "Field performance of testing of new woody germplasm". The latter project is closely allied to the work reported here and FloraSearch will define a substantial number of the species selected for evaluation.

In addition to these projects many of the research topics being considered within the CRC will contribute information to the ongoing development of FloraSearch.

2.2.2 WA Search

The WA project "Selection and development of multipurpose species for large-scale revegetation", commonly known as the "WA Search Project", was developed in 2000 with funding from NHT to screen the native woody flora of the Western Australian wheatbelt for species with the biological and product potential to become large-scale crop plants. Final reporting on this project occurred in September 2003 (Olsen *et al*. 2003).

The following excerpts of the executive summary of the Search report (Olsen *et al*. 2003) are included to provide background and understanding of the project objectives, methods and results as they related to product and species evaluation.

"The Search Project aimed to build a foundation for the development of commercially viable woody crops enabling sound NRM [natural resource management] *practice to be achieved within normal agricultural practice. This project focused on the Western Australian wheatbelt – the agricultural region of the southwest of Western Australia that has less than 600 mm rainfall per year. The project was constrained to domestication of native species to avoid the introduction of exotics that may pose a weed risk, an outcome incompatible with the biodiversity conservation objectives of NHT. A principal hypothesis was that short-cycle woody crops in the wheatbelt could produce industrial wood chip at a similar or lower cost to conventional high-rainfall industrial forestry plantations, providing an opportunity to develop new, large-scale biomass industries around processing infrastructure located in wheatbelt towns.*

The project had the following objectives:

1. *Search process: develop a procedure that systematically analyses plant and product attributes and identifies the best prospects for development.*
2. *Pre-feasibility investigation: assemble technical, economic, biodiversity and other information to select and rank a shortlist of the 12 most prospective species for development.*
3. *Industry Exploration:*
    - *A preliminary selection of "best bet" species for demonstration trials.*
    - *To plan and commence building industries, in particular, build a viable resource utilising best practice and planting design for prospects identified in 1 and 2.*

Objective 1 involved coarse screening of species and products. A simple six-step process was adopted where each step provides an increasingly rigorous filter of products, species, or combinations of products and species. The effort required, both in time and money, increases rapidly at each step, demanding that the early steps filter out as many poor prospects as possible, while rejecting as few prospective options as possible.

Product selection was the first step taken because it is a logical starting point for new industries, and it required fewer choices to be made than species selection. More importantly, it was not possible to select appropriate criteria for species selection until target products had been identified. Paper, made from chemical pulp, panel boards (particle board, and medium density fibreboard, or "MDF"), and solid fuel for bioenergy were identified as the most prospective large-scale products. The potential for extra revenue from extraction of chemicals was treated as a subordinate prospect, to be investigated for species that showed promise for one or more of the other products.

Key selection criteria for products included market size, presence of established industries in Australia, and likely suitability of feedstock from short-cycle crops. Feedstock criteria for pulp and panel products were expected to be strong discriminators between species, whereas the requirements for bioenergy were likely to be less stringent. An important role for bioenergy would be to consume all residues not used for higher value products, making bioenergy an almost obligatory complementary product.

The Western Australian flora was screened using criteria appropriate to the selected products. Key criteria used in this step were growth rate, wood density, wood colour and natural distribution. Utilising WA Herbarium records, data collected on wood density and colour, and the input of expert collaborators, approximately 50 highly prospective species were selected from a total of 9,977 Western Australian species.

The next step involved three levels of progressively more intensive testing of wood properties on decreasing numbers of species, proceeding to the final stage of manufacturing sample panels and paper. All wood samples were collected from the best stands that could be located within the time constraints of the project, from individual plants that represented the age and form that might be obtained from cultivated stands. These tests required the collection of 10 kg samples of debarked wood from 51 prospective species and included chipping, wet chemistry and fibre characterisation. Chemical pulping was performed on all samples, as it is a relatively inexpensive process that provides information on the pulp yield of each species

– a critical factor for this product. At the following level, 30 of the pulped species progressed to paper manufacture and testing, while a further 150 kg of wood was collected for species selected for panel board manufacture (19 species for MDF, and 20 species for particleboard). Pinus radiata was used as an "industry standard" control. Combustion tests and ash analyses were carried out on the selected species. Also some investigation of the sawn timber properties of twelve prospective long-cycle timber species was undertaken, although this was a minor part of the total project.

Results from pulp and paper testing varied widely. The best four species (Taxandria juniperina, Grevillea leucopteris, Alyogyne huegelii and Grevillea candelabroides) indicated considerable promise, and deserve further more intensive investigation. Selected species for MDF and particleboard production were all successfully converted into panels with minor variations in panel quality. The lower density species among those tested (Taxandria juniperina, Eucalyptus rudis, Viminaria juncea, Anthocercis littorea, Gyrostemon ramulosus, and Codonocarpus cotinifolius) should be tested further to optimise MDF and particleboard production by investigating and optimising a range of production variables. In the case of MDF, optimising process variables to reduce the 'fines' content would have high priority.

Furthermore, the conformability of wood species was generally poor in the particleboard panels. The most promising species in this respect were Codonocarpus cotinifolius and Gyrostemon ramulosus. The wood samples used for pulp and paper testing, and for panel board manufacture were from a single collection of wood from (mostly) native populations. There is almost certainly scope to improve their performance through genetic selection, plant breeding, development of appropriate management systems, choice of harvest age and optimisation of processing variables. Work on charcoal as a reductant and the combustion properties of residues of the most prospective paper and panel species also indicated promise."

2.2.3 Acacia Search

Acacia Search was supported by JVAP in 2002/2003 and has strong linkages to FloraSearch. Additional resources from FloraSearch were contributed to the Acacia Search team in order to fast track identification and collection of prospective Acacia species. The aims and geographical boundaries were defined by Maslin and MacDonald (2003):

"The project identified, evaluated and provided detailed information for Acacia species considered as prospective new woody crop plants in a study area that encompassed the States of Western Australia, South Australia, Victoria and New South Wales. It included the predominantly winter rainfall region (south of the Lachlan River, N.S.W.) from about 650 mm annual precipitation down to the limits of agriculture (which coincides with the 250 mm isohyet in eastern Australia and the 300 mm isohyet in Western Australia). Species were considered for this project if their natural distribution occurred wholly or partially within the target area, although a few species with known agroforestry potential that occurred just outside the region were also assessed. The areas of greatest species richness for Acacia within Australia are located within, or are peripheral to, this target area.

Emphasis is given to fast growing species with potential for producing large amounts of wood biomass that may find uses as solid and reconstituted wood products and for bioenergy, and which may possess commercially attractive by-products such as extractives (especially tannin and gum) and fodder. There is currently no large-scale commercial use of Acacia within the southern Australian agricultural zone despite the fact that this genus, in terms of species numbers, is the largest plant group in the area."

The main findings of Acacia Search that relate to the FloraSearch investigations are provided in the following excerpts from Maslin and McDonald (2003):

"Acacia is a diverse and enormous genus with almost 1,000 species currently recognized for Australia. These species represents vast resource for economic, environmental and social utilisation, but to date their major usage has been abroad. Many Australian Acacias produce good

quantities of wood biomass and display a range of variation in growth form, growth rate, longevity and coppicing/suckering ability. They are adapted to a wide range of soil types and climates, including drought- and frost-prone areas. Acacia species have hard-coated and relatively large seeds (which are amenable to direct-sowing techniques), have the ability to improve soil fertility through nitrogen fixation, are usually easy to germinate and grow, and generally show good survival and rapid growth rates under cultivation. These favourable attributes provide the encouragement for considering Acacia species for development as new woody crop plants for southern Australia.

Species were evaluated against a set of plant characteristics that indicate their potential suitability as feedstocks for selected products. Emphasis was given to products that have large markets, require large amounts of biomass for their manufacture, and for which short-cycle Acacia crops could provide suitable feedstock. Therefore, the most important plant characteristics were the ability for rapid production of commercial volumes of harvestable wood biomass, particularly that which has low wood density.

Existing knowledge was adequate to enable all species within the target area to be assessed on the basis of their expected growth rate, and their ability to produce acceptable quantities of wood biomass. These two important attributes took pre-eminence in the selection process and in the ranking of species, but they were supplemented by other plant characteristics relating to morphology, biology, ecology, silviculture and wood quality where these data were available (from both published and unpublished sources, and from our field assessment of the taxa). Unfortunately not all information necessary for a thorough evaluation of Acacia as a woody crop is currently available. There are critical data relating to wood and plant characteristics, and silviculture which need to be obtained from field trials and from further detailed study of plants in their native habitats. Also, there is a need for technical testing to determine how well the species meet the feedstock requirements of various end products.

There are 462 Acacia species that occur naturally within the target area. Thirty five species have been identified as having some crop potential for the southern Australian agricultural zone; however, because these species vary considerably they have been subjectively ranked to indicate how well each might be expected to perform as crop plants capable of delivering anticipated end products." Species ranked 1: *Acacia saligna*; a WA species, and ranked 1-2: *A. leucoclada* ssp. *leucoclada, A. linearifolia, A. retinodes* 'typical' variant, *A. salicina* and ranked 2: *A. decurrens, A. lasiocalyx, A. mearnsii, A. microbotrya, A. pycnantha, A. retinodes* 'swamp' variant, are considered the most prospective. *"They can be expected to display fast or moderately fast growth rates and produce high or moderately high volumes of wood biomass. They have potential to be cultivated over a reasonably wide geographic area, although in a number of cases this area is restricted to the temperate outer peripheral regions of the target zone.*

Species ranked 3 and 4 are regarded as less prospective. While these species possess acceptable growth characteristics, they display certain attributes that tend to reduce their potential for crop development (most commonly these attributes are poor growth form, reduced wood biomass production, or relatively slow growth rates." See Appendix A for the complete list of the 35 species reviewed.

"While all the 35 prospective species produce at least reasonable quantities of wood biomass the largest volumes of wood are generally found in the arborescent species which grow in (or just outside) the temperate peripheral parts of the target area in eastern Australia (e.g. Acacia dealbata, A. decurrens, A. implexa, A. leucoclada, A. linearifolia, A. mearnsii, A. melanoxylon, A. neriifolia, A. retinodes 'swamp' and 'Normanville' variants). In the drier inland regions of N.S.W., S.A. and W.A. many species are smaller in stature and often develop a form resembling the 'mallee' growth habit with wood contained in many rather slender stems (e.g. A. argyrophylla, A. euthycarpa, A. hakeoides, A. murrayana, A. rivalis, A. wattsiana). However, A. salicina and A. stenophylla are notable exceptions in that they develop into substantial trees, despite growing (along water courses) in the driest inland parts of the eastern target area. Some arborescent species do, however, occur in the drier semi-arid parts of the target zone (e.g. A. lasiocalyx, A. microbotrya, A. pycnantha, A. retinodes 'typical' variant, A. saligna, A. subfalcata).

Vigorous or moderately vigorous root suckering appears to be common in a number of the highly ranked species, namely, Acacia leucoclada, A. microbotrya, A. retinodes 'typical' variant, A. salicina and A. subfalcata.

Many Acacia species have the potential to display various aspects of weediness. A primary strategy adopted in this study to minimize the environmental weed risk was to assess only those species that occurred naturally within, or very close to, the target zone. It was considered inappropriate at this early stage of the selection process to preclude or unduly negatively weight species on the basis of weed potential. To do so would pre-empt the development of effective control measures through management, breeding and other strategies, should these be deemed necessary. As crop development progresses the knowledge of the biology and ecology of the species will expand, thus allowing a more rigorous prediction of weed risk that might occur should species be considered for translocation outside their natural area of occurrence. This strategy provides a safe development pathway for Acacia crops. Based on existing knowledge the following eight species perhaps have the greatest weed potential: Acacia baileyana, A. cyclops, A. dealbata, A. decurrens, A. mearnsii, A. melanoxylon, A. pycnantha and A. saligna. However, half of these species express weediness in relatively high rainfall areas, so it is not known to what extent (if at all) they will develop similar tendencies in the drier, semi-arid environments of the target area. It is important therefore to assess weed risk within the environment where species are intended to be cultivated. The three species that might pose greatest weed risk in the target area are A. cyclops, A. pycnantha and A. saligna. Notwithstanding the above it is noted that a number of prospective species grow naturally in disturbed agricultural landscapes with no recorded weed problems."

3. FloraSearch methodology

3.1 Introduction

The FloraSearch methodology has developed from the hydrological and agroforestry systems ideas articulated by Stirzaker *et al.* (2002) and the WA and Acacia Search projects. FloraSearch aims to identify and develop woody perennial species, and commercially viable industries, to control hydraulic processes that lead to dryland salinity and saline discharges to waterways in the FloraSearch region. The principals guiding the following product and species evaluation are:

- Plantings are to be undertaken on recharge areas (non-saline) in the 250-650 mm rainfall zone to control the causes not the symptoms of dryland salinity
- Deep-rooted woody perennials to be used
- All potential germplasm to be considered but with an early focus on native species due to the potential benefits for landscape sustainability and source of undeveloped germplasm;
- Development of dryland not irrigated crops
- Focus on crops with short lead times to commercial return (e.g. coppice crops and woody phase crops) in order to maximise attractiveness to investors and thus adoption. Sawn timber is considered to be part of farm forestry research and development and is specifically excluded
- Provision of feedstock to be for large-scale commodity markets in order to provide an economic driver to promote widespread revegetation on a large enough scale to impact on recharge
- Investigate the potential of multiple products from the one crop species to increase the chance of positive economic returns.

Wood has been identified by the Acacia Search and WA Search projects as the principal harvestable biomass to be produced by low rainfall agroforestry systems. Olsen *et al.* (2003) suggests that pulp and paper, panel boards, and fuel for bioenergy are the most prospective large-scale products. Other products such as oils, gums and tannins are considered as secondary products derived from the bark and foliage stream. This project accepts these findings but in the following chapters considers some additional product areas.

WA Search developed a six-step process for objective selection of the best species and product combinations to guide long-term commercial development (see Figure 2). This framework has been adopted by the Subprogram 4 of the CRC and has guided the development of FloraSearch. A detailed outline of this strategy can be found in Olsen *et al*. (2003). Briefly the six steps are:

Step 1 **Initial ranking of product options** based on assessment against a set of criteria appropriate to medium to low rainfall areas.

Step 2 **Initial ranking of species** based on simple characteristics such as plant type (site preference, regeneration capacity or form), growth rate (using size and vigour to indicate productivity) and diversity/distribution (to indicate likely adaptability as a crop).

Step 3 **Testing plant material** from species selected in Step 2 for their suitability as feedstocks for the products selected in Step 1.

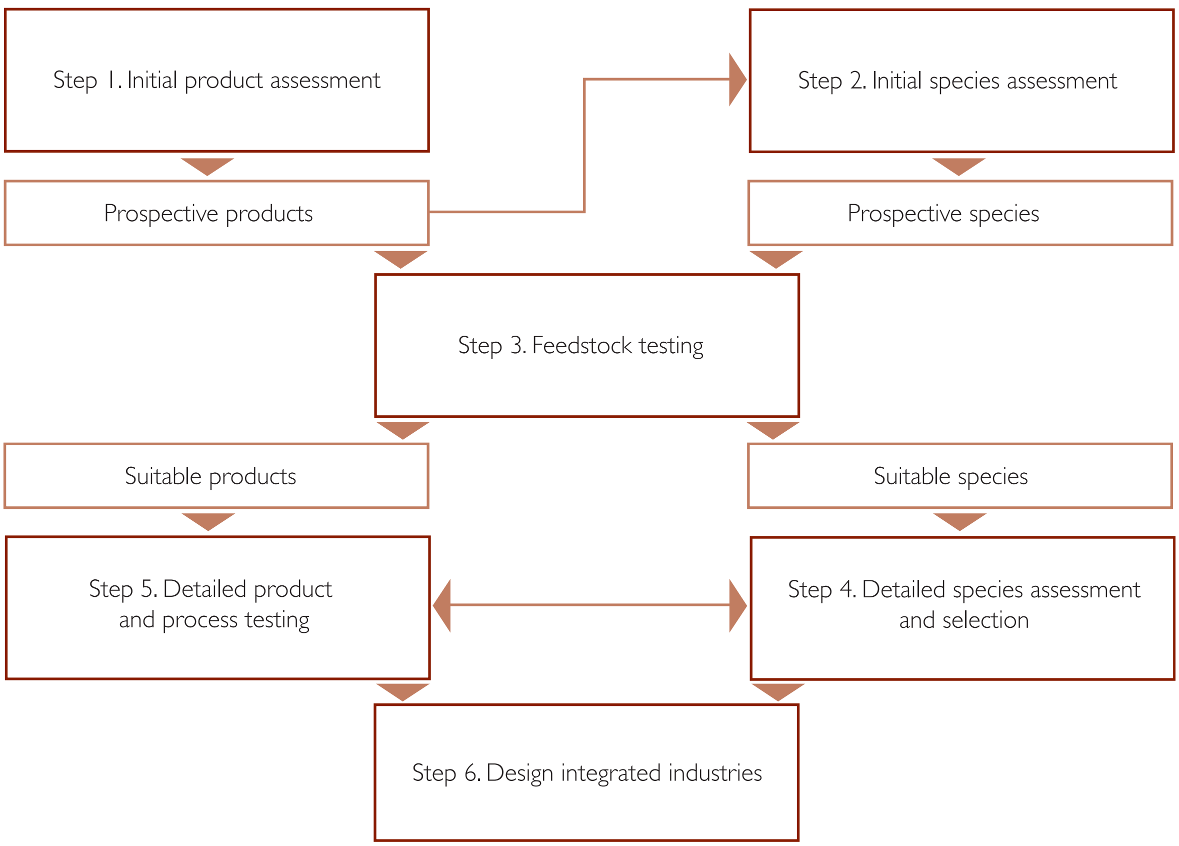
Step 4 **Detailed selection of species** from among those found to be most prospective in Step 3. It is based on more intensive collection and analysis of plant data and more detailed consideration of more characteristics such as weed risk, tolerances to environmental stresses, ease of propagation, quantity and quality of yield and production systems.

Step 5 **Detailed testing of products and production processes** to determine the commercial feasibility of making products from feedstock produced from the most prospective species.

Step 6 **Design of new integrated industries** for those species indicating best promise.

The FloraSearch project applies this strategy through the following chapters: Products and Markets (Step 1), Species Selection (Step 2), Species Evaluation (Steps 3, 4[part]), Regional Industry Potential Analysis (Step 5 [part], Step 6 [part]). Steps 4 to 6 will develop later as target species are developed, and research on product testing, industrial processes and facilities, farming system design, economic analyses and spatial/regional analyses continues. The six-step process of commercial development of agroforestry species and industries identified by Olsen *et al*. (2003) is

Figure 2. Diagrammatic representation of the simplified Search six-step process (from Olsen *et al.* 2003).



not a linear step-by-step process. It is an adaptive process, with feedback loops, where the provision of new information can reprioritise targeted species and industries.

3.2 Products and Markets

Step one in the six-step methodology is to define the products and markets that will utilise feedstock from newly developed woody crops. The preliminary selection of product areas enables definition of the pathway for selection of new species with desirable properties matched against key product areas for testing and subsequent agronomic development. Olsen *et al*. (2003) suggests three components to this step:

- Choose selection criteria (e.g. market size, trend, product value, potential geographic extent)
- Identify and evaluate each product option's ability to meet selection criteria
- Rank products in order of potential, based on the degree to which they meet or exceed the selection criteria.

FloraSearch follows this approach making a general evaluation of product potential for the study region. Findings of past projects and reviews including WA Search are considered along with evaluation of information provided through commissioned product reviews (see Hobbs (ed) 2008). Potential products and markets are dynamic as demand and prices vary from year to year and new policies, infrastructure and industries develop. The high priority products and markets presented in this report are based on analyses conducted in 2004. FloraSearch's "Agroforestry Species and Regional Industries" report (Hobbs *et al.* 2008) documents significant emerging products and markets and provides updated commodity values and production costs for analyses conducted in 2006.

3.3 Species Selection

The FloraSearch species selection process (Step 2) is based on the development of a series of databases on plant characteristics that enable a methodical identification and selection of species that meet the essential requirements for their development as a woody crop. It utilises extensive information on the taxonomy, distribution, lifeform, productivity, physical and chemical characteristics and prior uses to evaluate and rank the potential of species for each of the product/crop options identified in reviews of potential products and markets. Information has been gathered from state, national and private datasets, published and unpublished literature, and from extensive discussions with organisations and individuals involved in botany, land management and rural industries across Australia. Detailed information on many species is incomplete or diffuse. However, our plant databases are continually being updated as additional information becomes available. The selection process also incorporates information on taxonomic relationships between plants to infer which poorly known species are likely to have attributes worthy of testing and evaluation.

Limited resources for sampling and laboratory testing do not permit a complete evaluation of all possible germplasm. It requires a prioritisation approach that has the greatest chance of identifying suitable species, but inevitably a few suitable species or germplasm may be initially overlooked. FloraSearch species selection is an ongoing and iterative process, constantly being refined to more confidently target species, subspecies and variants with the greatest potential for development. The degree to which each species or taxa meet the essential requirements of woody crop development enables the prioritisation of each species/taxa for further evaluations and product testing.

3.4 Species Evaluation

Species and germplasm identified and prioritised by the FloraSearch species selection process are chosen for preliminary sampling, lifeform and productivity measurements, product testing and regional suitability mapping (Step 3). Laboratory analysis of wood, leaf and biomass properties provides insight to likely yields from each species for each industry type. Information gathered in this process is then methodically reviewed and the suitability of the germplasm for FloraSearch products and markets evaluated. Results are fed back into the plant databases to permit more detailed analyses of germplasm suitability and potential for development. Species and germplasm identified in this process are then chosen for more detailed germplasm sampling, testing, evaluation (including field trials), research and development (Step 4).

Most of the woody species that occur in the low rainfall FloraSearch region are poorly known in terms of wood/biomass characteristics, industry potential and productivity. However, some FloraSearch species also occur in the higher rainfall zone where they have been utilised in existing industries. Many of these typical forestry species have been tested, trialled and evaluated (including some germplasm development) for pulp, fibreboard and bioenergy industries in high rainfall areas. Some have a high potential for use as short-cycle crops in the FloraSearch region, but require further germplasm, material testing and productivity assessments in lower rainfall environments.

3.5 Regional Industry Potential Analysis

The regional industry potential analysis (RIPA) is designed to provide a preliminary evaluation of the economic feasibility and regional potential of representative species and industries in the FloraSearch study area (Step 5 [part], Step 6 [part]). With limited species attributes and productivity data, simple farming system design, and simplified economic and industry data, the analysis provides an indication of the potential spatial distribution of targeted industries and economic returns to landholders in the region.

Indicative productivity and yield data for five representative plant species have been matched to five core FloraSearch industries (i.e. pulp, fibreboards, essential oils, bioenergy, fodder) and several multi-product combinations. Economic and sensitivity analyses for each of these species/industry combinations provide an opportunity to estimate likely financial returns to primary producers. Economic analyses are then merged with spatial information on plant productivity, existing industries and associated facilities within a geographic information system to estimate the likely spatial distribution of economic returns (or losses) in the FloraSearch region. For each industry type the geographic information system and economic models forecast estimates of the likely financial returns for landholders providing feedstock to existing industries, and potential returns if new facilities were to be developed in the region. Although these economic analyses focus on expected landholder returns from farm forestry options at each point on the landscape, the spatial distribution of these likely returns can be used by large-scale biomass industries and government agencies to make informed decisions about potential for industry development at a regional level.

3.6 Future Development

This report provides preliminary evaluations of targeted species and industries for commercial development in the FloraSearch region based on analyses conducted in 2004. Results from initial species selection and evaluation processes will be used to determine which species warrant further research and development. Limited information on the productivity and physical/chemical attributes of nominated species, under cultivation in low rainfall environments, will be bolstered by field trials, and more detailed germplasm testing and development to be undertaken in the coming years (see Hobbs *et al.* 2008). Further research work will also develop the latter stages of the commercial development process, including research on farming system designs, more detailed economic and regional analyses, harvest technologies, and industrial processing.

4. Products and markets

4.1 Reviewing and Selecting Target Product Groups

Several preceding studies have considered the potential of commercial agroforestry in the low to medium rainfall zone of southern Australia (Zorzetto and Chudleigh 1999, Australian Greenhouse Office and Murray-Darling Basin Commission 2001). Zorzetto and Chudleigh (1999) investigated a wide range of enterprises particularly sawn timber, firewood, biomass for electricity and eucalyptus oil, with other enterprises given more descriptive consideration. It was concluded that fodder, eucalyptus oil and electricity from by-products and residues were most likely to be commercially successful. Latter projects such as WA Search, JVAP Best Bets and other market specific reviews have contributed to the development of a more detailed information base upon which to select key product areas. Product areas that have already been reviewed as part of these previous projects include:

- Appearance Grade Timber
  (Hague et al. 2007)
- Dry Formed Fibreboard (MDF)
  (Hague et al. 2007)
- Wood-Plastic Composites
  (Hague et al. 2007)
- Electricity from Woody Biomass
  (Hague et al. 2007)
- Alcohols – Ethanol and Methanol
  (Hague et al. 2007, Foran and Mardon 1999)
- Pyrolytic Bio-oil
  (Hague et al. 2007)
- Pulp and Paper
  (Hague and Clark 2003).

FloraSearch sought to integrate the conclusions of these studies and extend the knowledge base by commissioning reviews of other product and market areas. The product areas upon which further research was considered warranted under the auspices of FloraSearch include:

- Essential Oils
- Orientated Strandboard
- Tannins
- Gums and Biopolymers
- Fodder
  – In Situ Grazing
  – Manufactured Fodder Products.

A review of tannin has been undertaken during the current phase of FloraSearch and is reported in Hobbs (ed) (2008). The oils, gums and biopolymers review is pending. Caroline DeKoning, SARDI, and Peter Milthorpe, NSW Agriculture, recently reviewed fodder production for in situ grazing as part of a separately funded JVAP project and will not be reported on here (see DeKoning and Milthorpe 2004). This work looked at the productivity of Oldman Saltbush on non-saline recharge land and examined the native flora of the region for their grazing potential. Fodder production based on perennial woody species was not considered in the Search project. This followed an investigation of existing perennial woody species utilised in grazing systems in southern Australia (tree lucerne and Oldman Saltbush on saline discharge sites) and the native species of WA (Lefroy 2002). This study demonstrated that the perennial component of Western Australia's native flora lacks species with sufficiently high digestibility for use as the *sole diet* of sheep and cattle, or sufficiently high production rates to be commercial (Lefroy 2002). Further work on the currently used species was recommended. FloraSearch will retain some interest in this area including fodder as a secondary product from wood production for off farm use in feedstock and will include in situ fodder systems as a principal product option within the RIPA project.

Orientated strandboard (OSB) has been considered as a product area in a farm forestry context with Freischmidt *et al.* (2001) reporting on the suitability of eight young eucalypt species for use in OSB. Further work is warranted on species suited to the FloraSearch region, particularly in the greater than 450 mm rainfall zone, where pole production from single stem tree species in a short rotation system may be an option.

A summary of past reviews and draft reviews of some of the above products are presented in the sections below. In addition there are also several reports providing economic evaluations of woody crop options (Enecon 1999; Zorzetto and Chudleigh 1999; Kingwell *et al*. 2003; Abadi *et al*. 2006; Olsen *et al*. 2003) that are used to support economic analysis in RIPA (Chapter 7).

4.2 Product Options

4.2.1 Solid wood products

Demand for solid wood products can be defined in terms of structural and appearance grade products, and is often described separately for softwood and hardwood markets (Zorzetto and Chudleigh 1999).

Australian consumption of sawn timber is estimated[3] at around 4.1 million m^3 with 66% of this being softwood and approximately 44% hardwood (Zorzetto and Chudleigh 1999). Demand in Australia is expected to increase slightly over the next decade, in line with world trends. On examination of the market prospect and economics of production Zorzetto and Chudleigh (1999) found that although there may be niche opportunities for sawn timber production in the low rainfall zone it is unlikely that production would be economically viable across large areas.

Hague *et al*. (2007) found sawn timber industries viable in low rainfall situations required minimum productivity of $5m^3$ mean annual increment per annum which is only likely in the higher rainfall part of the FloraSearch study area (Boardman 1992). Also, Olsen *et al*. (2003) in an economic evaluation of crop options developed by WA Search showed that "long-cycle tree crops have poor economic prospects in medium and low rainfall areas, due to the large cash outlay at establishment, and the long wait for returns from the crop." Long-cycle crops are unlikely to be profitable, unless the value of indirect benefits is included. Following these findings long-cycle sawn timber has been given a low priority in FloraSearch.

There is ongoing work on this area in other projects such as the Australian Low Rainfall Tree Improvement Group, undertaking germplasm improvement for solid wood industries in the 400-650 mm rainfall zone.

[3] 1996-7 figures

Conclusions

- Solid wood products from lower rainfall plantings will require long rotation times, requiring substantial investment and no early returns to investors.
- Economic returns for below 700 mm rainfall regions are questionable.
- Selection and genetic improvement of species suitable for low rainfall regions is being undertaken as part of the Australian Low Rainfall Tree Improvement Group projects.

4.2.2 Composite wood products

The Australian Greenhouse Office and Murray-Darling Basin Commission (2001) identified composite wood products, including Medium Density Fibreboard (MDF), Laminated Veneer Lumber (LVL) and OSB, as having potential for manufacture from low rainfall plantation material. These products show strong growth in demand and have significant benefits over pulp and paper in having lower thresholds for economy of scale. Linkages to regions with existing infrastructure and processing facilities or development of new processing facilities in low rainfall districts are possibilities to support low rainfall plantings.

Hague *et al*. (2007) concluded that manufacture of composites (specifically MDF) from low rainfall wood products would face competition from established sources in high rainfall zones and from overseas. While technically feasible much rides on the economics of production of suitable feedstock from low rainfall industries. Raw material requirements for manufacture of composites are flexible, although most production at present is based on softwoods, with their low densities, long fibre length, low extractive content and "user friendly" chemical properties being preferred. However, MDF is manufactured commercially from eucalypts and acacias from existing forest industries in South America, Spain and Asia.

Hague *et al*. (2007) also examined the production potential of wood-plastic composites from low rainfall materials. Wood-plastic composites have shown strong growth in North American markets but have only just started to appear in markets in Australia. At present there is little or no serious commercial production of wood-plastic composites in Australia. An estimate of the potential market share for wood-plastic composites is in the order of 50,000 tonnes of product worth $200 million per annum by 2010 with significant export potential also possible. However, this market share would have negligible natural resource management impacts as plantation area needed to supply such an industry would be small. Sources of feedstock wood-plastic composites are flexible as the process can utilise a wide range of wood materials.

The development of a new industry based on OSB and Oriented Strand Lumber (OSL) has considerable potential in Australia (Freischmidt *et al*. 2001). These products are not currently manufactured in Australia, and there is potential for replacement of plywoods on Australian domestic markets and they are well placed for export to the Asian region. High growth rates for these products are predicted. OSB was developed in North America to utilise small diameter wood resources, particularly aspen. Logs of 30 cm are ideal for flake production but diameters down to 5 cm can be utilised resulting in efficient use of the resource with little wastage. Freischmidt *et al*. (2001) tested small diameter eucalypts from high rainfall species including *Eucalyptus globulus* ssp. *bicostata, E. nitens* and *E. viminalis* and found that all flaked readily and successfully fabricated OSB board.

Conclusions

- Composite wood products have potential to drive large-scale plantings if the issues of raw material quality and economically competitive production can be addressed.
- Composite woods have well understood raw material requirements for which prospective species can be screened.

4.2.3 Pulp and paper

A review of the pulp and paper industry was commissioned from CSIRO Forestry and Forest Products (Hague and Clark 2003) by the WA Search project. The report provides an industry overview including markets, manufacturing processes, feedstocks, paper types and future trends. The following excerpts (in italics) from the executive summary of the report provide an up-to-date industry perspective:

- *The world consumption of paper products is currently around 330 million tonnes per annum.*
- *Strong growth in world demand for all the main types of paper product is expected over the next decade. Growth in the Asia-Pacific region will be particularly strong (between 6 and 12% depending on paper type).*
- *The technologies used to produce pulp and to manufacture paper will remain essentially unchanged for the foreseeable future. The most significant changes will occur in the value-adding sector of the industry, e.g. printing, coating etc.*
- *Worldwide, Kraft chemical pulp and recycled fibre currently dominate the paper industry, with each providing approximately 40% of the total fibre used in the manufacture of products*
- *Kraft pulp and recycled fibre will continue to dominate the industry in the future, and non-wood pulp will decline in importance. New Kraft mills will be constructed around the world in the next decade, with older, less competitive mills being closed.*
- *The current market for hardwood chips for pulping in the Asia-Pacific region is around 13.5 million bone dry tonnes per annum. Japan is the dominant consumer (87%), and Australia is a major supplier (30%). The hardwood chip market in the region will remain strong in the future, with Japan continuing as the principal consumer.*
- *Woody biomass grown in the low rainfall agricultural regions of WA would most likely be derived from hardwood species. The material could thus potentially be a feed-stock for the Kraft hardwood pulp industry.*
- *To penetrate the wood chip market, low rainfall woody biomass would need to be competitive with respect to price and quality, with pulp yield, wood density and fibre length being the key material properties that would need to be addressed.*
- *A major barrier to market entry could be the generation of feed-stocks from species which were new and unfamiliar to the pulp industry. Significant initial investments would probably be required (from growers and suppliers) to ensure that the resource became accepted in the market place.*
- *An ideal scenario for low rainfall woody biomass would be the construction of an "in-land" pulp mill in WA, which could be supplied by wood resources derived from both high and low rainfall zones. This would reduce the impact of transport costs. However, it is likely that significant incentives would be required to persuade potential investors to fund such a venture.*

The pulp and paper products market could be accessed by low rainfall wood product for use in the domestic manufacture of pulp and paper, or by export of raw materials in the form of woodchips. While both mechanisms have potential, restrictions on the scale and cost of new infrastructure limit the potential for establishment of new pulp mills in low rainfall areas. The Australian Greenhouse Office and Murray-Darling Basin Commission (2001) noted that new mills must be of world class scale, requiring investment of AUD$1 billion and up to 3 million green tonnes per annum of feedstock. World scale Kraft plants have an output of 750,000 tonnes per annum whereas a chemi-thermomechanical mill would have an output of 250-300,000 tonnes per annum but this type of mill is less likely to be used for hardwood. Developments accessing low rainfall regions are more likely to succeed in areas adjacent to existing high rainfall forestry areas (Hague and Clark 2003).

Export markets for woodchip depend not only on the quality of raw material but also most importantly on the cost of production and transport. Hicks and Clark (2001) noted that wood costs are the single largest variable cost of producing chemical pulp for papermaking with chemicals comprising a much smaller proportion of the total costs. Recent trends demonstrate the expansion of plantations in high rainfall areas adjacent to export port facilities, thus lowering transport costs (Australian Greenhouse

Office and Murray-Darling Basin Commission 2001). This may be a significant challenge to production in low rainfall areas, which are more distant to port facilities than traditional high rainfall forestry regions.

WA, SA and Victoria state governments are seeking investors for the construction of pulp mills suited to *Eucalyptus globulus* feedstocks with the Portland-Mt Gambier region in the Lower SE of SA and Western Victoria a possible site (Leith Davis, pers comm.). There is ongoing expansion of woodchip exports as *E. globulus* forest developments come on stream. A blue gum chip mill and export facility was recently commissioned at Albany, WA, with a design capacity of around 1,000,000 tonnes per annum and Portland, Victoria, has a chip mill and export facility with a throughput of 850,000 tonnes per annum.

Conclusions

- Pulp and paper have potential to drive large-scale plantings if the issues of raw material quality and competitive production can be addressed.
- Pulp and paper have well understood raw material requirements for which prospective species can be screened.

4.2.4 Carbonised wood (charcoal and activated carbon)

Carbonised wood has three major applications: activated carbon, a reductant in metals production and a fuel source. Bio-oils are a common by-product of the carbonisation process and residues may be combusted for process heat or electricity. An intermediate product between wood and charcoal is "torrefied wood" which is suitable for co-firing with coal in a power station (Arcate 1998).

Activated carbon has application in waste treatment, gold mining and some manufacturing applications (Zorzetto and Chudleigh 1999). Carbon reductants from wood sources are preferred for production of silicon for alloying and electronic and photovoltaic applications due to their low ash content (Fung and Connor 2002). It is of lower value than activated carbon and probably not a tradeable commodity. Simcoa Operations Ltd have a reductant charcoal and silicon plant in operation in Kemerton, WA.

Activated carbon consumed by industry in Australia is generally imported from Asia where it is produced from coconut shells (Zorzetto and Chudleigh 1999). The Western Power – Narrogin plant in WA will produce activated charcoal once production begins, using patented technology developed by CSIRO Forestry and Forest Products (FFP).

Conclusions

- Carbonised wood products are likely to have a relatively small market potential and be limited to being a co-product.

4.2.5 Energy products – electricity

Zorzetto and Chudleigh (1999) rated biomass for electricity production as the third highest priority product from low rainfall agroforestry. There are several processes used for conversion of biomass to electrical energy some in commercial use internationally and in Australia (Hague *et al*. 2007);

- Direct combustion
- Co-firing with coal
- Gasification (heating in the presence of oxygen to produce a combustible gas)
- Pyrolysis (see Section 4.2.6)
- Cogeneration (production of both heat and power)
- Production of liquid fuels to power electrical generators.

Of these processes co-firing with coal in existing power stations and gasification are most likely to be viable in the Australian situation in the shorter term (Hague *et al*. 2007). A comparison of the costs of electricity from a variety of current generation technologies shows that conventional coal fired is the cheapest energy source. In general, biomass energy is more expensive to produce but is attractive when compared to other renewable sources (see Table 2).

Table 2. Comparison of current and projected generation costs of sources of electricity generation and their greenhouse gas contribution.

Technology	Greenhouse Gas intensity Kg CO_2/ kWh	Generation Costs per MWh	Generation Costs *long term trends to 2010* per MWh
Conventional			
Brown coal fired	1.1 - 1.2	$ 30 - 40	$ 40 - 50
Black coal fired	0.9 - 1.0	$ 30 - 40	$ 40 - 50
Gas fired single cycle	0.5 - 0.6	$ 40 - 50	$ 45 - 55
Gas fired combined cycle	0.3	$ 40 - 50	$ 45 - 55
Cogeneration gas fired	0.2	$ 40 - 55	$ 45 - 55
Renewables			
Biomass	"effectively no emissions"	$ 50 - 70	$ 50 - 55
Wind		$ 75 - 90	$ 55 - 60
Solar thermal		$ 100 - 200	$ 70 - 100
Solar photovoltaics		$ 480 - 800	$ 90 - 200

Source: Energy SA (2001).

Market factors currently driving increased adoption of renewable energy include the Commonwealth's Renewable Energy (Electricity) Act 2000. The mandatory renewable energy target (MRET) establishes a market premium for electricity from renewable sources. This includes energy sourced from biomass but current anomalies in the regulations preclude feedstock sourced from plantations grown solely for energy.

Electricity production from biomass is unlikely to be economic in its own right. Hague *et al.* (2007) stated that "even when biomass is available at near zero cost, with current technology it is not feasible to generate and supply electricity at a similar cost to that of the coal-based industry." Cost of supply of raw biomass significantly affects the competitiveness of the end product (Enecon 2002a). Co-production of biomass energy products such as eucalyptus oil and activated carbon as proposed in the Integrated Tree Processing plant at Narrogin in WA (Enecon 2001), is more likely to produce a commercial result. Current projects to produce electricity from biomass are being developed in Australia but mainly where biomass waste products such as forestry waste and bagasse are available at low or negative costs.

Market niches where electricity from biomass may prove to be most competitive include:

- Small scale biomass plants in regional areas where competition from other energy sources is lower and regional distribution networks favour distributed generation
- Situations where a combination of products are produced from biomass raw materials
- Where co-generation can improve the efficiency of generation
- Where market premiums, such as the sale of renewable sourced power to consumers at a higher price, can be utilised to increase the value of renewable energy.

Electricity generation from biomass, in particular woody crops, is inherently flexible and can accommodate a wide variety of biomass sources. Some of the key aspects determining suitability for biomass energy applications are water content of biomass source and calorific value. However within limits, quantity and price of supply of raw material are the primary determinants of feedstock suitability.

Conclusions

- Electricity generation from biomass is technically feasible with a variety of processes and plant available for implementation.
- It is likely to succeed only as a co-product and where cost of biomass supply is competitive.
- The market for electrical energy is sufficiently large to be a major driver, but market success will be determined by competition with fossil fuels. Key regional and industrial situations may prove to be market entry points for biomass energy.
- Market drivers for renewable energy such as MRET can advantage biomass energy from plantations, provided regulations are compatible with plantation sources.

4.2.6 Liquid fuels

There are three main types of liquid fuel that can be produced from woody biomass: ethanol; methanol; and pyrolytic bio-oil and its derivatives. The technical issues surrounding production from woody biomass and the potential of each of these products to become major commodities in the Australian market place are reviewed by Hague *et al.* (2007).

4.2.6.1 Ethanol

Ethanol is used as a transport fuel in internal combustion engines either as a mixture with petrol or as a pure fuel. While only low level mixtures are available in Australia, it is a common fuel in North and South America. About 3.3 billion litres of ethanol are produced world wide annually mainly from cereals or sugar (Hague *et al.* 2007). However any major expansion of the renewable fuel alcohol industry in Australia would need to derive feedstock from alternative sources such as woody biomass due to limited supply of sugar or grain emerging from competition with other market sectors. Although considerable technology and knowledge exists on the conversion of woody biomass to ethanol with several pilot plants in existence, there are no full scale woody biomass to ethanol plants currently operating anywhere in the world (Enecon 2002b).

The cost of conversion of woody feedstock to ethanol is the key limitations on the adoption of ethanol from woody biomass as a major commercial commodity (Foran and Mardon 1999). Compared to the traditional feedstocks of grain and sugar containing starch and simple sugars, woody biomass requires more steps in the process and results in by-products with little commercial value.

Hague *et al*. (2007) reported estimates for cost of production of ethanol from biomass as ranging from A$0.31 per litre to A$1.90 per litre. The lower estimates included production from mixed woody and non-woody sources. The most optimistic estimates suggest production costs for ethanol from woody biomass to be double that of petrol. Partial or complete exemption of excise duty would be needed to enable it to compete with petrol in the market place. Advances needed to decrease the cost of production include development of technologies to increase the recovery of ethanol from woody feedstock and markets for by-products.

Hague *et al*. (2007) reported that woody crops with high cellulose content would be advantageous for ethanol production and that selection of such species could be linked to plant selection and breeding for chemical pulp production.

4.2.6.2 Methanol

Methanol is one of the major commodity chemicals of the industrialised world. Much of it used to produce methyl-tertiary-butyl ether octane enhancer in unleaded petrol. It is also a potential replacement or supplement to transport fuels derived from petrochemicals. Foran and Mardon (1999) report that it is the fuel substitute of choice in Europe, while ethanol is favoured in

North and South America and Australia. Methanol is more toxic than ethanol but has advantages in higher conversion efficiencies from woody material and the existence of available technology for conversion of woody biomass.

The technology used for conversion of woody biomass to methanol appears well established with few major technical hurdles to be overcome. However Enecon (2002b) noted that although smaller scale demonstration plants exist, no full scale integrated wood-methanol plants have been developed Methanol is readily and cheaply produced from fossil resources with natural gas being the main current source (Hague *et al*. 2007).

Advantages of methanol over ethanol include the efficiency of conversion from raw biomass with conversion efficiencies of 40% reported for methanol and only 16% from ethanol from woody biomass (Foran and Mardon 1999). Methanol production is relatively insensitive to the type and quality of biomass feedstock. As the gasification process breaks down all substances (including lignin) to carbon dioxide, carbon monoxide, hydrogen and water. The utilisation of the lignin fraction adds to the conversion efficiency to methanol over ethanol where lignin is not utilised.

Biomass to methanol plants are likely to be less costly to construct than ethanol plants due to lower technical requirements and similarities to existing oil and gas facilities (Foran and Mardon 1999).

Foran and Mardon (1999) estimated costs of $1027 per tonne for methanol produced from woody biomass. When compared to market prices of $162 per tonne it leaves a considerable economic feasibility gap. Enecon (2002b) reported cost estimates of A$0.62/l for production of methanol from biomass, based on world's best technology, with a predicted price of A$0.50/l in fifteen years time with improvements in production processes.

Hague *et al*. (1999)[4] report that the hybrid HYNOL process where natural gas and biomass are used together to produce methanol has the possibility to be competitive with current industrial processes, producing methanol for US$0.114/litre. However these efficiencies are limited to a production plant requiring 1.6 million tonnes of dry woody biomass annually and therefore requiring substantial investment. It was concluded that the suitability of this industry for low rainfall regions was highly questionable because of the low productivity rates with resulting long distances to a plant. Haulage costs alone were expected to be prohibitive.

4.2.6.3 Pyrolytic bio-oil

Pyrolytic bio-oil is one of the potential products from pyrolysis of woody biomass material. A number of pyrolysis processes can be used to produce bio-oil, either as the major product (e.g. through flash pyrolysis) or as a co-product in conjunction with production of charcoal (slow pyrolysis). Bio-oil is produced by flash pyrolysis when small particles of biomass are subjected to high temperatures in the absence of oxygen, and the resultant gaseous mixture is condensed to a complex mix of organic liquids, solid char and uncondensed gaseous residue. Optimal recovery from this process can be as high as 75-80% bio-oil from the original biomass.

Hague *et al*. (2007) reviewed the potential of pyrolytic bio-oil as a driving force for low rainfall biomass production. Among the product areas and uses of bio-oil they identified were:

- A partial replacement for diesel in transport fuels
- A fuel for electricity generation through co-firing with coal or use in diesel fuelled generators
- Isolation of organic compounds (e.g. chiral synthons) within the bio-oil fraction for use in pharmaceutical uses

4 Citing Dong, Y. L. and Steinberg, M. (1997) HYNOL – an economical process for methanol production from biomass and natural gas with reduced CO_2 emission. International Journal of Hydrogen Energy. 22, 971-977.

- Extraction of phenol for use in phenol formaldehydes adhesives or as a feedstock for manufacture of polycarbonates
- Extraction of other organic compounds for uses in manufacturing and industry.

Bio-oil has been produced commercially from Australian native eucalypts in Brazil as a by-product of charcoal production (Fung and Connor 2002). It is currently produced from other biomass sources in commercial plants in Canada and the USA (Hague *et al*. 2007) for use in electricity generation and extraction of other organic compounds. However, in most cases bio-oil is a by-product and full commerciality has not been demonstrated.

Preliminary research on the nature and properties of pyrolytic bio-oil produced from eucalypts has been carried out in Australia, particularly the characterisation of bio-oil from red gum and jarrah (Bodnar *et al*. 2002; Connor *et al*. 2002). Indications from research to date suggest that pyrolytic products from hardwoods are more complex in their chemical composition than those derived from softwoods.

Hague *et al*. (2007) concluded that although pyrolytic bio-oil appears an attractive multi-use product from low rainfall biomass industries there are a significant number of barriers to its adoption. These centre around the cost of production of bio-fuels from pyrolytic bio-oil, the cost of extraction of useful compounds, and the need for advances in technology for economically efficient production on a large scale and fractionation into useful components.

Conclusions

- Ethanol from woody biomass is technically feasible but with current production methods and efficiencies is not price competitive with petrol.
- Penetration of non-fuel markets would encounter similar cost of production barriers.
- Methanol production from biomass is technically feasible but not cost competitive with methanol from natural gas.
- Methanol is not used as a fuel substitute in Australia where ethanol is favoured as a fuel substitute. Methanol is toxic and is a danger to human health and the environment.
- Ethanol or methanol production may be market drivers in the longer term as price competitiveness improves.
- Regulatory or other market mechanisms may provide a driver for the use of bio-alcohols in fuel but are unlikely to bridge the price gap with petrol.
- Pyrolytic bio-oil has not advanced to a commercial level and is dependant upon improvements in technology to provide suitable economics of production.
- Pyrolytic products are in direct competition with fossil resources and are unlikely to be competitive in the near future.

4.2.7 Essential oils

The extraction of essential oils from the leaves of members of the Myrtaceae family, particularly *Eucalyptus* and *Melaleuca* species, has a long history. There is extensive scientific literature that provides prior testing results of many southern Australian species. Turner (2001) and Bodopati *et al*. (2000) identify some commercially important constituents of Eucalyptus and Melaleuca oils to be:

- 1,8-cineole has a wide range of useful properties of industrial importance with one of the most significant being its stability against oxidation or polymerisation reactions that affect some natural oils during storage. Presently, its major uses have been confined to the medicinal and cosmetic industries. To date large-scale industrial applications have not been developed due to small scale production, high cost, low reliability of supply and strong competition from other materials.
- Phellandrene and piperitone are the major components of eucalyptus oil presently isolated for industrial use.

- Phellandrene is widely used in the manufacture of inexpensive disinfectants.
- Piperitone is the principal raw material for the manufacture of synthetic menthol and thymol (a fungicide).
- Methyl eugenol and E-methyl isoeugenol are of commercial interest.
- Terpinolene is the principal ingredient of the microbially active oil from *Melaleuca alternifolia.*

The pharmaceutical market for eucalyptus oil has remained relatively constant over the past four years with a total world market around 3,000 tonnes per annum. It is highly unlikely that this market will grow significantly unless new value-added products are formulated and marketed. The limited market size for pharmaceutical eucalyptus oil, combined with China's aggressive dominance of the world market and commitment to supply (even at below cost), provide little possibility for increased Australian supply to the world market (Zorzetto and Chudleigh 1999).

There is a strong focus in WA on the development of a eucalyptus oil industry. A large-scale market is being sought for eucalyptus oil as either crude oil (ca. 80% cineole) and/or pure cineole. Cineole's properties suit it to the industrial solvent market offering potential for large volume consumption of eucalyptus oil replacing synthetic products such as trichloroethane (Turner 2001). There may be potential in supplying other niche solvent markets, such as hand cleaners, where world prices may be greater (US$3.00/kg oil in 1999). Qualities such as being a natural product and low irritant, allow for easier marketing of eucalyptus oil in this market. Estimates of the world market indicate it is large enough to support large-scale production of eucalyptus oil in Australia. However, this potential is subject to commercial cost of production with cineole needing to compete against fossil resource derived solvents as well as other natural and cheaply produced products such as limonene and pinene (Zorzetto and Chudleigh 1999).

Promising areas for improvement in the economics of eucalyptus oil production in Australia are harvesting, processing and genetic improvement of planting materials leading to efficiency gains.

Conclusions

- Oils from biomass leaf fraction are a prospective option for southeastern Australia as identified for the WA ITP project.
- Improvements in harvesting and processing technology may lead to reduced production costs and the potential of supplying commodity markets for industrial solvents.

4.2.8 Tannins

FloraSearch commissioned CSIRO Forestry and Forest Products in 2003 to review the tannin industry. See Van Langenberg (2008) in Hobbs (ed) (2008) for details of this review.

Tannins are a class of polyphenolic materials produced as plant secondary metabolites. A search of the scientific, patent and commercial literature has found several potential applications for tannin-based products including:

- Tanning agents
- Wood adhesives
- Water flocculants
- Anti-corrosives and protective coatings
- Conditioning agent for drilling mud
- Biocides and wood preservatives
- Pharmaceuticals.

Tannins can be classified into condensed and hydrolysable tannins (Hillis 1997). The hydrolysable tannins were of great importance to the tanning industry but have been replaced by condensed tannins due to greater availability. The condensed tannins represent most of the important tanning materials, such as wattle or "mimosa", quebracho, mangrove and hemlock. The extraction of tannins from bark is typically achieved by water extraction from ground bark and spray drying of the solution to give a solid tannin extract.

There is a history of tannin extraction from the bark of Australian Acacia species. Barbour (2000) studied the suitability of plantation bipinnate acacias to produce tannin and fuel wood. The project investigated 12 different species and found that *Acacia mearnsii* was the most suitable species for tannin production in south-west Australia.

The tannin market is currently dominated by tannin extracted from Black wattle (*Acacia mearnsii*) (Doran 1995). Black wattle is grown commercially for tannin and wood products in a number of countries including South Africa, Brazil, China, Kenya, India, Zimbabwe and Tanzania with approximately 500,000 ha currently being grown. The bark of black wattle has been noted for its high tannin content of 36-44%, depending on site quality. Tannin extracted from the bark of the Green wattle tree (*Acacia decurrens*) has also been used overseas, particularly in Indonesia, where it has been used in fibreboard manufacture.

Australia currently imports all its tannin needs and this market has been estimated as approximately $10 million worth of tannin (*ca* 7,000 tonnes) per year. Approximately 600 tonnes is used in the leather industry whilst the remainder is used in the manufacture of adhesives for wood composites. The tannin from *Acacia mearnsii* appears to be preferred as a wood adhesive due to its bond strength and water repellency.

There have been many attempts to commercially utilize tannins with most of these operations failing. The failure has been attributed to a number of factors, including not being cost competitive with synthetic chemicals (such as phenol), inherent variability and limited stability of many tannin extracts, and failure to recognize industrial application and performance requirements. The timber industry has explored the feasibility of tannin extraction from bark waste from existing timber processing plants. Bunnings Timbachem conducted an economic viability study of a tannin extraction plant located next to a primary processing plant in 1988. The results of this study indicated that there was an attractive opportunity to supply a liquid tannin concentrate instead of the imported powdered extract. A liquid extract would eliminate the spray-drying equipment required to produce a powdered extract and reduce the capital investment. The cost of such a plant was estimated to be in the order of $200,000-500,000 (in 1988 dollars). An example of a failed tannin processing venture can be found in Chile. Chile imports approximately 4,000 tonnes of plant tannin a year. A pine tannin extraction facility was set up that had the capacity to produce 600 tonnes of tannin extract a year. However, the cost of producing the tannin extract was twice the price of the imported product (which was approximately US$1/kg) and the plant has since closed (Van Langenburg 2007).

There are several products that tannin produced in Australia must compete with, including imported tannins, tannin from other sources such as pine plantations and from chemicals produced by the petrochemical industry. Tannin is seen as a replacement for phenol and resorcinol in wood adhesives used for wood composite manufacture. Any tannin product must be able to compete on price with phenol. The spot price of phenol in the Asia Pacific region was around US$680-780 per tonne in October 2002 (Van Langenburg 2008).

The Australian Greenhouse Office (2001) found that the market for tannins is modest and that the market was unlikely to increase significantly. The production of tannin in Australia from mid to low rainfall areas was identified to be a high risk.

Conclusions

- Wood adhesives would be the largest market for tannin extract needing to replace petrochemical derived phenol and resorcinol.
- Other potential niche markets for tannin are small or still in the development stage.
- Australia imports all of its tannin with the quantity coming into Australia increased dramatically over the last 4 years. The price of the tannin extract has more than halved to A$0.60/kg.
- A stand-alone tannin industry in Australia would be a high-risk proposition.

4.2.9 Gums and biopolymers

Many plants occurring in the FloraSearch study area produce water-soluble polysaccharides (gums). Notable species include many of the Acacia genus and a number of other native plants such as *Brachychiton populneus,* *Alectryon oleifolius, Atalaya hemiglauca, Crotalaria eremaea, Lysiphyllum gilvumn* and *Ventilago viminalis*. The gums are exuded from the sites of injury into cracks and crevices in the bark or as irregular masses or "tears" onto the surface of the trunk or branches.

On an international scale the most important plant-derived exudate gum is Gum Arabic (*Acacia senegal* from Sudan). Gum production is a cottage industry involving rural communities that artificially wound trees, manually collect the tears of gum, and transport them to centres where they are cleaned to remove impurities and extraneous material. The total annual production of Gum Arabic was approximately 60,000 tons in the early 1990's (Whistler and BeMiller 1993). Supplies of good quality Gum Arabic have decreased because of the long-term civil disturbance in the Sudan and because of insufficient financial rewards for gum collectors. Insecurity of supply of plant based gums has stimulated the development of substitutes with notable centres of this work being the Whistler Centre for Carbohydrate Research, Purdue University, USA, and in Australia the CRC for Bioproducts which has a major interest in this area. Substitutes are being produced by modification of starches and bacterial and plant cell cultures. While this creates the impression that the market for plant-derived exudates gums has a limited future, none of these alternatives have the same desirable physical properties of Gum Arabic (Seigler 2002). In light of the world market for quality gums if a new plant based source was developed at reasonable cost, demand could well increase.

Technically the term "gums" refers to any polysaccharide that is dispersible in water to give a viscous solution, gel or colloidal dispersion. Gum Arabic is almost odourless and tasteless, highly soluble in water at concentrations of up to 50% by weight, and produces a clear mucilaginous solution of relatively low viscosity (Wang and Anderson 1994). Properties that decrease the value of gums include insolubility, dark colour, strong taste and the presence of tannins.

Most of the useful properties of gums are associated with their ability to form hydrophobic or hydrophilic colloids or gels at low dry substance content (Whistler and BeMiller 1993). The particles in solution or suspension become hydrated and associate with each other and with other particulate matter in various products (coacervation) (Glicksman and Sand 1973). Coacervates are considered as large interacting groups of molecules including the gums, water, and other components consisting of colloids with opposite charge. These interacting units "thicken" mixtures and keep various components from settling out of suspension or from crystallizing. When mixtures of this type are spray dried, or prepared by other technologies, the gums bind to various oils, carbohydrates, and proteins, stabilize and protect them from water. This "microencapsulation" of mixture components can produce free-flowing powders of otherwise intractable and even hazardous ingredients, making them more stable, as well as easier and/or safer to utilize.

Gums are important components of many products and processes including:

- Prepared food products as thickeners and emulsifiers to modify physical properties of the foods and to make them conform to consumer preferences
- Non-food applications such as cosmetics, toothpaste and dentifrices, soaps and laundry detergents, adhesives, paper and fabrics, and coatings for paper products
- Medical applications including emulsifiers and suspending agents for pharmaceuticals, antiseptics, pill and tablet manufacturing, and replacements for gelatin in capsules.

In the past gum, from a few Australian Acacia species including *Acacia pycnantha, A. decurrens, A. dealbata, A. sentis,* and *A. homalophylla* was collected and marketed (Glicksman and Sand 1973). Gum from *Acacia rivalis* provided the basis of a small commercial gum industry in Blinman, South Australia in the early 1900s (Whibley and Symon 1992). Most of these Australian gums were considered to be of inferior quality as they dissolved poorly, were darkly coloured, strong in taste, and had a tendency to form gels rather than mucilage with water.

There have been recent studies of acacia gums' physical and chemical properties. Some of those that occur in the study area include: *Acacia calamifolia, A. cyclops, A. dealbata, A. dealbata* species, *subalpina, A. deanii, A. decurrens, A. difformis, A. implexa, A. jennerae, A. leucoclada, A. ligulata, A. murrayana, A. pycnantha, A. retinodes, A. salicina* and *A. victoriae* (Anderson and Karamalla 1996, Anderson *et al*. 1971, 1972, 1984a, 1984b, 1985, Anderson and McDougall 1988). These studies provide information on the basic chemical properties of the gums but an evaluation of commercial potential following this testing is not available on the public record.

Cottage based approaches to gum production will not be economically feasible in Australia where production will require mechanised bulk handling of biomass and be linked to other on-going processes and co-products.

Conclusions

- Gums represent a resource that can complement other products and offer additional income for farmers. If wattle species are cultivated, harvested and used for sources of wood products, it may be possible to isolate gums as a by-product of these processes.
- Gums are a vital ingredient for food processing and there may be considerable market potential for an economically produced quality product.
- The Australian gum producing species have not been systematically tested with only a minor proportion of the species having been examined.

4.2.10 Fodder

Animal production is a predominant industry across the FloraSearch study area. Mostly this is integrated into grain production in the wheat-sheep zone but will grade into grazing-only farming systems on the high and low rainfall fringes of the area. SARDI and NSW Agriculture researchers plan to conduct studies of in situ grazing species and systems in the near future. As a result FloraSearch's fodder research efforts will be concentrated on industries using fodder species as a coproduct to other industries or harvested for off-farm use. Fodder harvested for off-farm processing has high potential use in feedlots, feed processing mills and supply to export feed markets. The Stock Feed Manufacturers' Council of Australia (SFMCA) represents feed milling companies throughout Australia and its members manufacture over 4,500,000 tonnes of feed annually, representing over 90% of all commercial feed sold within Australia (http://www.sfmca.com.au / info_centre/about_sfmaa/). Feedlot animal production is a major consumer of feed commodities with consumption of 2.3 million tonnes in 1994/95.

Zorzetto and Chudleigh (1999) reported on trees and shrubs planted for fodder production as an area of considerable promise. Also, Kingwell *et al.* (2003) stated that "perennial fodder species appear to offer the best short to medium term prospect of providing a means of managing salinity in many agricultural areas through boosting farm profit." The idea of integrating dual-purpose fodder trees that can be established and maintained in the normal course of farming through alley farming systems, offers potential (Knight *et al*. 1998). Historically, trees and shrubs, referred to as browse or top feed, have played an important role in animal production where there is a pronounced dry season. They provided supplementary feed when annual food sources are in short supply in late summer and autumn and can be the only feed reserve during drought.

There may be disadvantages of trees and shrubs as a food source as they are slow to establish requiring isolation from stock and may require new management strategies resulting in a higher cost of establishment and management in comparison with traditional pasture systems. The foliage often has higher levels of fibre and lignin than annuals, and may have high levels of anti-nutritive compounds such as tannins and oxalates. There is a shortage of technical information to evaluate the usefulness of native species for stock food. Most commentary is observation of palatability with some published chemical testing information of protein content and digestibility. The most important measure of fodder value is the weight gain produced by animals feeding on leaf material and this has not been undertaken. The introduction of evaluation with the grazing animal at a relatively early stage in the development of new forage species is recommended. This needs to be coupled to the biomass production of a species in different sites to provide a measure of digestible productivity. The generally accepted relationship between effective rainfall and forage production for the southern Australian climatic zone is around one tonne of digestible feed per hectare for each 100 mm of rain (Lefroy 1994).

Lefroy (2002) reported that there are currently approximately 200,000 ha of cultivated forage trees and shrubs in Australia. In southern Australia most of the plantings are Tagasaste (100,000 ha), Oldman Saltbush (50,000 ha) and *Acacia saligna* (10,000 ha). There has been minimal development work on any other species. Saltbush pastures and particularly Oldman Saltbush have been held in high regard from the early development of southeastern Australia's pastoral industry where they are considered to be amongst the most productive natural pastures. Research work into the productivity of planted stands has focused on salt affected regions where the evidence is that sheep do not thrive on saltbush alone due to excessive salt uptake (Lefroy 2002). Research is still needed on the productivity of Oldman Saltbush systems on non-saline recharge areas (Milthorpe, pers. comm.).

Conclusions

- There is potential to expand adoption of grazing systems based on perennial woody species in southern Australia, to increase farming system resilience throughout the year, and by providing feed reserves in late summer, autumn and during drought conditions.
- The livestock industry is well established in the study zone. Productive grazing systems have the potential to be readily accepted by farmers and adoption on even a modest scale could provide substantial natural resource management benefits.
- Some sectors of the livestock industry have been through a severe downturn with farmers abandoning sheep and relying on continual cropping of grain.

4.2.11 Other products – plant secondary compounds

The products and markets discussed above represent the major groups with potential to drive industry establishment, but many other compounds occur in smaller amounts or are less widespread across species. Some of these compounds could have commercial potential. Generally these substances include:

- Latex – Worldwide there are thousands of hydrocarbon producing plants that have been evaluated as commercial sources of oil and chemical resources. Well known species include *Euphorbia lathyris* and *Parthium argentatum* (Guayule). There are several native species occurring in the study area, usually of the families Euphorbiaceae, Apocynaceae and Asclepiadaceae that produce latex in the leaf and stem. Examples include *Sarcostemma viminale* subspecies *australe, Adriana klotzschii, Carissa ovata* and *Phyllanthus saxosu*.
- Terpenes – These are employed primarily as adhesives that might be useful in the manufacture of wood products such as fibreboard. Some diterpenes may serve as relatively versatile precursors for synthesis of other groups of useful compounds.
- Saponins – These glycoside compounds are often referred to as "natural detergents" because of their foamy texture. Saponins are in a diverse group of glycosides. Saponins are glycosidic compounds composed of a steroid or triterpenoid saponin nucleus with one or more carbohydrate branches. Saponins are of interest because of their biological activity including as anti-carcinogens.
- Proline analogues – Plants accumulate these low-molecular weight organic osmoprotectants in response to various environmental stresses. These

solutes include sugars, sugar alcohols (polyols), an amino acid (proline) and their N-methyl derivatives (including betaines). These substances contribute to stress resistance by osmotic adjustment and by protecting and stabilising proteins and membranes. The genus *Melaleuca* has been a particular interest in regard to these chemicals and there is a demonstrated relationship between the chemical nature of the proline analogues accumulated and the ecological habit of various species (Naidu *et al*. 2000). There are agricultural applications of these proline chemicals. Germination and vigour of salt-affected commercial crops such as wheat, cotton, and pasture legumes were significantly increased by treating seed with betaine (Naidu 1995). Finnsugar Bioproducts based in Helsinki, Finland, produces an estimated 90% of the world production of betaine as a by-product from the sugar beet industry. The current price in Australia is about $25, up from $4 in 1991. Finnsugar is well advanced in a program to utilise betaine for foliar application on various crops. An increase in demand for betaine of at least 100 fold is predicted if the foliar application technologies become successful for other horticultural crops. On this basis, the current production from sugar beet would be insufficient to provide for expected future requirements and suggests the need to look for alternative sources.

- Alkaloids and pharmaceutical compounds – This is a highly specialised area of plant compound research and development. With other bioprospecting projects currently being undertaken in Australia, it is not an active area of FloraSearch research.

Conclusions

- Secondary plant compounds have potential for being valuable co-products of other crops.
- Many of these compounds are topical, with widespread interest in their investigation.
- Specialised methods of testing are required.

4.3 Focus Markets for FloraSearch

4.3.1 Background

With the large number of prospective products available it is essential to prioritise and select a small subset of products on which to focus attention. Each product will have particular feedstock requirements and these can then define the sampling and testing protocols.

Olsen *et al.* (2003) suggested the following criteria by which the potential of each product option may be assessed:

- Domestic market size
- Export market size
- Growth rates of domestic and export markets
- Market stability (probability of rapid change in demand or supply)
- Accessibility of markets;
- Flexibility of the product to use a range of feedstock sources and attributes
- Sensitivity of product cost to feedstock cost (to maximise advantage of low-cost wheatbelt producers);
- Competitive position of wheatbelt based industry (growing and processing) relative to existing suppliers
- Potential for regional processing to improve competitive position
- Size of processing plant and the amount of raw material needed
- Scale and cost of processing and delivery infrastructure
- Potential efficiency in integrated multiple product processing (co-product synergy).

For many products this level of detail is unavailable due to the prospective nature of the products. Products are being considered where feasible technological is still some time away (e.g. pyrolysis and ethanol) and although research in these areas is progressing, particularly in North America and Europe, market prospects are constrained by cheap feedstock supplies from fossil resources.

4.3.2 FloraSearch product selection

Search (Olsen *et al*. 2003) undertook an evaluation process of prospective wood products focussing on two factors:

- Market size that could be available to new industries utilising feedstock from the target zone. As new woody crop options must have the potential to be planted on a large scale to impact on natural resource management issues only industries with substantial feedstock requirements are to be considered as principal products. Secondary products can be extracted from foliage and bark.
- Feasibility of making products of adequate quality at the required scale and at a competitive price from feedstock grown in the target zone.

The most promising wood products from the Search analysis were pulp and paper, particleboard and medium density fibreboard (MDF). Energy products were also ranked highly, especially electricity and heat production from the combustion of woody residues. Other more speculative and long-term products with potential for large-scale development included ethanol, pyrolytic oils and potential emergence of a "carbon economy" in which many of the products currently made from cheap fossil resources could be manufactured from the carbohydrates in biomass.

FloraSearch used the same selection criteria and ranking described by Olsen *et al*. (2003) but expanded on the range of potential products. The findings of Search are incorporated in the prioritisation of products described here (see Table 3). Oriented strand wood products are considered worthy of further consideration with emerging markets in Asia and technology available aimed at the utilisation of small diameter logs. High potential exists for bioenergy, but further development of technologies for harvesting and processing is required. Fodder is important with a high potential for adoption following relatively simple species and grazing system development. The scale of this option is extensive with application across the entire study zone. However, with changing markets, technologies and government policies new products will emerge and priorities shift. Some of these recent changes in woody biomass products and market directions are detailed by Hobbs *et al.* (2008).

This chapter concludes by selecting a group of products including pulp and paper, wood composites (MDF and particleboard), bioenergy and fodder upon which the species selection and evaluation, and the RIPA will be based. Wood product often requires separation of foliage and bark, and species selection can ensure that these secondary feedstock streams can be utilised for valuable product such as essential oil from leaf or tannin and gum from the bark. Secondary products from subsidiary feedstock streams of leaf and bark are recognised as being important in the economic viability of many biomass industries. Essential oils, tannin and processed fodder are thought to be most prospective from this analysis, while oils and fodder also have merit.

FloraSearch's strategy for integrating these product groups into the selection of new germplasm is presented in the following chapters. Also, product options are considered further in the Regional Industry Potential Analysis (Chapter 7) where a regional approach is taken to examine the potential of various product groups as driving forces for the establishment of large-scale industries based on woody perennials.

Table 3. Rating of potential products based on current markets and technologies.

Rating 1 highest potential to 4 lowest potential. WA Search results for wood products are included (Olsen *et al.* 2003).

Product group	Examples	Market	Feasibility	Rating
Solid timber	Specialty	Tiny	High	4
	Appearance	Medium	Low	4
	Construction	Large	Low	4
	Packaging	Medium	Low	4
	Posts, rails, piles, poles	Medium	Medium	3
Wood panels	Particleboard	Large	High	1
	Medium density fibreboard	Large	High	1
	Oriented strand board	Medium	Medium	2
Processed wood	Pulp and paper	Large	High	1
	Export woodchips	Large	Medium	3
	Wood plastics	Medium	High	2
	Charcoal	Medium	High	2
	Activated carbon	Small	High	3
Bioenergy	Electricity	Large	Medium	1
Liquid bio-fuels	Pyrolysis	Large	Low	4
	Ethanol	Large	Medium	3
	Methanol	Large	Low	4
Tannins (Secondary)		Medium/Small	Medium	3
Essential oils (Secondary)	Cineole	Large	Medium/Low	2
Fodder (Primary) (Secondary)	In Situ Processed off farm	Large Medium	High Medium	1 2
Gums (Secondary)		Medium	Low	3
Specialty chemical (Secondary)		Small	Low/Medium	3

5. Species selection

5.1 Introduction

The selection of species for broad scale industries in the FloraSearch study area is challenging due to the range of potential products, the limited attribute information for most species occurring in the region and the variability of environmental conditions across the vast study area. A few species from higher rainfall zones that also occur in the study region have been the subject of previous low rainfall farm forestry trials and are relatively well documented (Fairlamb and Bulman 1994). Kiddle, Boardman and van der Sommen (1987) reported on woodlot trials throughout the agricultural regions of SA and provide extensive data on the growth characteristics of *Eucalyptus cladocalyx, E. porosa, E. leucoxylon* and *E. sideroxylon.* Some fodder species are quite well known from rangelands research and some these, such as Oldman Saltbush, have an established history of use in plantations for livestock grazing (Vercoe 1987; Breakwell 1923; Chippendale 1963; Cunningham *et al*. 1981). Information from these and several other preceding studies is included into the following descriptions of species characteristics. However, for the majority of the species in the FloraSearch region there is little published information beyond taxonomic descriptions and comments relating to horticultural potential. Therefore early assessments to sort prospective species from the 10,000 or so taxa occurring in the region rely on basic attribute criteria.

The Search project was also constrained by the difficulty in obtaining detailed information on species and used simple data already available to eliminate as many species from contention as possible. Direct data that was needed to assess the commercial potential of the remaining species was then collected. This approach followed the product assessment work that identified paper pulp, panel boards and energy as the most prospective large-scale industries. It was then possible to screen the flora using growth form as a criterion and eliminate small plants from further consideration. Wood density was then used to discriminate further between species (Olsen *et al*. 2003).

FloraSearch undertook a systematic approach capturing herbarium and survey data from state agencies in SA, NSW, ACT and Victoria on all species recorded in the region. Together with the limited attribute information available an extensive database was compiled. The key criteria used in this process include:

- Lifeform and growth habit
- Distribution in relationship to landscapes and climate of the region
- Capacity for regeneration
- Growth rates and potential yield
- Existing or previous use in industries
- Attributes suitable for targeted products.

In the selection process species were sorted by several criteria into one or more broad product areas: multi-purpose biomass; fodder; and specialised high-value products. Multi-purpose biomass species are ones that potentially produce a large volume of biomass, grow quickly and are suited to a variety of climatic regions and landscapes. Fodder species are those with suitable growth characteristics and are palatable and nutritious to livestock. Specialised high-value species were selected from plant families known to produce essential oils and latex. Species with the potential for multiple products (e.g. eucalypts producing wood fibre, oil and biomass energy) may have an economic advantage over single purpose species and received a higher prioritisation in the FloraSearch species selection process.

5.2 Methods

5.2.1 Database development

5.2.1.1 Primary species list

Lists of all plant species and infraspecific taxa (subspecies and varieties) for the ~516,000 km² FloraSearch study area were extracted from state-based plant databases: Florlist (2002); Atlas of Victorian Wildlife (2002) and Wild plants of Victoria (Viridans 2001); and Atlas of NSW Wildlife (2002). These databases contained information on plant taxonomic division and lifeform that enabled the identification of perennial conifer and dicotyledon species. The taxonomy of each database was standardised to create a common species list to cover the three states. These datasets also contained information on plant lifeform, height, crown width and threatened species status under state and federal legislation. Where information on lifeform and habit was lacking literature searches were used to fill in the missing information (primarily Elliot and Jones 1982, 1983, 1986, 1989, 1990, 1993, 1997; Cunningham *et al*. 1981; Black 1986; Brooker *et al*. 2002, Maslin 2001). Plants species that do not grow to a 50cm free-standing height (e.g. low shrubs, climbers, vines, arboreal parasites) and those species listed under the Endangered Species Protection Act 1992 were excluded from the primary FloraSearch selection list. A number of yet to be named, poorly described, hybrid or rare species variants were also excluded.

5.2.1.2 Spatial distribution data

Plant data

Point location data for plant species was obtained from the SA Biological Survey and Research database (Keith Casperson, DEH, pers. comm.), Atlas of Victorian Wildlife, Atlas of NSW Wildlife; NSW, SA and Australian National Herbaria.

Environmental data

Geographic Information System – ArcGIS™ 8.2 (ESRI 2002) was used to identify the rainfall distribution for each plant record. Grid coverage of average annual rainfall (1980-1999) with a spatial resolution of accuracy of 0.05° was obtained from CSIRO Land and Water (2001). Plant species with minimum rainfall values near 650 mm, or maximums near 250 mm were plotted and visually assessed for the degree to which they matched the FloraSearch study area. Species that appeared to be vagrants or unsuited to the region were excluded.

5.2.2 Prioritisation process

5.2.2.1 Acacia Search

Maslin and MacDonald (2003) reviewed 462 Acacia species (comprising 538 taxa) growing in the region. Using their collective expert knowledge of species life histories, plant growth rates and likely ability to produce acceptable quantities of wood biomass, they selected and ranked species for further analysis. Limited field surveys of highly ranked Acacia species in the region were conducted with staff of the CSIRO Australian Tree Seed Centre to gather information on the attributes of a number of species. Their report provides a summary of uses of Australian Acacias, potential perennial crop types, species selection criteria, nominated potential species, and nominated species characteristics and requirements. See Appendix A for the Acacia Search short-list of most prospective Acacia species.

5.2.2.2 Workshops

Workshops with botanical and revegetation experts were held in Adelaide, Bendigo and Canberra in 2002 to communicate the activities of the FloraSearch project to others and to gather local knowledge and experience to assist the FloraSearch staff in the species selection process. The workshops discussed the range of potential industries suited to the study area and identified species and local variants that may be suitable for broadscale industries. Observations on plant distributions; life histories; known physical, chemical and product values; and previous human uses were collated and used to identify candidate species for further evaluation by the FloraSearch project. A list of participants, identified species and product areas can be found in Appendix B and a list of species identified at the workshops that warrant further investigation in Appendix C.

5.2.2.3 Currency Creek Arboretum – Dean Nicolle collection

Dean Nicolle's Currency Creek Arboretum located on the eastern edge of the Mount Lofty Ranges in South Australia contains an extensive botanically vouchered collection of approximately 875 eucalypt taxa from all over Australia. The gentle sloping site with sandy loam soils receives an annual rainfall of approximately 485mm. Planting began in 1993, continued over many years and is ongoing. Nicolle has undertaken regular height and health assessments for each taxa planted at the arboretum. This arboretum is valuable, providing data on the growth rate, vigour and persistence of taxonomically correct eucalypt taxa in a low rainfall site. Although comprehensive, information from this site must be treated cautiously when making predictions across the study area as the data refers to plants from a single collection of most species grown on a single specific site.

Nicolle was contracted to provide FloraSearch with a subset of his data, which includes an assessment of fifth year height, health and survival for all taxa over five years old, and lists of taxa less than five years old. Also provided were measurements of tree height, health, stem counts and diameters at 50 cm and 130 cm heights, and leaf density estimates for all taxa naturally occurring within the FloraSearch study area. This data is used in the following species selection and testing prioritisation process and for the construction of models to estimate primary productivity for highly rated species.

5.2.2.4 FloraSearch species selection

Information on species product areas and plant attributes from other research projects, workshops, literature searches and plant databases has been integrated with the primary species list. For each species, information on taxonomic variations, number of herbarium records in the study area, maximum height and crown width, lifeform, mean annual rainfall, minimum and maximum annual rainfall was collated. Also, where available, information on growth rates, palatability to livestock, coppicing and suckering ability, previous product uses, timber density, oil yield and constituents, gum characteristics, fodder digestibility, crude protein and drought persistence was tabulated (see Table 4).

Several FloraSearch species also occur in the wheat-sheep zone of WA and have been assessed and have undergone product testing by the WA Search project. These and results of the Acacia Search project have been noted within the FloraSearch database and their results incorporated.

Each species was allocated to one or more potential product areas based on existing knowledge. Where knowledge was lacking, results from well documented species were extrapolated to closely related species (e.g. gums and tannins for Acacia species). Some generalisations were made based on known plant Family properties (e.g. oils from Myrtaceae, Rutaceae and Lamiaceae; latex from Apocynaceae, Asclepiadaceae and Euphorbiaceae; fodder value of Chenopodiaceae and Fabaceae). For the prioritisation process a minimum height was invoked for each member of the main product areas: multipurpose biomass species only group = 4 metres; fodder species = 0.5 metre; and specialised high-value products = 1.5 metres.

Table 4. A summary of plant species attributes compiled for the FloraSearch species selection process.

Information Type (units or classification)
Species & Infraspecific Variants (subspecies, varieties)
Family
Number of Records in the Study Area
Mean Annual Rainfall (mm)
Minimum & Maximum Annual Rainfall (mm)
Maximum Height & Crown Width (metres)
Lifeform (Tree/Mallee/Shrub)
Growth Rate (Fast/Moderate/Slow)
Coppicing & Suckering Ability
Timber Density (kg/m^3)
Oil Yield & Constituents (% volume)
Gum Characteristics (compound % volume, optical & physical characters)
Palatability to Livestock (High/Moderate/Low/Not Palatable)
Fodder Digestibility (% dry matter)
Crude Protein (% dry matter)
Drought Fodder Persistence (High/Moderate/Low)
Product Areas - Previous, Current & Potential (Timber/Fodder/Oil/Gum/Tannin)
Prior Product Testing Results
Calculated Indices (indices between 0 = least desirable and 1 = most desirable)
Volume Index - maximum potential space an individual plant occupies
Rainfall Range Index - rainfall range of a species as a proportion study region
Growth Rate Index - growth rate (fast, moderate, slow)
Fodder Palatability Index - Palatability to Livestock (high, moderate, low, not palatable)
Optimal Fodder Height Index - height above optimal grazing height
Biomass Priority Index - a combination of Volume, Rainfall Range and Growth Rate indices
Fodder Priority Index - a combination of Biomass Priority, Fodder Palatability and Fodder Height indices

To prioritise and rank species for further analysis and collection within the FloraSearch project a series of calculated indices relating to the broad product area have been created:

- **Volume Index** – Using maximum height and crown width, the cylindrical volume (m^3) that each species occupies was calculated. The highly skewed distribution of volumes was normalised using a natural logarithmic transformation. The results were then rescaled into an index ranging from smallest volume to greatest volume. The index is a surrogate for the maximum potential yield at full maturity for each species.
- **Rainfall Range Index** – To indicate a species' adaptability to rainfall, and in part its spatial distribution, the overlap of each species' minimum and maximum rainfall records with the 200-700 mm annual rainfall zone has been expressed as a proportion and rescaled to lowest proportion of the range to across the entire range.
- **Growth Rate Index** – Three categories of growth rate, based on expert observations or the literature, have been transformed into an index of growth rate (fast, moderate, slow). Species without reliable information on growth rate were assigned a moderate default value.
- **Fodder Palatability Index** – Four categories of fodder palatability to livestock, based on expert observations or the literature, have been transformed into an index of fodder palatability (high, moderate, low, not palatable). Species without reliable information on palatability were assigned a moderate default value.
- **Optimal Fodder Height Index** – The maximum optimum grazing was nominated at 1.2 metres (fodder height score of 1), to give a selection advantage to species that do not require any mechanical management in a grazing system. Fodder species taller than 1.2 metres had their score reduced by their height above 1.2 metres expressed as a proportion of the height of the tallest fodder species above 1.2 metres. Fodder height scores were scaled from 0.25 (tallest fodder species) to 1 (below 1.2 metres).
- **Biomass Priority Index** – The average of Volume, Rainfall Range and Growth Rate indices, with double weighting of Growth Rate Index.
- **Fodder Priority Index** – The average of Biomass Priority, Fodder Palatability and Fodder Height indices.

The Biomass Priority Index and Fodder Priority Index were used to rank and prioritise every species in the multi-purpose biomass and fodder product areas. Only a few species solely exist in the specialised high-value product group (i.e. oil and latex) and they have been given equal ranking of 1.

5.2.2.5 Overseas species

While the present focus of FloraSearch is the selection and development of species indigenous to the study zone a review of potential exotic species is also warranted. One of the basic principles the project has built upon is that taxa from similar climatic zones will be most suited to development as broad scale crop species. While there are examples of species that adapt well to climatic regimes outside their own natural occurrence, this principle generally holds true. A scan of species that occur in similar climatic regimes overseas that may be suited to development as broadscale crop species in the wheat-sheep belt of Southern Australia was prepared by CSIRO as part of the FloraSearch project.

The terms of reference for this review were:

- Identify exotic woody perennial species with the potential to be developed as large-scale economic crops in the 250 to 650 mm winter or uniform rainfall zone. These species will either come from a Mediterranean climate or have been shown to grow successfully under cultivation in this climatic zone.

- Identify institutions/researchers with knowledge of these species and/or have access to sources of genetic material.
- Provide basic information (in table form) on the species identified, including botanical family, lifeform, country of origin and product potential.
- Identify (where known) if short listed species are already in collections in Australia, and (where possible) comment on the suitability of these collections for genotype selection.
- Present the above results in report format giving details of the rationale, methods and results of the survey, including discussion of the potential/limitations of the species to be developed as broad scale crops in low-medium rainfall Mediterranean climate zones of Australia.

The results of this survey are presented by Macdonell (2008) in Hobbs (ed) (2008). Eighteen species were reported as being potentially suitable for the study region. Lists of species for summer rain areas and less suitable species are also provided. It should be acknowledged that while species from outside Australia may provide scope for development issues of quarantine, germplasm import, weed risk and other environmental concerns would have to be addressed. Germplasm of some species will already be present in Australia, while others may be unknown in cultivation.

5.3 Results and Discussion

5.3.1 WA Search and Acacia Search projects

Sixty-eight FloraSearch species overlap with the WA Search (Bartle & Olsen pers. comm.) and Acacia Search projects (Maslin and MacDonald 2003) (see Table 5). Most of these species have been subject to basic wood properties testing (basic density & colour). Samples of some species have also been delivered to CSIRO Forestry and Forest Products for more detailed wood fibre testing. These results are considered in Chapter 6.

The WA Search project has identified eight species which overlap with the FloraSearch species list that have basic density values below 650 kg/m³: *Codonocarpus cotinifolius*, *Gyrostemon ramulosus*, *Duboisia hopwoodii*, *Viminaria juncea*, *Acacia murrayana*, *Eucalyptus camaldulensis* and *Santalum murrayanum*. A maximum basic density value of 650 kg/m³ is used by CSIRO Forestry and Forest Products as an indication of a species' usefulness for wood fibre products. The Acacia species with the highest potential and which occur naturally in the FloraSearch study area include: *Acacia leucoclada* ssp. *leucoclada*, *A. linearifolia*, *A. retinodes* var. *retinodes* (hill form) and *A. salicina,* with *A. decurrens*, *A. mearnsii*, *A. pycnantha* and *A. retinodes* var. *retinodes* (swamp form) given lower preferences.

5.3.1.1 Currency Creek Arboretum – Dean Nicolle collection

Nicolle's assessments of height, health and survival of eucalypt taxa growing with approximately 485 mm annual rainfall provides a list of 57 taxa that can grow to 6 metres or more in five years (see Appendix D). His fastest growing eucalypt species, which attain a height of 7 metres or more in 5 years, include FloraSearch region species – *Eucalyptus aromaphloia* ssp. *sabulosa*, *E. ovata* var. *ovata*, *E. globulus* ssp. *bicostata*, *E. chloroclada* and *E. cladocalyx* – and non-FloraSearch region species – *E. banksii*, *E. grisea*, *E. mannifera*, *E. alaticaulis, E. fraxinoides*, *E. gomphocephala*, *E. megacornuta*, *E. punctata* and *E. tereticornis* ssp. *tereticornis*.

5.3.2 FloraSearch priority species

There are 1214 taxa of taxonomically distinct, freestanding perennial dicotyledon and conifer plants that can grow to 50 cm or greater in height and which naturally occur within the FloraSearch study area. Of this list, we have identified 392 taxa, which include the most highly ranked multi-purpose biomass species (top 300 using Biomass Priority Index values), fodder species (top 100 Fodder Priority Index values) and specialised high-value product (e.g. oil, latex) species. The number of potential species in each of the FloraSearch product categories, and species prioritised for review, collection and product testing in the first stage of the FloraSearch project are provided in Table 6.

The most highly ranked species in each product category have been targeted for collection. The resulting list contains 392 priority taxa for the first stages field survey and sampling, and product testing. The priority FloraSearch species are listed in Table 7 (Appendix E lists prospective species with observed annual average rainfall ranges). Also provided in this table is the number of point records for specimen collection for each species within the FloraSearch region and the total recorded. This gives an estimate of the frequency of occurrence of a species both over its entire range and within the FloraSearch study area.

The selection of species for review, collection and analysis during the first stage of the FloraSearch project has been based on the best available knowledge of each species. Very few species that grow naturally in the FloraSearch study region are well documented. Where available, reliable published and unpublished information has been integrated into the FloraSearch database. Of the product categories, only "Essential Oils" has reasonable data already available, reflecting a long history of interest in the essential oils of the Australian flora. Joe Brophy (University of NSW) has provided detailed yield and chemical constituent data on 117 of the 171 oil-bearing species targeted by FloraSearch. The Acacia Search results and various farm forestry trials and research projects, provided further guidance to the most promising species and varieties for the FloraSearch study area. Some data contained within the database is derived from anecdotal evidence provided by a range of botanical and land management professionals, and although not scientifically rigorous, this evidence is often based on many years of keen observations.

Information on intra-specific variations, distributions, growth rates, lifeform, other plant attributes and product suitability for each species will be updated in later stages of FloraSearch as results of other research, additional herbarium records and field survey becomes available. In the following chapter results from WA Search and FloraSearch wood property testing by CSIRO Forestry and Forest Products further refine our list of potential species.

The FloraSearch project also reviewed the potential of a number of species not naturally occurring in the study area. These include other Australian species identified by other low rainfall farm forestry projects and Dean Nicolle's eucalypt collection, and species nominated from outside of Australia by a review contracted in 2003 from the Australian Tree Seed Centre at CSIRO Forestry and Forestry Products.

Information on plantation productivity is a critical component in the development of commercial crops in the FloraSearch study area. Chapter 6 will outline methods for estimating primary production based on field survey results attained from the FloraSearch project, observations from allied studies and the development of productivity models linked to geographic information systems. FloraSearch Phase 2 and related CRC PBMDS projects, in particular "Field Trials of Woody Germplasm" will initiate programs of species trial across the study area providing direct productivity and adaptability information supporting the development of plantation productivity estimates. This will in turn further refine the list of potential species and varieties suited to the study area.

Table 5. List of FloraSearch (FS) species which overlap with the WA Search (WA) and Acacia Search (AS) project, and ratings within each project (1=Highest to 5=Lowest).

# denotes species subject to detailed wood fibre testing at CSIRO FFP.

Species	WA	AS	FS
Acacia aneura	3	5	3
Acacia argyrophylla		3-4	3
Acacia baileyana		3	1
Acacia burkittii	3	5	3
Acacia cyclops	2#	4	1
Acacia dealbata		2-3	1
Acacia decurrens		2	1
Acacia dodonaeifolia		4	1
Acacia doratoxylon		3	2
Acacia euthycarpa		4	4
Acacia filicifolia		3	1
Acacia hakeoides		3	1
Acacia implexa		3	1
Acacia jennerae	2	5	4
Acacia leucoclada ssp. *leucoclada*		1-2	1#
Acacia ligulata		5	1
Acacia linearifolia		1-2	4
Acacia mearnsii		2	1
Acacia melanoxylon		3	1
Acacia murrayana	1#	2-3	1
Acacia neriifolia		2-3	2
Acacia parramattensis		3	1
Acacia prainii	3	5	5
Acacia pycnantha		2	1
Acacia retinodes var. *retinodes (hill form)*		1-2	1#
Acacia retinodes var. *retinodes (swamp form)*		2	1#
Acacia retinodes var. *uncifolia*		3	1
Acacia rivalis		2-3	3
Acacia salicina		1-2	1
Acacia stenophylla		3	1
Acacia victoriae ssp. *victoriae*		3	1
Acacia wattsiana		3	1

Table 5. Continued

Species	WA	AS	FS
Alectryon oleifolius	3		4
Alyogyne hakeifolia	2#		5
Alyogyne huegelii	1#		5
Callitris canescens	3		3
Callitris glaucophylla	2#		1
Casuarina obesa	1#		5
Codonocarpus cotinifolius	1#		1
Dodonaea ptarmicaefolia	3		5
Duboisia hopwoodii	2#		4
Eremophila alternifolia	3		5
Eremophila deserti	3		2
Eremophila longifolia	2		2
Eremophila oppositifolia	3		4
Eremophila serrulata	3		5
Eucalyptus camaldulensis	1#		1
Eucalyptus incrassata	3		2#
Eucalyptus polybractea			3
Grevillea nematophylla	2		4
Grevillea pterosperma	2		2
Gyrostemon ramulosus	1#		1
Hakea francisiana	2		2
Melaleuca acuminata	3		3
Melaleuca lanceolata	2		1#
Melaleuca leiocarpa	2		5
Melaleuca pauperiflora	3		4
Melaleuca quadrifaria	3		5
Melaleuca uncinata	3		2#
Myoporum platycarpum	1		1#
Pittosporum angustifolium	2#		1
Pittosporum phylliraeoides	2#		2
Santalum acuminatum	3		4
Santalum murrayanum	3		4
Templetonia retusa	3		5
Viminaria juncea	1#		1

Table 6. Number of potential species in each of the FloraSearch product categories, and number of species prioritised for review, collection and product testing in the first stage of FloraSearch project.

Product Category	Number of Potential Species	First Stage Priority Species
Biomass & Wood Fibre	300	212
Fodder	117	94
Oil	171	140
Gum	95	77
Tannin	83	65
Latex	12	12

Table 7. Species selected for FloraSearch review.

Potential product types: [W]ood fibre; [O]il; [T]annin; [F]odder; Uppercase represents selection rank 1-2, lowercase rank 3-4. Number of herbarium and plant survey records used in analysis (All) and those located in the FloraSearch (FS) region.

Species		No. of Records FS Zone	All
Acacia acinacea	[F]	1976	2606
Acacia adunca	[wt]	7	96
Acacia anceps	[wt]	419	573
Acacia aneura	[wtF]	76	3052
Acacia argyrophylla	[wtF]	170	196
Acacia ausfeldii	[wtF]	158	208
Acacia baileyana	[WTF]	149	380
Acacia beckleri	[wt]	102	337
Acacia brachybotrya	[wt]	1368	1432
Acacia brachystachya	[wt]	11	296
Acacia burkittii	[wt]	31	679
Acacia burrowii	[wt]	28	137
Acacia buxifolia	[wt]	159	612
Acacia caesiella	[wt]	6	165
Acacia calamifolia	[wtF]	993	1277
Acacia cambagei	[wt]	5	506
Acacia cana	[wt]	2	93
Acacia caroleae	[wtf]	33	182
Acacia cheelii	[wt]	35	159
Acacia conferta	[wt]	18	300
Acacia cultriformis	[wt]	57	161
Acacia cupularis	[wt]	369	569
Acacia cyclops	[WT]	62	253
Acacia dealbata	[WTF]	196	1236
Acacia deanei	[WTf]	904	1268

Table 7. Continued

Species	No. of Records FS Zone		All
Acacia decora	[wt]	527	1068
Acacia decurrens	[WTF]	26	382
Acacia difformis	[wt]	160	187
Acacia dodonaeifolia	[WTF]	196	298
Acacia doratoxylon	[WTF]	706	956
Acacia euthycarpa	[wt]	877	1005
Acacia excelsa	[wt]	42	291
Acacia farnesiana	[wtf]	33	508
Acacia filicifolia	[WTF]	3	318
Acacia genistifolia	[wt]	729	1230
Acacia gillii	[wtf]	195	208
Acacia gunnii	[F]	126	730
Acacia hakeoides	[WTF]	1340	1510
Acacia harpophylla	[wt]	57	368
Acacia havilandiorum	[wt]	190	355
Acacia implexa	[WTF]	217	767
Acacia iteaphylla	[wtF]	100	199
Acacia leiophylla	[F]	407	527
Acacia leptoclada	[f]	1	102
Acacia leucoclada	[WTF]	41	184
Acacia ligulata	[WTF]	1556	4098
Acacia linearifolia	[Wt]	38	160
Acacia loderi	[wt]	61	212
Acacia longifolia	[wtf]	655	2067
Acacia mearnsii	[WTF]	118	790
Acacia melanoxylon	[WTF]	176	1629
Acacia melvillei	[wt]	250	363
Acacia microcarpa	[wt]	558	571
Acacia mitchellii	[F]	36	230
Acacia mollifolia	[wt]	68	93
Acacia montana	[wtF]	766	863
Acacia muelleriana	[wt]	15	82
Acacia murrayana	[WTF]	35	856
Acacia myrtifolia	[F]	813	2970
Acacia neriifolia	[WTF]	20	321
Acacia notabilis	[wt]	451	619
Acacia omalophylla	[WT]	132	197

Table 7. Continued

Species	No. of Records FS Zone		All
Acacia oswaldii	[wt]	1228	2900
Acacia oxycedrus	[wt]	42	418
Acacia paradoxa	[wt]	1344	2640
Acacia pendula	[WTF]	337	464
Acacia penninervis	[wtf]	132	725
Acacia podalyriifolia	[wtf]	5	139
Acacia pravifolia	[f]	96	174
Acacia pravissima	[wt]	14	225
Acacia pycnantha	[WTF]	2744	5304
Acacia ramulosa	[wt]	4	758
Acacia retinodes	[WTF]	317	1060
Acacia rigens	[wt]	1447	1760
Acacia rivalis	[WtF]	6	467
Acacia rubida	[wt]	17	713
Acacia salicina	[WTF]	304	1197
Acacia spectabilis	[wt]	141	299
Acacia spinescens	[f]	2097	2372
Acacia stenophylla	[WTF]	419	1161
Acacia stricta	[wtf]	2	504
Acacia tetragonophylla	[wt]	8	2013
Acacia trineura	[wt]	168	171
Acacia triquetra	[f]	315	367
Acacia verniciflua	[wt]	283	992
Acacia verticillata	[wtf]	259	1282
Acacia vestita	[wtf]	23	105
Acacia victoriae	[WTF]	247	2591
Acacia wattsiana	[WTF]	142	143
Alectryon oleifolius	[wF]	973	2628
Alectryon subdentatus	[w]	4	39
Allocasuarina diminuta	[w]	182	439
Allocasuarina helmsii	[w]	34	178
Allocasuarina littoralis	[w]	6	1187
Allocasuarina luehmannii	[W]	1605	1804
Allocasuarina muelleriana	[wF]	1858	2959
Allocasuarina paludosa	[w]	102	737
Allocasuarina striata	[w]	348	883
Allocasuarina verticillata	[WF]	1558	3161

Table 7. Continued

Species	No. of Records FS Zone		All
Alphitonia excelsa	[W]	18	590
Alstonia constricta	[wf]	26	126
Angophora costata	[wo]	6	300
Angophora floribunda	[wo]	35	494
Angophora melanoxylon	[wo]	12	113
Aotus sspinescens	[f]	846	877
Apophyllum anomalum	[wF]	116	229
Atalaya hemiglauca	[WF]	40	486
Atriplex cinerea	[f]	179	934
Atriplex nummularia	[F]	284	1284
Atriplex paludosa	[f]	328	1973
Atriplex vesicaria	[F]	1220	4346
Babingtonia behrii	[O]	1524	1581
Banksia marginata	[w]	1191	2618
Beyeria viscosa	[w]	97	344
Boronia anemonifolia	[O]	53	499
Boronia glabra	[O]	38	172
Brachychiton populneus	[W]	324	507
Bursaria spinosa	[wF]	2274	3611
Callistemon brachyandrus	[wo]	89	102
Callistemon citrinus	[wo]	3	295
Callistemon rugulosus	[wo]	608	699
Callistemon sieberi	[wo]	53	420
Callistemon viminalis	[wo]	1	259
Callitris canescens	[w]	423	497
Callitris endlicheri	[w]	473	978
Callitris glaucophylla	[W]	1969	3374
Callitris gracilis	[W]	1452	1924
Callitris rhomboidea	[w]	239	703
Callitris verrucosa	[W]	1564	1846
Calytrix alpestris	[O]	416	513
Calytrix glaberrima	[o]	309	363
Calytrix involucrata	[O]	413	500
Calytrix tetragona	[O]	3589	5769
Canthium latifolium	[WF]	4	46
Canthium oleifolium	[WF]	22	75
Capparis mitchellii	[wF]	63	302

Table 7. Continued

Species	No. of Records FS Zone		All
Cassine australis	[w]	12	126
Cassinia aculeata	[w]	52	548
Cassinia laevis	[w]	580	1160
Cassinia longifolia	[w]	11	340
Cassinia quinquefaria	[w]	28	197
Casuarina cristata	[WF]	280	520
Casuarina cunninghamiana	[W]	38	395
Casuarina pauper	[W]	491	1862
Chenopodium auricomum	[f]	21	483
Chenopodium gaudichaudianum	[F]	25	123
Chenopodium nitrariaceum	[f]	483	803
Codonocarpus cotinifolius	[W]	107	312
Correa aemula	[O]	37	151
Correa alba	[O]	14	419
Correa glabra	[O]	225	379
Correa pulchella	[o]	410	461
Correa reflexa	[O]	1600	2809
Correa schlechtendalii	[O]	30	37
Crowea exalata	[O]	58	359
Cullen australasicum	[F]	81	1007
Daviesia asperula	[f]	310	326
Daviesia brevifolia	[f]	1035	1502
Daviesia genistifolia	[f]	214	498
Daviesia leptophylla	[f]	285	1175
Daviesia ulicifolia	[f]	630	2018
Dillwynia hispida	[f]	993	1805
Dodonaea hexandra	[f]	1035	1078
Dodonaea humilis	[f]	539	623
Dodonaea viscosa	[WF]	3746	8093
Duboisia hopwoodii	[w]	16	190
Enchylaena tomentosa	[F]	4656	9723
Eremophila bignoniiflora	[W]	38	384
Eremophila deserti	[Wf]	420	976
Eremophila duttonii	[w]	1	693
Eremophila glabra	[f]	1424	2654
Eremophila longifolia	[WF]	674	1943
Eremophila maculata	[f]	79	660

Table 7. Continued

Species	No. of Records FS Zone		All
Eremophila mitchellii	[W]	223	530
Eremophila oppositifolia	[w]	175	718
Eremophila santalina	[w]	47	73
Eremophila sturtii	[w]	96	961
Eucalyptus alaticaulis	[WO]	5	23
Eucalyptus albens	[WO]	366	963
Eucalyptus albopurpurea	[WO]	104	109
Eucalyptus angulosa	[WO]	83	295
Eucalyptus arenacea	[WO]	454	476
Eucalyptus argyphea	[WO]	2	80
Eucalyptus aromaphloia	[WO]	84	374
Eucalyptus banksii	[WO]	1	150
Eucalyptus baxteri	[WO]	444	1289
Eucalyptus behriana	[wo]	555	615
Eucalyptus blakelyi	[WO]	395	1266
Eucalyptus botryoides	[WO]	2	314
Eucalyptus brachycalyx	[wo]	631	778
Eucalyptus bridgesiana	[WO]	43	870
Eucalyptus calcareana	[WO]	77	169
Eucalyptus calycogona	[wo]	881	1102
Eucalyptus camaldulensis	[WO]	2091	4729
Eucalyptus ceratocorys	[wo]	36	102
Eucalyptus chloroclada	[WO]	144	427
Eucalyptus cladocalyx	[WO]	374	403
Eucalyptus cneorifolia	[wo]	184	237
Eucalyptus concinna	[wo]	19	464
Eucalyptus conglobata	[WO]	64	72
Eucalyptus conica	[wo]	194	446
Eucalyptus coolabah	[wo]	113	1160
Eucalyptus cosmophylla	[WO]	274	828
Eucalyptus crebra	[wo]	113	1544
Eucalyptus cyanophylla	[WO]	316	320
Eucalyptus dealbata	[WO]	209	588
Eucalyptus diversifolia	[WO]	1844	2209
Eucalyptus dives	[WO]	3	943
Eucalyptus dumosa	[WO]	2855	3523
Eucalyptus dwyeri	[WO]	774	989

Table 7. Continued

Species	No. of Records FS Zone		All
Eucalyptus fasciculosa	[WO]	897	2305
Eucalyptus fibrosa	[WO]	114	758
Eucalyptus flindersii	[WO]	8	273
Eucalyptus globulus	[WO]	47	784
Eucalyptus gomphocephala	[WO]	1	110
Eucalyptus goniocalyx	[WO]	504	1777
Eucalyptus gracilis	[WO]	2577	3397
Eucalyptus incrassata	[WO]	2903	3276
Eucalyptus intertexta	[WO]	296	1261
Eucalyptus lansdowneana	[wo]	19	77
Eucalyptus largiflorens	[WO]	1996	2519
Eucalyptus leptophylla	[WO]	2524	2768
Eucalyptus leucoxylon	[WO]	2601	3869
Eucalyptus macrorhyncha	[WO]	459	1040
Eucalyptus maculata	[wO]	2	264
Eucalyptus mannifera	[WO]	6	917
Eucalyptus megacornuta	[WO]	2	80
Eucalyptus melanophloia	[WO]	36	579
Eucalyptus melliodora	[WO]	992	2058
Eucalyptus microcarpa	[WO]	2434	3004
Eucalyptus moluccana	[wo]	1	422
Eucalyptus morrisii	[wo]	67	143
Eucalyptus nortonii	[WO]	56	528
Eucalyptus obliqua	[wo]	177	2149
Eucalyptus occidentalis	[WO]	6	302
Eucalyptus ochrophloia	[wo]	0	138
Eucalyptus odorata	[WO]	1097	1516
Eucalyptus oleosa	[WO]	2276	3154
Eucalyptus ovata	[WO]	95	1346
Eucalyptus petiolaris	[WO]	177	181
Eucalyptus phenax	[wo]	583	807
Eucalyptus pileata	[wo]	30	226
Eucalyptus pilligaensis	[wO]	107	192
Eucalyptus polyanthemos	[WO]	491	1214
Eucalyptus polybractea	[wo]	358	375
Eucalyptus populnea	[WO]	854	1367
Eucalyptus porosa	[WO]	1176	1576

Table 7. Continued

Species	No. of Records FS Zone		All
Eucalyptus radiata	[wo]	4	885
Eucalyptus remota	[wo]	135	138
Eucalyptus rossii	[wo]	63	441
Eucalyptus rubida	[WO]	9	649
Eucalyptus rugosa	[WO]	873	1031
Eucalyptus siderophloia	[WO]	1	499
Eucalyptus sideroxylon	[WO]	493	802
Eucalyptus socialis	[WO]	3123	4855
Eucalyptus sporadica	[WO]	2	261
Eucalyptus striaticalyx	[wo]	3	218
Eucalyptus tereticornis	[WO]	7	1402
Eucalyptus tessellaris	[wo]	5	124
Eucalyptus trachyphloia	[wo]	15	187
Eucalyptus tricarpa	[wO]	412	601
Eucalyptus utilis	[WO]	2	80
Eucalyptus viminalis	[WO]	490	3016
Eucalyptus viridis	[WO]	852	1037
Eucalyptus willisii	[wO]	31	540
Eucalyptus yalatensis	[wo]	283	528
Eucalyptus yumbarrana	[wo]	219	377
Eutaxia diffusa	[f]	192	220
Eutaxia microphylla	[f]	2815	3350
Flindersia maculosa	[WOF]	17	121
Geijera parviflora	[woF]	478	851
Goodia lotifolia	[w]	26	359
Goodia medicaginea	[w]	289	459
Grevillea juncifolia	[w]	19	349
Grevillea linearifolia	[w]	106	209
Grevillea nematophylla	[w]	2	144
Grevillea pterosperma	[W]	494	589
Grevillea robusta	[W]	3	32
Grevillea striata	[Wf]	5	186
Gyrostemon ramulosus	[W]	39	148
Hakea decurrens	[w]	46	368
Hakea ednieana	[W]	3	355
Hakea francisiana	[W]	212	394
Hakea leucoptera	[W]	449	1271

Table 7. Continued

Species	No. of Records FS Zone		All
Hakea muelleriana	[w]	912	918
Hakea nodosa	[w]	126	296
Hakea repullulans	[w]	121	192
Hakea rostrata	[w]	780	2253
Hakea sericea	[W]	123	350
Hovea purpurea	[w]	70	145
Indigofera australis	[F]	305	932
Indigofera brevidens	[f]	6	58
Jacksonia scoparia	[w]	3	205
Kunzea ambigua	[wO]	16	168
Kunzea ericoides	[WO]	6	186
Kunzea parvifolia	[O]	18	118
Lasiopetalum baueri	[f]	862	921
Lasiopetalum discolor	[f]	434	517
Leionema microphyllum	[o]	17	17
Leptospermum continentale	[wo]	524	1744
Leptospermum coriaceum	[WO]	1919	2054
Leptospermum divaricatum	[wo]	305	329
Leptospermum laevigatum	[WO]	9	439
Leptospermum lanigerum	[wo]	92	927
Leptospermum myrsinoides	[wo]	1373	2981
Leptospermum obovatum	[wo]	31	284
Leptospermum polygalifolium	[wo]	18	840
Leucopogon parviflorus	[w]	766	1579
Lycium australe	[f]	227	789
Maireana aphylla	[f]	308	1063
Maireana georgei	[F]	161	1193
Maireana microphylla	[f]	216	337
Maireana planifolia	[F]	2	170
Maireana pyramidata	[F]	635	2136
Maireana rohrlachii	[F]	342	371
Maireana tomentosa	[F]	14	187
Maytenus cunninghamii	[w]	18	59
Melaleuca acuminata	[wo]	1555	1762
Melaleuca armillaris	[WO]	91	420
Melaleuca bracteata	[WO]	7	302
Melaleuca brevifolia	[wo]	928	1141

Table 7. Continued

Species	No. of Records FS Zone		All
Melaleuca decussata	[wo]	630	1227
Melaleuca densispicata	[wo]	6	68
Melaleuca dissitiflora	[wo]	0	206
Melaleuca eleutherostachya	[wo]	191	225
Melaleuca erubescens	[O]	51	85
Melaleuca gibbosa	[O]	769	1057
Melaleuca glomerata	[wo]	1	896
Melaleuca halmaturorum	[WO]	691	1046
Melaleuca lanceolata	[WO]	4042	5609
Melaleuca leiocarpa	[O]	12	14
Melaleuca parvistaminea	[wo]	16	141
Melaleuca pauperiflora	[wo]	411	690
Melaleuca squarrosa	[wo]	6	494
Melaleuca styphelioides	[wo]	1	75
Melaleuca uncinata	[WO]	2309	2858
Micromyrtus sessilis	[o]	22	100
Myoporum brevipes	[f]	139	205
Myoporum insulare	[W]	457	1164
Myoporum montanum	[w]	416	1084
Myoporum platycarpum	[WF]	1438	2473
Myoporum viscosum	[F]	115	204
Nitraria billardierei	[F]	592	1654
Owenia acidula	[WF]	6	70
Ozothamnus diosmifolius	[w]	28	301
Petalostylis labicheoides	[f]	28	309
Phebalium bullatum	[O]	852	867
Phebalium glandulosum	[O]	109	177
Phebalium obcordatum	[o]	177	180
Phebalium squamulosum	[wo]	40	522
Phebalium stenophyllum	[o]	69	79
Philotheca angustifolia	[O]	150	213
Philotheca brevifolia	[o]	60	60
Philotheca ciliata	[O]	30	42
Philotheca difformis	[O]	65	150
Philotheca myoporoides	[wO]	74	351
Philotheca salsolifolia	[O]	34	250
Philotheca verrucosa	[wO]	190	294

Table 7. Continued

Species	No. of Records FS Zone		All
Phyllota pleurandroides	[f]	779	910
Pimelea microcephala	[w]	455	1086
Pittosporum angustifolium	[WF]	2087	3131
Pomaderris paniculosa	[f]	664	916
Pomaderris racemosa	[w]	10	93
Prostanthera behriana	[O]	161	321
Prostanthera lasianthos	[wO]	6	830
Prostanthera nivea	[O]	120	240
Prostanthera ovalifolia	[wO]	68	206
Prostanthera rotundifolia	[wO]	29	162
Prostanthera saxicola	[O]	16	96
Prostanthera spinosa	[o]	286	353
Prostanthera striatiflora	[O]	41	477
Pultenaea daphnoides	[F]	107	1304
Rhagodia candolleana	[f]	926	2308
Rhagodia crassifolia	[f]	932	1463
Rhagodia parabolica	[f]	726	1445
Rhagodia spinescens	[F]	1278	3208
Rhagodia ulicina	[f]	158	542
Santalum acuminatum	[wF]	1267	2082
Santalum lanceolatum	[wf]	49	1000
Santalum murrayanum	[w]	488	575
Santalum spicatum	[f]	10	91
Scaevola crassifolia	[f]	170	265
Scaevola spinescens	[f]	393	932
Senna artemisioides	[F]	3363	9637
Templetonia retusa	[F]	489	802
Thomasia petalocalyx	[f]	495	577
Thryptomene calycina	[O]	12	48
Ventilago viminalis	[WF]	28	240
Viminaria juncea	[WF]	57	417
Westringia cheelii	[O]	28	52
Westringia eremicola	[O]	332	439
Zieria cytisoides	[O]	25	202

6. Species evaluation

6.1 Introduction

The preceding two chapters of this report describe the most prospective product sectors and the selection of species for further testing. The aim of this chapter is to sift the group of 392 species defined in Chapter 5 by providing additional knowledge on specific attributes, which in turn supports exclusion, or inclusion, in a final set of "best bet" species. This links the conclusions on products and species selection by undertaking more detailed evaluation in two areas:

- Product testing – Each species will have attributes suiting it for consideration for a particular product type. This creates a complex matrix of species and plant parts requiring particular sampling and test regimes. Testing will relate to products selected as having the highest priority in Chapter 4, namely, pulp and paper, wood composites, bioenergy, fodder and essential oils.
- Species adaptability and productivity – Each selected species has biotic characteristics relating to growth and productivity potential. The most important aspect is the potential yield of each species and how this varies in response to climate and soil changes. Also important are attributes relating to cropping systems such as the regenerative capacity of species by coppicing or suckers, or the form of the plant, for example the need for upright trunks if individual stem harvesting was considered.

6.2 Methods

6.2.1 Field collection

Field collection from species identified in the preceding section commenced in February 2003. The general methodology of field sample collection is outlined below. Detailed sampling protocols are provided in Appendix F.

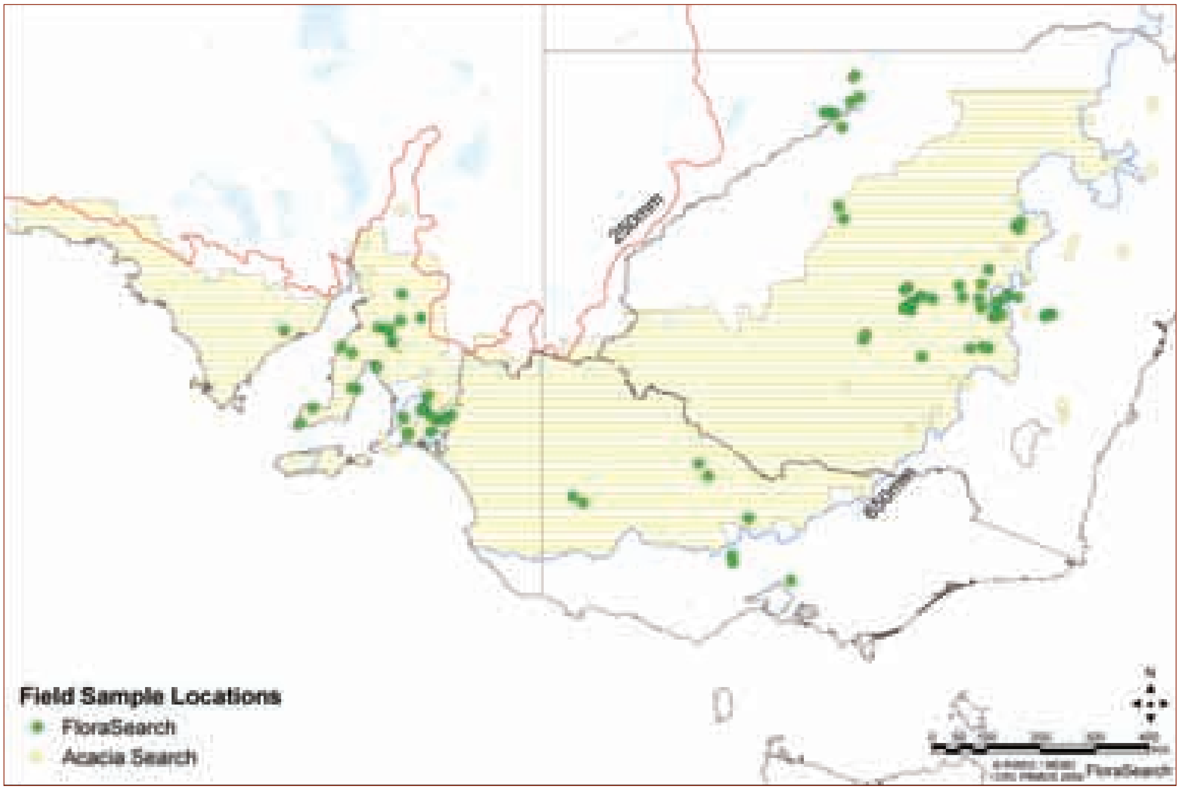
Site and Plant Information

- A description of the location, landscape and soil, and plant community from which the sampled plants are selected.
- Species name and assigned collection number.
- Botanical voucher specimen for one (minimum) of sampled population.
- Photos of plant, trunk/bark and leaves.
- Plant height, crown width, form (e.g. tree, shrub, mallee), age (if known or approximate) and numbers of stems at 0.5 m height.

Wood Samples

- Sample three to six plants.
- Measure trunk/stem diameter, including bark, at 0.5 m and 1.3 m.

Figure 3. Sample point locations for Acacia Search and FloraSearch sampling.



- For multi-stemmed species measure diameters of all stems (2 cm or greater) at 0.5 m and 1.3 m.
- Measure bark thickness at 0.5 m for north and south aspect of plants.
- Take a wood core or disc at 0.5 m.
- Tree or shrub stems cut into 1-1.2 m long sections or billets of wood. 20 kg samples were collected from each species or, if material was limited, a 1 kg sample was collected. Billets were debarked at the time of collection.

Bark (Acacias only) and Gum samples

- Bark from six plants bulked to produce 250 g or more of air-dried bark. Weigh and store in calico bags.
- Gum was collected from three or more plants with a bulked sample of 50 g or more. Weigh and store in calico bags.

Leaf Samples for Fodder and Oils

- Sample six plants at various heights and locations on plant taking an amount required for specified testing regime for that species.
- Bulk collection, mix and extract approximately 200 g for each sample. Weigh and store in paper bag to air-dry or refrigerated where specified.

6.2.2 Species for testing

6.2.2.1 Acacia Search species

The Acacia Search report selected and ranked 35 taxa as having potential for crop development. Of these, Paul Macdonell (CSIRO Forestry and Forest Products) collected 10 taxa occurring in the FloraSearch area for more detailed assessment. The distribution of locations at which Acacia species were sampled is shown in Figure 3 Ten specimens of branch or stem (~30 cm lengths with bark intact) were taken from ten individual trees for each Acacia species except for *Acacia retinodes* × *uncifolia*, of which only three trees were available.

6.2.2.2 FloraSearch species

Field sampling of selected species was undertaken February to October 2003 by FloraSearch staff and contractors. Wood, leaf and bark samples were collected from 140 species in all, with wood samples from 100 species tested at some at some level and leaf from 45 species tested for fodder value. The field sample locations are shown in Figure 3.

6.2.3 Sample testing

6.2.3.1 Wood

This section sets out the testing applied to Acacia Search and FloraSearch samples supplied to the CSIRO Forestry and Forest Products laboratories, Clayton, Vic. Detailed wood preparation, testing procedures and results are presented in the report "Assessment of Australian Native Woody Perennials for Potential Use in Forest Products" by Freischmidt *et al*. (2008) in Hobbs (ed) (2008).

Wood Sample Preparation

Upon receipt of wood billets by the Clayton laboratories, three 2.5 cm discs were cut. The first two discs were used for basic density measurements. The third disc had a 5 mm wide segment removed running across its diameter and this was used for fibre length determination. For 20 kg wood samples the screening procedure involved chipping the woody material in a pilot scale chipper followed by screening for acceptable chip sizes. Chipped material was then stored in sealed plastic bags for pulping studies. Pulp fibres were taken for fibre length and width determinations.

Whole Wood Basic Density

Two discs from each 1 m billet of wood were used for basic density determination. Basic density is defined as the oven-dry weight divided by the green (maximum swollen) volume. FloraSearch staff also performed basic wood density testing on a single disc cut in the field from each of three sample plants following the method of Freischmidt *et al.* (2008).

Water Soluble and Dichloromethane Extractives

Extractives were calculated as a percentage of oven dried (OD) wood. Results are a mean of duplicate extractions. Results from these tests indicate likely yields for products such as pulp and fibreboard, and the potential magnitude (and hence treatment costs) of process effluent. Hot water soluble extractives include tannins, sugars and free acids. Solvent extraction using dichloromethane will remove resin and oxidised resin from softwoods, and fats (fatty acids) and waxes from hardwoods.

Cellulose Content

Cellulose was calculated as a percentage of OD wood. Results are a mean of duplicate determinations. This is a possible indicator of the suitability (in terms of product yield) of a potential feedstock for chemical pulp production.

pH and Wood Meal Buffering Capacity

The pH and buffering capacity of wood materials is particularly important in reconstituted products, because the cure characteristics of resins can be significantly affected. Extremes in pH can either inhibit resin cure or accelerate it too quickly. Similarly, some weak acids and bases present in wood can resist changes to pH and consequently influence resin curing.

Fibre Length

Fibre length and width were determined on fibres prepared by chemical digestion of randomly selected midsections from the discs described above. The mean fibre length and fibre width distribution of a potential feedstock is a good indicator of its suitability for pulp and panel boards. In broad terms short fibre length (~1 mm) pulps provide quality printing papers and long fibre (~2 mm) pulp provide sacking papers for packaging.

Pulp Testing

Pulp yield is the amount (by weight) of usable pulp fibres produced by chemical Kraft cooking. Pulp yields of greater than 45% would be considered as favourable results for any of the species investigated, warranting further detailed investigation into both pulp yield and paper properties. Pulp yield was determined as the oven dry equivalent of pulp divided by the oven dry equivalent of wood starting material for a pulp having a Kappa number of 18.

6.2.3.2 Oils

For the initial FloraSearch project a broad survey approach was to have been undertaken. On review of the published literature, numerous Australian species have already been tested for oil yield and composition. The remaining, previously untested, FloraSearch species will be directed to Dr Joe Brophy, University of NSW, for analysis.

Typically, leaf samples will be weighed on arrival at the laboratory and if not processed immediately are allowed to air dry. The isolation of oil from the leaves is achieved through steam distillation with the distillations carried out until no more oil is produced. The oil yield will be calculated on the weight of the oil remaining and the weight of the leaf material used in distillation. The oils are to be analysed by both gas chromatography (gc) and combined gas chromatography-mass spectrometry (gc-ms). Components of the various oils are identified using their identical gc retention times with known compounds and by comparison of their mass spectra with either known compounds or published spectra (Boland *et al*. 1991).

Later work involving further testing of targeted species to check on the variability of the oil content, the procedure would be steam distillation of the supplied samples and analysis of the oils obtained by gas chromatography only, since quantitative differences only are expected.

6.2.3.3 Fodder

The limited availability of information on native species is probably due to difficulties in assessing the "fodder value" of a plant. Most studies have concentrated on chemical compositions and digestibility due to ease of obtaining such data. However the most important measure of fodder value is weight gain produced by animals in feed tests (Vercoe 1988). This information is largely unavailable but will be important to obtain for species targeted from initial chemical testing as it accounts for palatability and anti-nutritive factors.

The initial survey undertaken by FloraSearch is a screening process based on chemical testing. This utilises the "FeedTest" services of Agriculture Victoria. The basic chemical tests include:

- Crude protein
- Estimated metabolisable energy
- Digestibility (in vitro)
- %Dry matter (in vivo).

These results are then compared with commercially produced fodder material or with widely utilised forages such as lucerne tree and Oldman Saltbush. Additional chemical tests that could be undertaken later if required include fibre and full mineral (Na, Cl, K, Mg, Cu, N and P) testing.

6.3 Species Productivity and Potential Range

6.3.1 Species productivity

Information on individual plant growth rates, yield and plantation productivity are critical in the process of evaluating species for their potential commercial development. In the FloraSearch project we have amalgamated data from FloraSearch field surveys and FloraSearch-contracted Eucalypt growth observations of 162 taxa at Currency Creek Arboretum to develop preliminary models of plant productivity. The Currency Creek Arboretum measurements included 10 fast growing species not indigenous to the FloraSearch study area. Production rates (m^3/ha/year) are calculated using data of plant volumes and age collected during field sampling, from Dean Nicolle's plantings and data obtained from existing trial sites. Observations of plant height, stem diameter and density were used to calculate outer bark stemwood volumes. Bark volumes were estimated using measures of bark thickness and outer bark stem area at 0.5 m high.

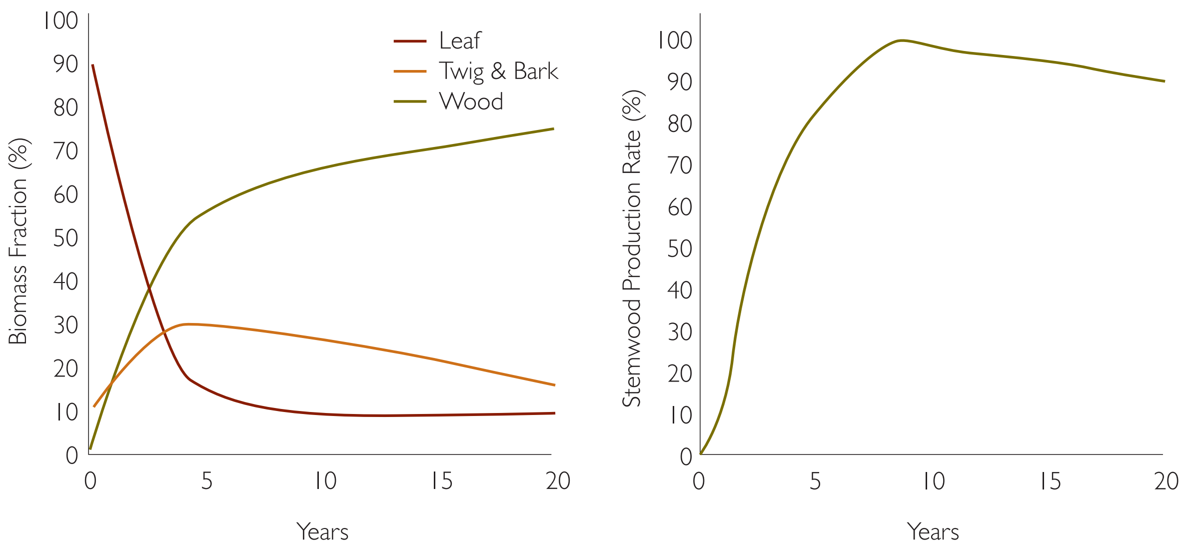
Volume estimates are derived from measurements of total height, and the stem area at 0.5 m and 1.3 m high. For multi-stemmed species the sum of all stem areas at 0.5 m and 1.3 m heights was calculated. Total stemwood volume calculations are based on:

- Volume 1: 0.1 m (harvest height) to 0. 5m
  = volume of a cylinder formula
- Volume 2: 0.5 m to 1.3 m
  = Smalian's frustrum of a paraboloid formula
- Volume 3: 1.3 m to max height
  = paraboloid formula
- Total outer bark stemwood volume
  = sum of volumes 1, 2 and 3

The age of Dean Nicolle's records is accurately documented, and many FloraSearch survey records are from known-age sites. The remaining FloraSearch samples are from poorly documented revegetation sites or from wild sources, with little or no age information. Native species are usually considered difficult to age from growth ring counts. However, the FloraSearch samples are typically immature specimens with little or no heartwood development and often display apparent growth rings. For these specimens the age has been estimated using growth rings counts with results calibrated against samples of precise known age. Estimates of mean annual increments of stemwood volumes were then calculated using total stemwood volumes divided by plant ages for each plant.

Measurements of bark thickness, green wood density and basic (dry) density were used to determine solid wood (inner bark) volumes, bark and wood moisture contents. Leaf and twig density estimates and their correlations with stemwood volumes have allowed estimates of leaf and twig productivity. Proportions of wood, leaf, twig and bark change during the life

Figure 4. Changes in green biomass fractions by weight with time for moderately densely-leaved Eucalypt species (left) and stemwood production rate as a percentage of maximum stemwood production by year (right), after Landsberg 3PG model, in Sands (2001).



stages of woody plants. We have used measurements gathered from Eucalypt species from WA trials (G. Olsen, pers. comm.) and FloraSearch surveys sites to determine the relationship of proportional change in green biomass fractions with time (Figure 4). The change in green wood fraction with time is represented by the equation:

wood fraction (% green weight)
$= 27.5 \times \ln(\text{year} + 1)$ [$r^2=0.97$];

and the residual biomass is divided as 54% leaf and 46% twig and bark. Stemwood production rates have been estimated from field measurements and changes in productivity rates with time (Figure 4) are based on data from the Landsberg's 3PG model in Sands (2001).

Estimates of stocking density were determined by dividing one hectare by the crown area of each plant. Solid wood producing species with calculated stocking densities of less than 1,000 stems/ha were set at the crown determined density value. Wood species with calculated stocking densities greater than 1,000 stems/ha were set at 1,000 stems/ha. The smaller "fodder only" species were set at a stocking density of 2,000 stems/ha. These stocking densities were combined with mean annual increments of individual stemwood volumes to estimate their stemwood productivity per unit area (m^3/ha/year). Subtracting bark proportions, and multiplying by green and basic wood density, provides estimates of mean annual productivity of green and bone dry tonnes per hectare. Modelled productivity of the individual fractions of the biomass (i.e. wood, bark, twig, leaf) allow the prediction of specific product yields when combined with data such as pulp yields, oil yields, calorific value and fodder value. Site productivity data on 186 taxa were linearly correlated with mean annual rainfall observations at their survey sites and standardised to their equivalent stemwood productivity for 500mm of annual rainfall (Table 10).

Stemwood productivity results reported in Table 10 may be higher than expected for some species. Admittedly, particular sites or lower planting densities may have advantaged some sampled plants. Plants sampled at Currency Creek Arboretum were from block plantings less than 10 years old at ~625 trees per hectare and not irrigated. Although some species have higher productivity results than expected, these results may be partially explained by genetic variations within a species (to be targeted for germplasm development), the multi-stemmed nature of some species, or increased soil moisture and nutrients stores in sites previously used for annual cropping and only recently revegetated with woody species. Such soil and nutrient stores, typical of annual cropping areas, will advantage many short-rotation agroforestry options and may result in higher initial productivity rates in these systems than originally envisaged. However, these productivity rates may diminish over longer harvest periods as soil moisture and nutrients are exhausted. Alley designs on landscapes with lateral ground water flow systems (e.g. WA wheatbelt and SA south east regions) may provide more persistent high rates of biomass production.

Preliminary models of productivity have been created using the information and processes outlined above. More accurate models will require the acquisition of more detailed data on species productivity. Some data can be gathered from more detailed evaluations of earlier trial sites and revegetation projects. To provide reliable models of plant productivity will require more accurate parameterisation to take into account issues that influence plant productivity. This is typically achieved in agricultural and forestry systems through the use of scientifically rigorous field trials covering a range of species, plant varieties, plantation designs, management and locations. In the future FloraSearch will conduct field trials (some in conjunction with the Field Trials of Woody Germplasm project) and evaluate other existing farm forestry trials to provide the extra information required for more accurate plant growth models.

Table 8. Summary of key plant attributes, averages and ranges [Minimum - Maximum].

Plant Group	Stemwood productivity [m^3/ha/yr @500mm]	Basic Density [kg/m^3]	Wood Moisture [% wet weight]	Bark Volume [% volume]	Leaf Moisture [% wet weight]	Pulp Yield [% dm]	Water Solubles [% dm]	pH	Oil Yield [% dm]	Crude Protein [% dm]	Digestibility [% dm]	Metabolisable Energy [MJ\kg dm]
All	5.93 [0.07-35.09]	719 [389-996]	38 [16-65]	22 [8-43]	50 [19-85]	46.3 [36.5-55.9]	10.0 [0.7-26.6]	4.7 [3.2-5.9]	1.21 [0.01-4.07]	14.1 [4.3-27.3]	59.3 [37.0-82.8]	8.5 [4.9-12.2]
Eucalyptus	8.69 [0.18-35.09]	710 [490-896]	40 [27-57]	23 [15-43]	46 [35-55]	47.0 [38.3-53.8]	8.9 [3.3-16.0]	4.5 [3.2-5.9]	1.21 [0.01-4.07]			
Acacia	3.69 [0.28-22.5]	763 [558-996]	32 [23-39]	22 [10-22]	49 [30-56]	49.8 [43.4-55.9]	12.6 [5.0-26.6]	4.7 [3.8-5.7]		14.0 [9.6-19.0]	51.4 [42.2-65.4]	7.2 [5.7-9.4]
Fodder	3.30 [0.07-22.5]	741 [389-996]	35 [16-65]	21 [8-27]	54 [34-83]	47.1 [38.0-55.9]	11.5 [0.7-26.6]	5.0 [3.8-5.8]		14.1 [4.3-27.3]	59.3 [37.0-82.8]	8.5 [4.9-12.2]

6.3.2 Other plant attributes

Information gathered on plant attributes and specific product testing are contained within the report by Hobbs and Bennell (2008). Table 8 provides a summary of key plant attributes and testing results from FloraSearch surveys.

6.3.3 Potential distributions

We have utilised plant distribution data from herbarium records (Australia's Virtual Herbarium 2003, B. Conn and G. Chapple, pers. comm.), state government surveys (SA DEH, Vic DNRE and NSW NPWS), Acacia Search and FloraSearch surveys, and bioclimatic models to predict the likely distribution of 250 FloraSearch selected taxa. The bioclimatic models are based on the Boxcar approach of BIOCLIM (Busby 1991) and implemented through BioLink 2.0 Software (CSIRO Entomology 2003). Climatic variables used in the modelling included mean annual rainfall, rainfall seasonality, mean rain in the dry quarter, mean annual temperature, maximum temperature in the warm period and minimum temperature in the cool period. These parameters closely correspond to those identified by previous JVAP research by Jovanovic and Booth (2002) for "improved climatic profiles". The occurrence and bioclimatic potential distributions for five of the representative species underpinning RIPA analysis (*Eucalyptus viminalis* ssp. *cygnetensis*, *E. porosa*, *E. cladocalyx*, *Acacia retinodes* and *Atriplex nummularia*) are represented in Figure 5 – Figure 9. Darker shadings on these maps represent areas with the highest potential for cultivation and lighter shades show areas of lower potential. The outputs from those models for other species are presented in Hobbs and Bennell (2008).

Figure 5. Occurrence and predicted potential distribution of *Eucalyptus viminalis* ssp. *cygnetensis*.

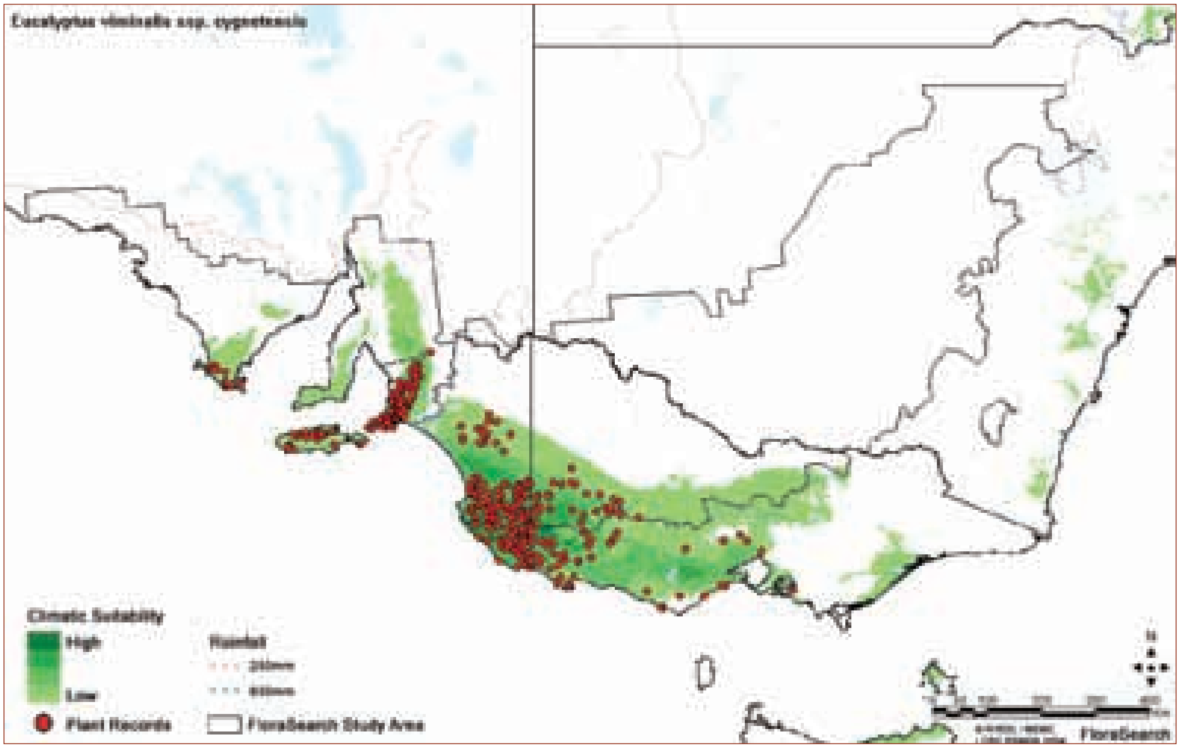


Figure 6. Occurrence and predicted potential distribution of *Eucalyptus porosa*.

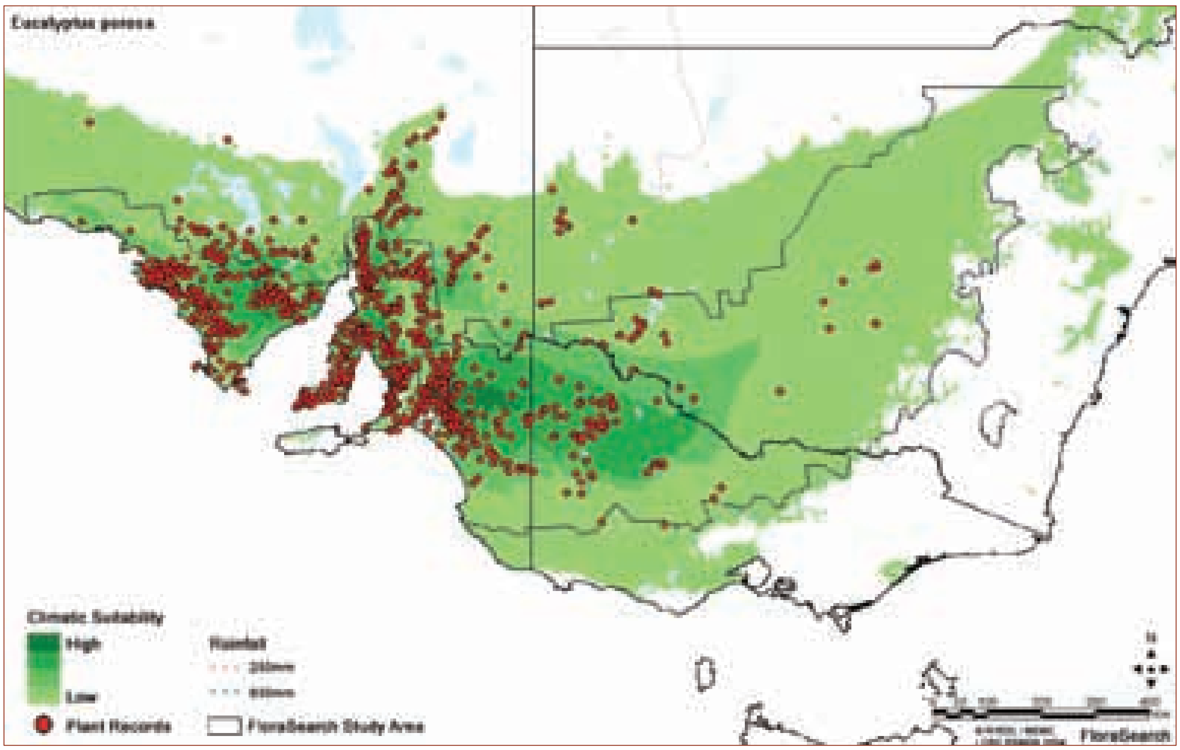


Figure 7. Occurrence and predicted potential distribution of *Eucalyptus cladocalyx*.

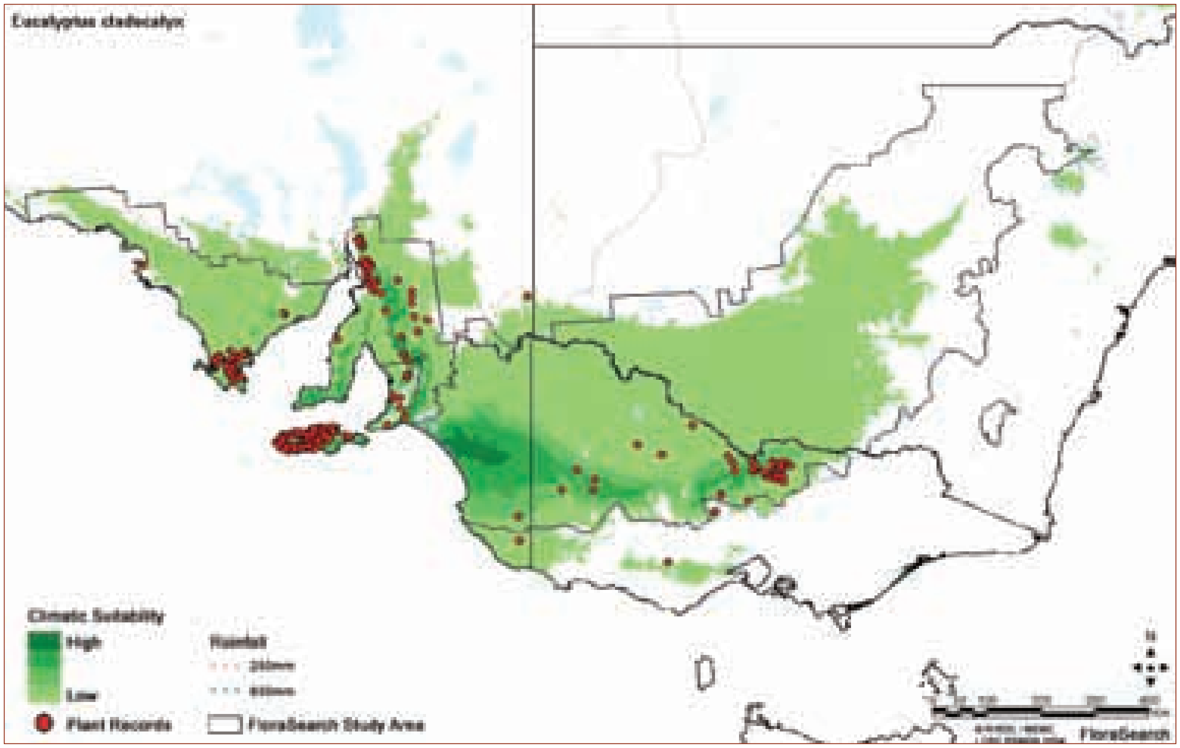


Figure 8. Occurrence and predicted potential distribution of *Acacia retinodes*.

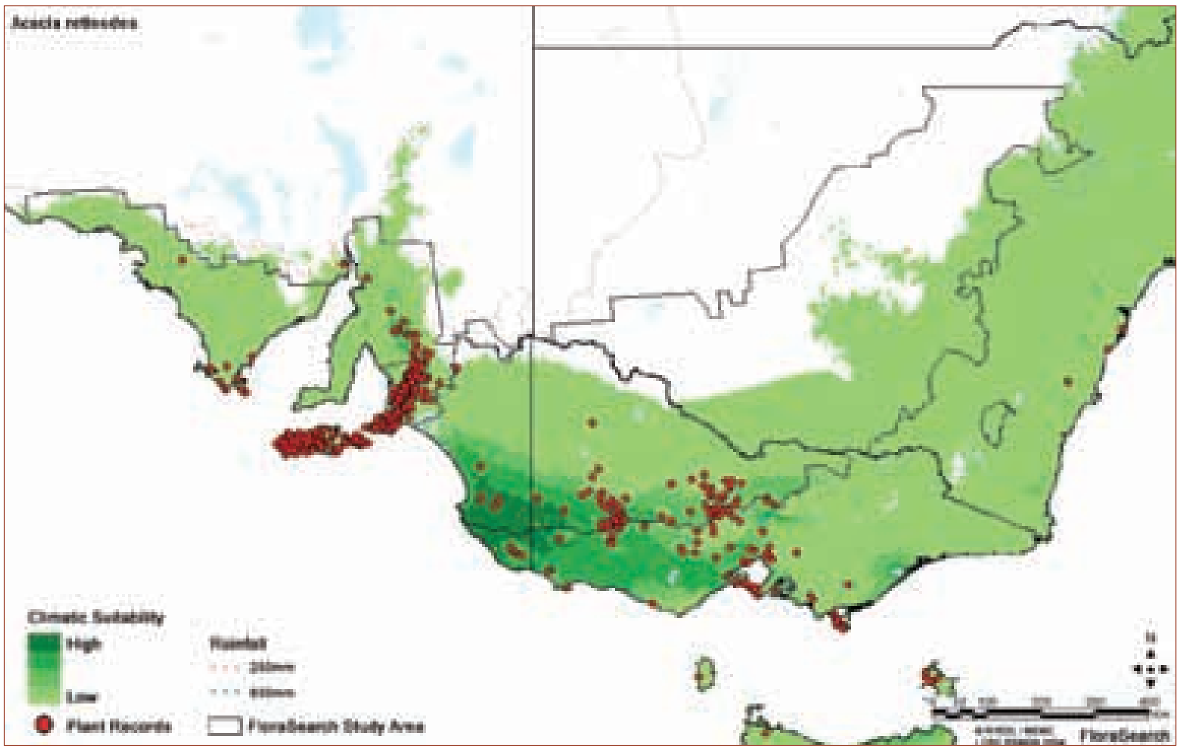
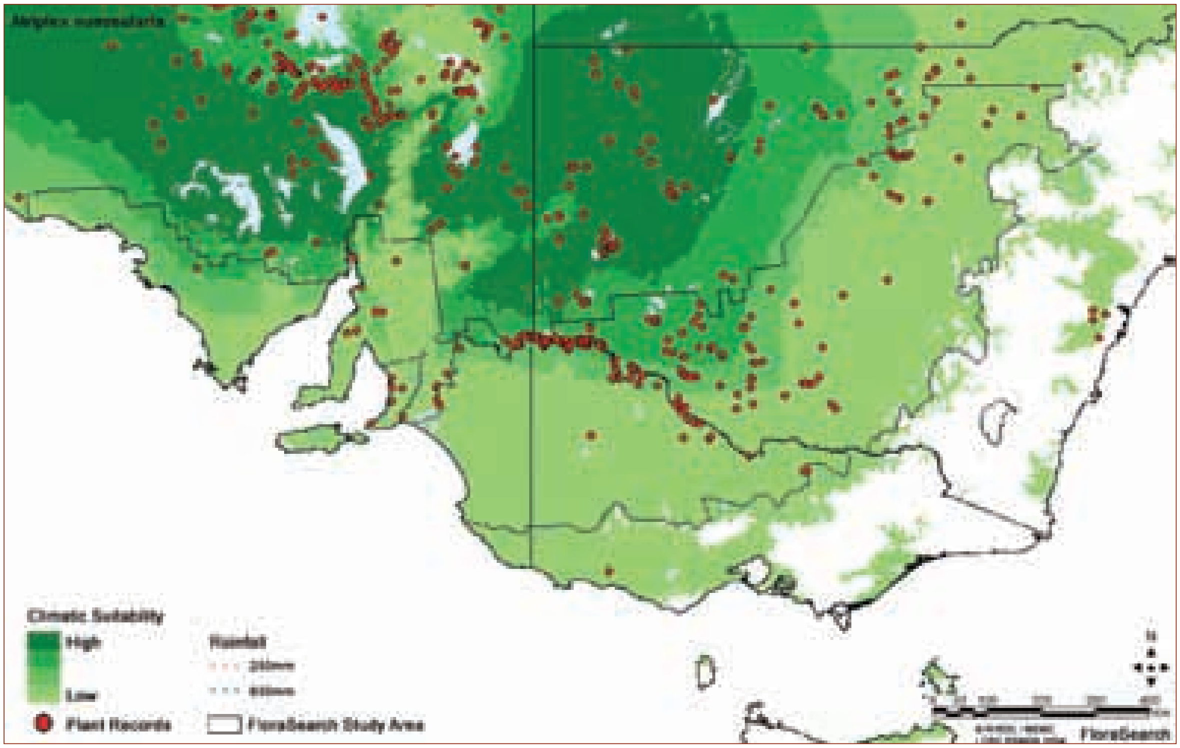


Figure 9. Occurrence and predicted potential distribution of *Atriplex nummularia.*



6.4 Results and Discussion

6.4.1 Field collection

Species that have been sampled for product testing are listed in Table 9.

Table 9. Taxa sampled for product testing (133 germplasms and 126 taxa).

Acacia aneura	*Allocasuarina verticillata*	*Eucalyptus brachycalyx (x2)*	*Eucalyptus socialis*
Acacia argyrophylla	*Alstonia constricta*	*Eucalyptus bridgesiana*	*Eucalyptus viminalis* ssp. *cygnetensis*
Acacia baileyana	*Apophyllum anomalum*	*Eucalyptus camaldulensis*	
Acacia brachybotrya	*Atalaya hemiglauca*	*Eucalyptus chloroclada*	*Eucalyptus viridis* ssp. *viridis* ssp. *wimmerensis*
Acacia cyclops	*Atriplex nummularia (x2)*	*Eucalyptus cladocalyx*	
Acacia dealbata	*Atriplex vesicaria*	*Eucalyptus cneorifolia*	
Acacia deanei ssp. *deanei*	*Beyeria viscosa*	*Eucalyptus conica*	*Flindersia maculosa*
Acacia decora	*Brachychiton populneus* ssp. *populneus*	*Eucalyptus cosmophylla*	*Geijera parviflora*
Acacia decurrens		*Eucalyptus fasciculosa*	*Grevillea striata*
Acacia doratoxylon	*Callistemon rugulosus*	*Eucalyptus fibrosa*	*Hakea sericea*
Acacia euthycarpa	*Callistemon sieberi*	*Eucalyptus globulus* ssp. *bicostata*	*Indigofera australis*
Acacia implexa	*Callitris endlicheri*		*Leptospermum continentale*

Table 9. Continued

Acacia leucoclada ssp. *leucoclada*	*Callitris glaucophylla (x2)*	*Eucalyptus goniocalyx*	*Leptospermum coriaceum*
	Callitris gracilis	*Eucalyptus gracilis*	*Leptospermum laevigatum*
Acacia mearnsii	*Callitris verrucosa*	*Eucalyptus incrassata*	*Maireana pyramidata*
Acacia melanoxylon	*Canthium oleifolium*	*Eucalyptus largiflorens*	*Maireana rohrlachii*
Acacia murrayana	*Capparis mitchellii*	*Eucalyptus leptophylla*	*Melaleuca acuminata*
Acacia myrtifolia	*Casuarina cristata*	*Eucalyptus leucoxylon*	*Melaleuca armillaris* ssp. *armillaris*
Acacia notabilis	*Casuarina cunninghamiana*	*Eucalyptus macrorhyncha*	
Acacia omalophylla	*Casuarina pauper*	*Eucalyptus melanophloia*	*Melaleuca halmaturorum*
Acacia pendula	*Chenopodium nitrariaceum*	*Eucalyptus melliodora*	*Melaleuca lanceolata (x2)*
Acacia penninervis	*Dodonaea viscosa* ssp. *mucronata* ssp. *spatulata*	*Eucalyptus microcarpa*	*Melaleuca uncinata*
Acacia pycnantha		*Eucalyptus odorata*	*Myoporum insulare*
Acacia retinodes var. *retinodes (hill form)* var. *retinodes (swamp form)*		*Eucalyptus ovata*	*Myoporum platycarpum*
	Enchylaena tomentosa	*Eucalyptus petiolaris*	*Nitraria billardierei*
	Eremophila bignoniiflora	*Eucalyptus phenax*	*Owenia acidula*
Acacia salicina	*Eremophila deserti*	*Eucalyptus pilligaensis*	*Petalostylis labicheoides* var. *labicheoides*
Acacia stenophylla	*Eremophila deserti*	*Eucalyptus polyanthemos*	
Acacia verniciflua	*Eremophila longifolia (x2)*	*Eucalyptus polybractea (x2)*	*Pittosporum angustifolium*
Acacia vestita	*Eremophila mitchellii*	*Eucalyptus populnea* ssp. *bimbil*	*Rhagodia spinescens*
Acacia victoriae	*Eucalyptus albens*		*Santalum acuminatum*
Allocasuarina diminuta	*Eucalyptus aromaphloia* ssp. *sabulosa*	*Eucalyptus porosa*	*Senna artemisioides*
Allocasuarina luehmannii		*Eucalyptus rubida*	*Templetonia retusa*
Allocasuarina muelleriana	*Eucalyptus baxteri*	*Eucalyptus sideroxylon*	*Ventilago viminalis*
	Eucalyptus blakelyi		

6.4.2 Wood property tests

The objective of this part of the study was to investigate the potential of the selected species for use in forest products. A range of potential wood products have been considered but in this work, paper and reconstituted wood-based products were the principal forest products investigated. Part way through the sampling and testing process refinements were made to some analysis methods as they lacked the required sensitivity to differentiate between species for their suitability for selected products. The following assaying methods were halted during the project: solvent extraction content, cellulose content, buffering capacity and fibre length. The results from an initial set of FloraSearch species and also WA Search (Olsen *et al*. 2003) showed little differentiation between species for these tests. Consequently an abbreviated test protocol was adopted:

- Basic density
- Pulp yield
- pH
- Total hot water extractives content.

The results from these tests, fodder and essential oil yield, and those of the stem wood production estimation for all tested species are included into a single table (Table 10) to facilitate cross referencing of results for each species. Two typical commercial plantation woods were used for comparison: *Eucalyptus nitens* (14 years old) and *Pinus radiata* (25-30 years old) (Freischmidt *et al*. 2008). These species supply much feedstock for the forest product industries in Australia and are therefore representative of wood properties expected by industry.

6.4.2.1 Basic density

The range of wood densities in FloraSearch taxa sampled to date varied from ~350 to 1,000 kg/m³. See Table 10 and Appendix G for a comprehensive listing of test results. Basic density is a key indicator of pulpwood quality and has been correlated with paper properties so that feedstocks of different density ranges are suited to different paper products (Hicks and Clark 2001). Eucalypts at the high end of the density range of commercial pulpwoods have fibres with thick walls relative to diameter are stiff and resistant to collapse. This results in a bulky open paper sheet that is porous and more compressible thereby giving better printing properties. Medium density eucalypts are considered superior raw material for tissue. Woods at the low end of the commercial range (as low as 400 kg/m³) collapse more readily giving papers of high tensile and bursting strength with low opacity and are used for packaging grades (Higgens 1978).

Density also affects the economics of road transport. Basic density is inversely related to moisture content which influences road transport costs since regulation limits truck weight. Typically, higher density woods have lower transport costs per BDU (Hicks and Clark 2001).

The growing conditions and age of the plant can influence basic density. A lower than normal growth rate due to unfavourable growing conditions may be expected to result in a higher density. The effect of high salinity on *Eucalyptus camaldulensis* appeared to be similar to that of reduced water availability with mean density increasing by 37 kg/m³ over trees grown in low salinity on the same site (Clark *et al*. 1999). There is also evidence of an increase in wood density with tree age for eucalypts, which is usually attributed to increases in cell wall thickness with increased cambial age (Clark and Rawlins 1999).

6.4.2.2 Extractives content (hot water and dichloromethane) and cellulose content

Hot water soluble extractives include tannins, sugars and free acids while solvent extraction removes resin and oxidised resin from softwoods, and fats (fatty acids) and waxes from hardwoods. These compounds can have detrimental effects on the manufacturing processes of various forest products. Adhesive bonding may be impaired, the level of effluent produced in pulping processes excessive or yields of product may be reduced.

The cellulose content gives a reasonable indication of likely pulp yield resulting from chemical digestion of wood. Table 10 shows the hot water extractive level for all samples that were tested for wood properties. Table 11 shows the level of extractives and cellulose content found in the sampled Acacias and early FloraSearch samples before the test protocol was adjusted.

Table 10. Summary of results for stem wood productivity, wood tests, essential oil yield and fodder testing for all priority FloraSearch species for which testing has been undertaken or published information is available.

Additional results incorporated from Acacia Search (a), WA Search (w), Noel Clark (c), Jugo Ilic (i), Dean Nicolle contracted survey (n), & extrapolations from closely related species (e).

Taxa	Stemwood production [m^3/ha/year@500mm]	Basic density [kg/m^3]	Woodchip production [bdt/ha/year@500mm]	Pulp yield [%dm@ Kappa 18]	Water Solubles [%dm]	pH	Oil Yield [%dm]	Crude Protein [%dm]	Digestibility [%dm]	Metabolisable Energy [MJ/kg dm]	Palatability [High Med Low Not]
Acacia aneura	0.79	875	0.56		10.1	5.0		12.6	51.6	7.2	H
Acacia argyrophylla		891a			13.2	3.8		10.5	49.7	6.9	
Acacia baileyana	1.71a	735a	0.98					13.3	46.5	6.4	
Acacia brachybotrya	1.14	851	0.88								
Acacia cyclops	3.22	657w	1.65	48.8w	9.3	5.3					
Acacia dealbata	4.11a	664a	2.13					17.2	50.7	7.1	
Acacia deanei ssp. *deanei*	1.83	781	1.12		16.4	4.9		13.7	52.7	7.4	M
Acacia decora	0.69	793	0.43					9.6	65.4	9.4	
Acacia decurrens	3.46a	791a	2.14					14.3	50.0	7.0	
Acacia doratoxylon	4.88a	884a	3.37					13.5	46.7	6.4	M
Acacia euthycarpa	2.08	729	1.22		9.9	4.1		11.7	54.5	7.7	
Acacia farnesiana											H
Acacia filicifolia	1.55a	642a	0.78								
Acacia hakeoides	1.05a	856a	0.70								N
Acacia implexa	2.15	779a	1.31					15.4	55.0	7.8	L
Acacia leucoclada ssp. *leucoclada*	3.32a	627	1.63	49.1				17.2	48.1	6.7	
Acacia ligulata	1.76a	916a	1.25								M
Acacia linearifolia		766a									
Acacia mearnsii	2.66a	756a	1.57	54.8c							
Acacia melanoxylon	2.19a	599a	1.02	55.9c				13.0	42.2	5.7	
Acacia montana											M
Acacia murrayana	2.66	692w	1.44	43.4w	14.9	5.3		15.5	44.9	6.2	M
Acacia myrtifolia	1.46										
Acacia neriifolia	1.72a	811a	1.09								M
Acacia notabilis	1.15	762	0.71		17.0	3.9					
Acacia omalophylla	1.13	996	0.87		26.6	4.2		12.6	53.7	7.6	

Table 10. Continued

Taxa	Stemwood production [m³/ha/year@500mm]	Basic density [kg/m³]	Woodchip production [bdt/ha/year@500mm]	Pulp yield [%dm@ Kappa 18]	Water Solubles [%dm]	pH	Oil Yield [%dm]	Crude Protein [%dm]	Digestibility [%dm]	Metabolisable Energy [MJ/kg dm]	Palatability [High Med Low Not]
Acacia pendula	0.78	900	0.55					14.9	55.8	7.9	H
Acacia penninervis	2.13	710	1.18		14.4	4.5					
Acacia pycnantha	1.42a	745a	0.83					12.2	46.6	6.4	H
Acacia retinodes var. *retinodes (hill form)*	22.50	720	12.82	43.4	11.6	5.7		16.3	50.6	7.1	
Acacia retinodes var. *retinodes (swamp form)*	2.43a	558a	1.06	55.3	5.0	4.6		14.8	52.0	7.3	
Acacia salicina	14.11a	648a	7.13	45.3				14.3	62.3	8.9	L
Acacia stenophylla	7.42a	868a	5.03					10.8	49.7	6.9	M
Acacia verniciflua	0.28	720	0.16		10.5	4.7					
Acacia vestita	0.76	730	0.43		9.7	4.1					
Acacia victoriae ssp. *victoriae*	0.85a	756a	0.50					19.0	50.1	7.0	M
Acacia wattsiana		709a									N
Alectryon oleifolius											H
Allocasuarina diminuta	0.73										
Allocasuarina luehmannii	2.40	738	1.38		10.1	4.7					
Allocasuarina muelleriana	0.56	737	0.32		10.8	4.3		7.1	52.4	7.4	H
Allocasuarina verticillata	4.40	782	2.76	41.5	13.4	5.7		10.2	49.3	6.9	H
Alstonia constricta	1.00	529	0.41	<36	11.0	5.3		17.7	82.0	12.1	M
Apophyllum anomalum	0.35	802	0.22					11.1	50.7	7.1	H
Atalaya hemiglauca	2.49	751	1.71	<39	14.6	5.8		13.8	45.7	6.3	H
Atriplex nummularia	1.54	450e	0.54					20.4	75.6	11.1	M
Atriplex paludosa											M
Atriplex vesicaria	0.38	450e	0.13					20.1	69.4	10.1	H
Beyeria viscosa	0.68										
Brachychiton populneus	2.19	389	0.66		15.0	5.5		13.9	49.4	6.9	
Bursaria spinosa											H
Callistemon rugulosus	1.13	840	0.75		11.7	5.0					
Callistemon sieberi	0.68	702	0.37		11.3	4.7					
Callitris endlicheri	0.67	577	0.30					4.3	56.6	8.0	

Table 10. Continued

Taxa	Stemwood production [m^3/ha/year@500mm]	Basic density [kg/m^3]	Woodchip production [bdt/ha/year@500mm]	Pulp yield [%dm@ Kappa 18]	Water Solubles [%dm]	pH	Oil Yield [%dm]	Crude Protein [%dm]	Digestibility [%dm]	Metabolisable Energy [MJ/kg dm]	Palatability [High Med Low Not]
Callitris glaucophylla	1.58	603	0.74	<35w	6.4	4.8					
Callitris gracilis	9.66	529	4.40	<37	0.7	5.5		5.4	55.9	7.9	
Callitris verrucosa	3.11	657	1.64	<38	6.5	4.1					
Canthium latifolium		660i									M
Canthium oleifolium	0.60	780	0.41		13.1	4.3		10.4	80.6	11.9	H
Capparis mitchellii	5.11	695	3.06	38	19.1	5.6		16.1	64.6	9.3	H
Casuarina cristata	1.10	837	0.72	<37				8.5	46.0	6.3	H
Casuarina cunninghamiana ssp. *cunninghamiana*	3.50	491	1.34	48.2c	13.4	5.6					
Casuarina pauper	3.72	707	2.20	<39	10.0	4.6					
Chenopodium auricomum											M
Chenopodium gaudichaudianum											M
Chenopodium nitrariaceum								20.8	78.6	11.5	M
Codonocarpus cotinifolius	9.74	397w	3.29	46.5	9.0	5.7					
Cullen australasicum											H
Daviesia asperula											M
Daviesia brevifolia											M
Daviesia genistifolia											M
Daviesia leptophylla											M
Dodonaea viscosa ssp. *mucronata*		824			8.8	5.2					L
Dodonaea viscosa ssp. *spatulata*	2.64	836	1.88		8.8	5.2		10.3	61.5	8.8	L
Duboisia hopwoodii		479w		36.5	12.2	5.0					
Enchylaena tomentosa	0.07							18.5	66.3	9.6	H
Eremophila bignoniiflora	2.74	813	1.83		12.0	4.7		12.0	82.6	12.2	
Eremophila deserti	1.07	803	0.67		8.9	4.5		14.0	82.8	12.2	
Eremophila glabra											M
Eremophila longifolia	2.35	672	1.23	<38	8.8	5.2		13.2	75.4	11.0	H

Table 10. Continued

Taxa	Stemwood production [m³/ha/year@500mm]	Basic density [kg/m³]	Woodchip production [bdt/ha/year@500mm]	Pulp yield [%dm@ Kappa 18]	Water Solubles [%dm]	pH	Oil Yield [%dm]	Crude Protein [%dm]	Digestibility [%dm]	Metabolisable Energy [MJ/kg dm]	Palatability [High Med Low Not]
Eremophila maculata											M
Eremophila mitchellii	1.39	838	0.91		13.2	4.8					
Eucalyptus alaticaulis	15.48n	660e	7.97								
Eucalyptus albens	6.46	850	4.28		8.7	3.8	0.05				
Eucalyptus albopurpurea	3.70n	777e	2.24								
Eucalyptus angulosa	3.38n	768e	2.03				0.68				
Eucalyptus arenacea	2.18n										
Eucalyptus argyphea	15.13n	660e	7.79								
Eucalyptus aromaphloia ssp. *sabulosa*	25.49n	540	7.85	44.5	7.7	4.5	2.95				
Eucalyptus banksii	32.74n	660e	16.85				0.30				
Eucalyptus baxteri	10.85	490	3.15	46.0	8.0	4.6	0.55				
Eucalyptus behriana	3.90n	883e	2.68				0.68				
Eucalyptus blakelyi	7.02n	543	2.97	44.7	3.4	5.2	1.60				
Eucalyptus botryoides	8.46n	599c	3.95	47.9c			0.37				
Eucalyptus brachycalyx	6.59	810	4.37				1.30				
Eucalyptus bridgesiana	13.85n	539	5.82	46.2	8.8	4.4	0.58				
Eucalyptus calcareana	3.26n	815e	2.07				1.40				
Eucalyptus calycogona	1.24n	830i	0.81				1.00				
Eucalyptus camaldulensis	19.24n	502	7.53	38.3w	16.0	5.4	1.50				
Eucalyptus ceratocorys	1.83n	860i	1.23				1.20				
Eucalyptus chloroclada	20.31n	621	9.84	39.9	14.0	4.0					
Eucalyptus cladocalyx	22.05n	753	12.11	49.6	8.4	4.3	0.05				
Eucalyptus cneorifolia	9.90	854	6.53		8.5	4.5	1.45				
Eucalyptus concinna	0.18n	820i	0.11				2.97				
Eucalyptus conglobata	1.79n						0.10				
Eucalyptus conica	8.82n	679	4.67	44.5	8.5	4.3	0.75				
Eucalyptus coolabah	1.38n	884i	0.95								
Eucalyptus cosmophylla	12.37n	549	3.97	42.9	10.9	4.6	0.40				
Eucalyptus crebra	1.58n	830i	1.02				0.52				
Eucalyptus cyanophylla	1.05n						2.10				

Table 10. Continued

Taxa	Stemwood production [m³/ha/year@500mm]	Basic density [kg/m³]	Woodchip production [bdt/ha/year@500mm]	Pulp yield [%dm@ Kappa 18]	Water Solubles [%dm]	pH	Oil Yield [%dm]	Crude Protein [%dm]	Digestibility [%dm]	Metabolisable Energy [MJ/kg dm]	Palatability [High Med Low Not]
Eucalyptus dealbata	12.98n	772i	7.82				1.30				
Eucalyptus diversifolia	6.83n	674e	3.59				0.50				
Eucalyptus dives	7.42n	603i	3.49	39.4			3.81				
Eucalyptus dumosa	4.37n	815e	2.78				1.25				
Eucalyptus dwyeri	9.19n	621e	4.45				2.05				
Eucalyptus fasciculosa	8.75	704	3.80	43.7	10.2	4.8	0.16				
Eucalyptus fibrosa	11.58n	801	7.23		12.8	3.2	0.40				
Eucalyptus flindersii	6.91n	781e	4.21				0.80				
Eucalyptus globulus ssp. *bicostata*	22.43n	656	9.61	46.7	8.0	4.6	1.15				
Eucalyptus gomphocephala	35.09n	842i	23.05								
Eucalyptus goniocalyx	9.56n	660	4.92	46.4	9.0	3.8	1.20				
Eucalyptus gracilis	4.42	849	3.17				0.75				
Eucalyptus gypsophila	1.71n	840i	1.12								
Eucalyptus incrassata	5.04n	768	3.14	48.6	4.6	5.9	2.80				
Eucalyptus intertexta	1.13n	900i	0.79				0.77				
Eucalyptus lansdowneana	0.72n						1.30				
Eucalyptus largiflorens	9.41n	883i	6.33		11.1	5.0	0.90				
Eucalyptus leptophylla	7.91	779	4.90		3.6	5.4	0.80				
Eucalyptus leucoxylon	19.29n	773	9.92	43.0	9.5	5.5	1.65				
Eucalyptus macrorhyncha ssp. *macrorhyncha*	8.68n	668	4.52	40.4	10.6	3.5	0.30				
Eucalyptus maculata	12.30n	797i	7.64				0.65				
Eucalyptus mannifera	19.58n	615i	9.39				1.35				
Eucalyptus megacornuta	15.40n	660e	7.93								
Eucalyptus melanophloia	5.06n	844	3.32		11.9	3.6	0.35				
Eucalyptus melliodora	10.33n	719	5.79		9.7	4.9	1.23				
Eucalyptus microcarpa	12.32n	775	7.45		7.7	4.7	0.23				
Eucalyptus moluccana	4.47n	840i	2.93				0.48				
Eucalyptus morrisii	2.56n	780e	1.56				1.70				

Table 10. Continued

Taxa	Stemwood production [m³/ha/year@500mm]	Basic density [kg/m³]	Woodchip production [bdt/ha/year@500mm]	Pulp yield [%dm@ Kappa 18]	Water Solubles [%dm]	pH	Oil Yield [%dm]	Crude Protein [%dm]	Digestibility [%dm]	Metabolisable Energy [MJ/kg dm]	Palatability [High Med Low Not]
Eucalyptus nortonii	8.78n	660e	4.52	<39			0.70				
Eucalyptus obliqua	0.41n	579i	0.18				2.08				
Eucalyptus occidentalis	9.85n	554c	4.26	50.1c							
Eucalyptus ochrophloia		850i					2.20				
Eucalyptus odorata	8.80n	777	5.45		6.2	3.9	1.40				
Eucalyptus oleosa	3.28n	954i	2.44				3.10				
Eucalyptus ovata	18.73n	504	6.13	49.5	8.2	4.5	0.95				
Eucalyptus petiolaris	12.25n	664	6.22	47.1	10.1	4.3	2.10				
Eucalyptus phenax	6.46	815	4.49		3.3	4.8	0.63				
Eucalyptus pileata	2.97n	815e	1.89				3.70				
Eucalyptus pilligaensis	3.72	896	2.60		11.9	3.2					
Eucalyptus polyanthemos	12.55n	783	7.67		15.3	4.0	1.13				
Eucalyptus polybractea	2.55n	770	1.53	54.0	7.4	4.4	2.35				
Eucalyptus populnea ssp. *bimbil*	1.51n	862i	1.02								
Eucalyptus porosa	6.44n	641	3.04	49.9	7.7	5.1	2.10				
Eucalyptus radiata	1.59n	581i	0.72				4.07				
Eucalyptus remota	7.68n	700e	4.19				0.68				
Eucalyptus rossii	3.61n	654i	1.84				1.10				
Eucalyptus rubida	13.52n	529	4.98	46.5	8.7	3.9	1.15				
Eucalyptus rugosa	5.12nn	860e	3.43				0.90				
Eucalyptus siderophloia	9.48n	868i	6.42				0.15				
Eucalyptus sideroxylon	11.63n	759	6.89		11.0	4.8	1.77				
Eucalyptus socialis	6.62	765	4.10		4.9	4.9	1.60				
Eucalyptus sporadica	11.40n	554e	4.93								
Eucalyptus tereticornis	8.71n	781i	5.31				0.82				
Eucalyptus tessellaris		860i					0.07				
Eucalyptus trachyphloia	6.84n	846i	4.52				0.20				
Eucalyptus tricarpa	3.83n	773e	2.31								
Eucalyptus utilis	6.41n	554e	2.77								

Table 10. Continued

Taxa	Stemwood production [m³/ha/year@500mm]	Basic density [kg/m³]	Woodchip production [bdt/ha/year@500mm]	Pulp yield [%dm@ Kappa 18]	Water Solubles [%dm]	pH	Oil Yield [%dm]	Crude Protein [%dm]	Digestibility [%dm]	Metabolisable Energy [MJ/kg dm]	Palatability [High Med Low Not]
Eucalyptus viminalis ssp. *cygnetensis*	17.50	532	5.98	44.3	11.2	5.0	1.36				
Eucalyptus viridis	3.85	845	2.74		7.2	4.6	1.23				
Eucalyptus viridis ssp. *viridis*	2.24n	837	1.46		5.2	5.2	1.23				
Eucalyptus viridis ssp. *wimmerensis*	7.98n	853	5.71		9.2	3.9	1.23				
Eucalyptus yalatensis	1.45n						0.01				
Eucalyptus yumbarrana	1.27n						1.40				
Flindersia maculosa	2.06	821	1.51	<40	6.4	4.5					H
Geijera parviflora	2.30	908	1.63		9.3	5.1		16.9	60.7	8.7	H
Grevillea striata	2.35	769	1.32		13.4	4.2		5.5	37.0	4.9	M
Gyrostemon ramulosus		416w		44.3	8.6	5.7					
Hakea sericea	2.14				11.7	4.6					
Indigofera australis								20.9	70.2	10.2	H
Leptospermum continentale	0.50	635	0.27		9.1	4.7					
Leptospermum coriaceum	4.09	701	2.30		8.7	4.9					
Leptospermum laevigatum	3.12	741	1.75		6.7	4.6					
Lycium australe											M
Maireana aphylla											M
Maireana georgei											H
Maireana planifolia											H
Maireana pyramidata		450e						25.8	68.5	9.9	M
Maireana rohrlachii	0.09							27.3	64.7	9.3	H
Maireana tomentosa											H
Melaleuca acuminata	1.47										
Melaleuca armillaris ssp. *armillaris*	14.79	576	7.02	43.0	12.5	4.8					
Melaleuca halmaturorum ssp. *halmaturorum*	6.16	690	3.31	40.4	8.6	4.7					
Melaleuca lanceolata	6.41	680	3.71	39.4	5.8	5.5					

Table 10. Continued

Taxa	Stemwood production [m³/ha/year@500mm]	Basic density [kg/m³]	Woodchip production [bdt/ha/year@500mm]	Pulp yield [%dm@ Kappa 18]	Water Solubles [%dm]	pH	Oil Yield [%dm]	Crude Protein [%dm]	Digestibility [%dm]	Metabolisable Energy [MJ/kg dm]	Palatability [High Med Low Not]
Melaleuca uncinata	2.82	650	1.52	39.5	4.6	5.7					
Myoporum insulare	3.63	713	1.78	44.2	10.4	4.9					
Myoporum platycarpum	3.73	685	2.15	49.8	5.0	4.8		10.2	57.9	8.2	H
Nitraria billardierei	0.13							18.5	81.3	12.0	M
Owenia acidula	2.56	801	1.68	<40	11.6	4.6		13.8	55.8	7.9	H
Petalostylis labicheoides var. *labicheoides*	1.44	639	0.72		7.7	5.6		19.5	74.0	10.8	N
Pittosporum angustifolium	2.42	871w	1.65	<36w	16.9	5.2					
Pomaderris paniculosa											M
Rhagodia crassifolia											M
Rhagodia spinescens								20.8	67.0	9.7	M
Santalum acuminatum	1.63	630i	0.80					5.4	82.3	12.1	H
Santalum lanceolatum		710i									H
Santalum spicatum		802i									H
Scaevola spinescens											H
Senna artemisioides	0.68							10.6	64.3	9.3	M
Templetonia retusa	1.38							12.6	59.8	8.5	
Ventilago viminalis	6.90	843	4.87	<39	10.0	5.6		13.3	61.1	8.7	H
Viminaria juncea		478w		44.7	9.4	4.6					

Table 11. Solvent extractives contents, cellulose content, buffering capacity and mean weighted fibre length and width of Acacia and initial FloraSearch samples.

#BBC: Base Buffering Capacity; ABC: Acid Buffering Capacity, WBC: Wood Buffering Capacity.

Taxa	Solvent Extractives [%]	Mean Weighted Fibre Length (Standard Deviation) [µm]	Mean Weighted Fibre Width (Standard Deviation) [µm]	Cellulose Content [%]	Buffering capacities# BBC [mmol/g]	ABC [mmol/g]	FBC [mmol/g]
Acacia decora	0.2	496 (181)	19.5 (4.5)	42.1			
Acacia decurrens	0.4	423 (158)	19.0 (4.7)	39.0	0.04	0.04	0.08
Acacia hakeoides	0.3	589 (231)	20.8 (5.5)	38.9	0.05	0.04	0.10
Acacia leucoclada	0.4	495 (190)	19.0 (4.6)	39.4	0.03	0.03	0.06
Acacia linearnifolia	0.4	472 (246)	19.5 (4.9)	37.3	0.06	0.06	0.13
Acacia parramattensis	0.4	449 (168)	19.0 (4.6)	38.1	0.06	0.03	0.09
Acacia pendula	0.8	443 (177)	17.4 (4.0)	35.7			
Acacia pycnantha (A.G.)	0.3	509 (195)	18.6 (4.9)	38.3	0.06	0.04	0.10
Acacia pycnantha (K.S.)	0.2	524 (192)	19.5 (4.8)	40.0	0.05	0.04	0.09
Acacia retinodes var. *retinodes (hill form)*	0.4			40.1			
Acacia retinodes var. *retinodes (swamp form)*	0.3	481 (180)	18.8 (4.5)	43.0	0.07	0.03	0.10
Acacia retinodes x uncifolia	0.5	453 (171)	17.5 (4.5)	39.8	0.07	0.03	0.10
Acacia rivalis	0.4	514 (214)	18.2 (4.1)	41.2	0.14	0.05	0.19
Acacia victoriae	0.3	484 (187)	18.2 (4.6)	38.3	0.06	0.07	0.12
Allocasuarina verticillata	0.4			41.9			
Apophyllum anomalum	0.7	334 (116)	18.3 (4.8)	35.8			
Callitris endlicheri	0.4	1220 (692)	24.7 (7.1)	46.4			
Callitris glaucophylla	0.7	898 (449)	22.4 (5.6)	43.4			
Callitris gracillis	1.0			46.0			
Casuarina cristata	0.3			35.8			
Eucalyptus camaldulensis	0.3	515 (195)	17.6 (4.3)	41.1			
Eucalyptus incrassata	0.3			39.6			
Eucalyptus leucoxylon	0.5			37.7			
Eucalyptus populnea	0.5	430 (138)	17.1 (4.6)	37.8			
Melaleuca lanceolata	0.3			38.7			
Melaleuca uncinata	0.5			39.0			
Controls							
Pinus radiata	1.1	2000	30	~40	0.04	0.03	0.08
Eucalyptus nitens	0.3	630		40.4	0.05	0.04	0.09

Freischmidt *et al*. (2008) recommend total hot water extractives of <15% for general screening of species for wood products. Although similar cellulose and solvent extractives contents were found for Acacias and initial FloraSearch species subject to these tests, and the commercial reference species, very high levels of hot water extractives were found in the Acacias. This is in general agreement with the known naturally high levels of water-soluble tannins found in bark and foliage of many Acacias. Tannin testing will be undertaken on Acacia bark in the following stage of FloraSearch. Several Acacia wood samples exceed the recommended threshold including *Acacia deanei, A. notabilis* and *A. homalophylla.* Apart from *Capparis mitchellii* all other species tested at less than the 15% threshold.

6.4.2.3 pH and buffering capacity

The pH and buffering capacity of wood materials are important in reconstituted products as cure characteristics of resins can be significantly affected. Extremes in pH can either inhibit resin cure or accelerate it too quickly. Similarly, some weak acids and bases present in wood can resist changes to pH and consequently influence resin curing. Freischmidt *et al*. (2008) recommended a pH range of 4 to 5. Results in Table 10 and Table 11 show that minor differences were found between the species tested and the commercial examples in pH and buffering capacities. Tested species have a range of 3.2-5.7 with most falling in the accepted range. These results will be reviewed further following the selection of "best bet" species based on evaluation of productive potential, and product suitability on density and pulp results to confirm any influence on product performance arising from pH.

6.4.2.4 Fibre length

There is a relationship between fibre length and feedstock suitability for particular paper and reconstituted wood products. For example, long softwood fibres (2 mm +) would be favoured in MDF and sacking papers and short (<1 mm) fibres would be favoured in high quality printing papers. The tested species all had relatively short mean fibre lengths (see Table 11) and would therefore appear to be best suited to chemical pulps for printing and writing papers. There was little differentiation between species with all but *Callitris endlichii* being < 1 mm, a result consistent with the Search results (Olsen *et al*. 2003).

6.4.2.5 Pulp evaluation

Pulping quality includes pulp yield, processing costs and papermaking properties that will vary with pulp wood resources determined by genetic and environmental factors (Clark and Rawlins 1999). The assessment undertaken at this stage of the FloraSearch is a screening process based on pulp yield to determine which species are worthy of more detailed attention. Samples are from a single location and provide a general indication of potential but no information on the influence of genetic or environmental variability on yield. At this stage paper making properties have not been investigated. Of the 90 species dispatched to CSIRO – FFP for wood testing 29 were assessed for pulp yield. Also provided are results for FloraSearch species tested by WA Search that also occur in the FloraSearch region and published results from other studies (see Table 10).

6.4.3 Species matching to product

6.4.3.1 Pulp and paper

As a general guide an acceptable commercial density for pulp is in a range of 400-600 kg/m³ (Clark and Rawlins 1999) but Hicks and Clark (2001) refer to one Australian paper company accepting wood up to 650 kg/m³ for Kraft pulping and paper manufacture. For species selection in this study, density up to 700 kg/m³ for pulp was adopted giving a buffer above the accepted commercial limit to allow for improvements likely from future production systems, improved silviculture methods, and genetic improvement of planting stock. Although pulp can be manufactured from wood having higher density, the capacity of the digester is a limiting factor. High density wood can be more difficult to impregnate with cooking liquors leading to uneven delignification (i.e. chemical breakdown of wood into fibres from woodchips). This may lead to an increased cook time, making the use of such feedstock commercially unfeasible.

There is strong association between low rainfall and poor quality pulpwood quality (Clark *et al*. 1999) suggesting that pulp produced from low rainfall material may not be as suitable as that grown in high rainfall areas. Trees of several eucalyptus species grown with restricted water availability tend to have higher wood densities, poorer pulping and paper making properties, and slower growth rates.

Species with yields higher than 45% by weight have been selected for further evaluation for pulp and paper-making properties. Three species with higher than the nominated maximum basic density value are included (*Eucalyptus incrassata, E. polybractea* and *Acacia mearnsii*) because of their current high profile in revegetation projects and high yield values. See Table 12 for selected pulp species and their corresponding productive potential.

The species identified as being suited for pulp are further sorted on the following criteria: pulp yield >45%; high productivity >3 m^3/ha/year@500 mm; density <700 kg/m^3; and priority WA Search species which also occur in the FloraSearch region.

Table 12. FloraSearch species selected for pulp production showing estimated productive capacity and wood test results.
Additional results incorporated from Acacia Search (a), WA Search (w), Noel Clark (c), Dean Nicolle contracted survey (n).

Taxa	Stemwood production [m^3/ha/year@500mm]	Basic density [kg/m^3]	Woodchip production [bdt/ha/year@500mm]	Pulp yield [%dm@Kappa 18]	Water Solubles [%dm]	pH	Oil Yield [%dm]
Acacia melanoxylon	2.19a	599a	1.02	**55.9**c			
Acacia retinodes var. *retinodes (swamp form)*	2.43a	558a	1.06	**55.3**	5.0	4.6	
Acacia mearnsii	2.66a	756a	1.57	**54.8**c			
Eucalyptus polybractea	2.55n	770	1.53	**54.0**	7.4	4.4	2.35
Eucalyptus viminalis ssp. *cygnetensis*	17.50	532	5.98	**44.3**	11.2	5.0	1.36
Eucalyptus occidentalis	9.85n	554c	4.26	**50.1**c			
Eucalyptus porosa	6.44n	641	3.04	**49.9**	7.7	5.1	2.10
Myoporum platycarpum	3.73	685	2.15	**49.8**	5.0	4.8	
Eucalyptus globulus ssp. *bicostata*	22.43n	656	9.61	**46.7**	8.0	4.6	1.15
Eucalyptus ovata	18.73n	504	6.13	**49.5**	8.2	4.5	0.95
Acacia cyclops	3.22	657w	1.65	**48.8**w	9.3	5.3	
Eucalyptus incrassata	5.04n	768	3.14	**48.6**	4.6	5.9	2.80
Acacia leucoclada ssp. *leucoclada*	3.32a	627	1.63	**49.1**			
Casuarina cunninghamiana ssp. *cunninghamiana*	3.50	491	1.34	**48.2**c	13.4	5.6	
Eucalyptus botryoides	8.46n	599c	3.95	**47.9**c			0.37
Eucalyptus goniocalyx	9.56n	660	4.92	**46.4**	9.0	3.8	1.20
Codonocarpus cotinifolius	9.74	397w	3.29	**46.5**	9.0	5.7	
Eucalyptus bridgesiana	13.85n	539	5.82	**46.2**	8.8	4.4	0.58

6.4.3.2 Reconstituted wood products (MDF and fibreboard)

A positive outcome of Search (Olsen *et al*. 2003) and Freischmidt *et al*. (1998) was that MDF and particleboard could be successfully manufactured from a large range of species. For reconstituted wood based composites a maximum density of 600 kg/m³ was recommended for acceptable commercial results (Freischmidt, pers. comm.). For sifting of FloraSearch species an upper limit of 700 kg/m³ is retained to provide a buffer as explained above for pulp. Higher density feedstock results in fibreboard with a density exceeding market acceptability due to handling difficulties and to product quality issues from the lack of compressibility of harder feedstock. This property may result in panels with high residual internal stress and the possibility of delamination. See Table 13 for selected species and their estimated productivity.

6.4.3.3 Electricity generation from general biomass

The generation of electricity from woody biomass (bioenergy) is a targeted industry of the FloraSearch project. CSIRO Energy Technology is testing Australian biomass feedstocks with bioenergy potential and compiling an internet enabled database of the results as part of the Biofuel Database Project (http://www.det.csiro.au/science/energyresources/biomass.htm). They provide information on a range of bioenergy characteristics such as elemental composition, ash composition, calorific value, combustion and gasification characteristics for a selection of feedstocks such as agricultural waste materials, bio-solids, discarded material from sawmills and woody weeds. FloraSearch has provided samples of two prospective taxa to this study to determine their bioenergy generation characteristics (*Eucalyptus cneorifolia* [18.03 MJ/kg air dry] and *Melaleuca uncinata* [19.11 MJ/kg air dry]; see website above for detailed assessments). FloraSearch co-product testing results and initial productivity assessments provide a guide to other species that may be suitable for future combustion testing and development as bioenergy species (Table 14).

WA Search has tested 27 species generally considered as having high potential for wood processing. Standard tests for materials considered for combustion uses included calorific value and proximate analysis. In addition, CSIRO Energy Technology also tested for combustion chamber fouling and corrosion potential. Other tests being carried out include analysis of the risk of environmental pollution from metals contained in the ash of each tested species. The cost of safe ash disposal can be significant for feedstocks high in certain metals (Olsen *et al*. 2003).

6.4.3.4 Bioenergy and essential oil

In the FloraSearch project essential oils are being considered as a secondary outcome of wood production, predominantly in combination with bioenergy products, but also in combination pulp or fibreboards. As mentioned in Section 4.2.7 a substantial proportion of the species considered to be potential oil producers have been previously tested with results mostly published in the scientific literature with some unpublished at this stage. As an important first step in deciding on species to test further and for the later evaluation of current survey data, this information has been collected from all possible sources. Information has been entered into a database listing species, oil yield, the constituents, code to indicate the testing completeness, and source of the information.

Only a few species for which essential oil test data was not available were collected with the majority of potential oil producing species having already been tested at a high standard. Consequently, leaf material collected by FloraSearch to date has not been tested for oils. Evaluations of species' co-product potentials will identify those species to be oil tested. The oil yields for all species with published testing data are listed in Table 10. Oil yield together with composition will be the important criteria for species selection. Composition is too complex to represent within the report.

Table 13. Species suitable for reconstituted wood products (MDF and fibreboard) selected on having a basic density <700 kg/m³ and hot water extractives <15%.

Additional results incorporated from Acacia Search (a), WA Search (w), Noel Clark (c), Jugo Ilic (i), Dean Nicolle contracted survey (n), & extrapolations from closely related species (e).

Taxa	Stemwood production [m³/ha/year@500mm]	Basic density [kg/m³]	Woodchip production [bdt/ha/year@500mm]	Pulp yield [%dm@Kappa 18]	Water Solubles [%dm]	pH	Oil Yield [%dm]
Eucalyptus banksii	**32.74n**	**660e**	16.85				0.30
Eucalyptus aromaphloia ssp. *sabulosa*	**25.49n**	**540**	7.85	44.5	**7.7**	4.5	2.95
Eucalyptus globulus ssp. *bicostata*	**22.43n**	**656**	9.61	46.7	**8.0**	4.6	1.15
Eucalyptus chloroclada	**20.31n**	**621**	9.84	39.9	**14.0**	4.0	
Eucalyptus mannifera	**19.58n**	**615i**	9.39				1.35
Eucalyptus ovata	**18.73n**	**504**	6.13	49.5	**8.2**	4.5	0.95
Eucalyptus viminalis ssp. *cygnetensis*	**17.50**	**532**	5.98	44.3	**11.2**	5.0	1.36
Eucalyptus alaticaulis	**15.48n**	**660e**	7.97				
Eucalyptus megacornuta	**15.40n**	**660e**	7.93				
Eucalyptus argyphea	**15.13n**	**660e**	7.79				
Melaleuca armillaris ssp. *armillaris*	**14.79**	**576**	7.02	43.0	**12.5**	4.8	
Acacia salicina	**14.11a**	**648a**	7.13	45.3			
Eucalyptus bridgesiana	**13.85n**	**539**	5.82	46.2	**8.8**	4.4	0.58
Eucalyptus rubida	**13.52n**	**529**	4.98	46.5	**8.7**	3.9	1.15
Eucalyptus cosmophylla	**12.37n**	**549**	3.97	42.9	**10.9**	4.6	0.40
Eucalyptus petiolaris	**12.25n**	**664**	6.22	47.1	**10.1**	4.3	2.10
Eucalyptus sporadica	**11.40n**	**554e**	4.93				
Eucalyptus baxteri	**10.85**	**490**	3.15	46.0	**8.0**	4.6	0.55
Eucalyptus occidentalis	**9.85n**	**554c**	4.26	50.1c			
Codonocarpus cotinifolius	**9.74**	**397w**	3.29	46.5	**9.0**	5.7	
Callitris gracilis	**9.66**	**529**	4.40	<37	**0.7**	5.5	
Eucalyptus goniocalyx	**9.56n**	**660**	4.92	46.4	**9.0**	3.8	1.20
Eucalyptus dwyeri	**9.19n**	**621e**	4.45				2.05
Eucalyptus conica	**8.82n**	**679**	4.67	44.5	**8.5**	4.3	0.75
Eucalyptus nortonii	**8.78n**	**660e**	4.52	<39			0.70
Eucalyptus macrorhyncha ssp. *macrorhyncha*	**8.68n**	**668**	4.52	40.4	**10.6**	3.5	0.30
Eucalyptus botryoides	**8.46n**	**599c**	3.95	47.9c			0.37
Eucalyptus dives	**7.42n**	**603i**	3.49	39.4			3.81
Eucalyptus blakelyi	**7.02n**	**543**	2.97	44.7	**3.4**	5.2	1.60

Table 13. Continued

Taxa	Stemwood production [m³/ha/year@500mm]	Basic density [kg/m³]	Woodchip production [bdt/ha/year@500mm]	Pulp yield [%dm@Kappa 18]	Water Solubles [%dm]	pH	Oil Yield [%dm]
Eucalyptus diversifolia	**6.83n**	**674e**	3.59				0.50
Eucalyptus porosa	**6.44n**	**641**	3.04	49.9	**7.7**	5.1	2.10
Eucalyptus utilis	**6.41n**	**554e**	2.77				
Melaleuca lanceolata	**6.41**	**680**	3.71	39.4	**5.8**	5.5	
Melaleuca halmaturorum ssp. *halmaturorum*	**6.16**	**690**	3.31	40.4	**8.6**	4.7	
Acacia dealbata	**4.11a**	**664a**	2.13				
Myoporum platycarpum	**3.73**	**685**	2.15	49.8	**5.0**	4.8	
Eucalyptus rossii	**3.61n**	**654i**	1.84				1.10
Casuarina cunninghamiana ssp. *cunninghamiana*	**3.50**	**491**	1.34	48.2c	**13.4**	5.6	
Acacia leucoclada ssp. *leucoclada*	**3.32a**	**627**	1.63	49.1			
Acacia cyclops	**3.22**	**657w**	1.65	48.8w	**9.3**	5.3	
Callitris verrucosa	**3.11**	**657**	1.64	<38	**6.5**	4.1	
Melaleuca uncinata	**2.82**	**650**	1.52	39.5	**4.6**	5.7	
Acacia murrayana	**2.66**	**692w**	1.44	43.4w	**14.9**	5.3	
Acacia retinodes var. *retinodes (swamp form)*	**2.43a**	**558a**	1.06	55.3	**5.0**	4.6	
Eremophila longifolia	**2.35**	**672**	1.23	<38	**8.8**	5.2	
Acacia melanoxylon	**2.19a**	**599a**	1.02	55.9c			
Santalum acuminatum	**1.63**	**630i**	0.80				
Eucalyptus radiata	**1.59n**	**581i**	0.72				4.07
Callitris glaucophylla	**1.58**	**603**	0.74	<35w	**6.4**	4.8	
Acacia filicifolia	**1.55a**	**642a**	0.78				
Petalostylis labicheoides var. *labicheoides*	**1.44**	**639**	0.72		**7.7**	5.6	
Alstonia constricta	**1.00**	**529**	0.41	<36	**11.0**	5.3	
Callitris endlicheri	**0.67**	**577**	0.30				
Leptospermum continentale	**0.50**	**635**	0.27		**9.1**	4.7	
Eucalyptus obliqua	**0.41**	**579**	0.18				2.08
Gyrostemon ramulosus		**416**		44.3	**8.6**	5.7	
Viminaria juncea		**478**		44.7	**9.4**	4.6	
Duboisia hopwoodii		**479**		36.5	**12.2**	5.0	
Canthium latifolium		**660**					

Table 14. General biomass species selected on the basis of high estimated productive potential.
Additional results incorporated from Acacia Search (a), WA Search (w), Noel Clark (c), Jugo Ilic (i), Dean Nicolle contracted survey (n), & extrapolations from closely related species (e).

Taxa	Stemwood production [m³/ha/year@500mm]	Basic density [kg/m³]	Woodchip production [bdt/ha/year@500mm]	Pulp yield [%dm@Kappa 18]	Water Solubles [%dm]	pH	Oil Yield [%dm]
Eucalyptus gomphocephala	**35.09n**	842i	23.05				
Eucalyptus banksii	**32.74n**	660e	16.85				0.30
Eucalyptus aromaphloia ssp. *sabulosa*	**25.49n**	540	7.85	44.5	7.7	4.5	2.95
Acacia retinodes var. *retinodes (hill form)*	**22.50**	720	12.82	43.4	11.6	5.7	
Eucalyptus globulus ssp. *bicostata*	**22.43n**	656	9.61	46.7	8.0	4.6	1.15
Eucalyptus cladocalyx	**22.05n**	753	12.11	49.6	8.4	4.3	0.05
Eucalyptus chloroclada	**20.31n**	621	9.84	39.9	14.0	4.0	
Eucalyptus mannifera	**19.58n**	615i	9.39				1.35
Eucalyptus leucoxylon	**19.29n**	773	9.92	43.0	9.5	5.5	1.65
Eucalyptus camaldulensis	**19.24n**	502	7.53	38.3w	16.0	5.4	1.50
Eucalyptus ovata	**18.73n**	504	6.13	49.5	8.2	4.5	0.95
Eucalyptus viminalis ssp. *cygnetensis*	**17.50**	532	5.98	44.3	11.2	5.0	1.36
Eucalyptus alaticaulis	**15.48n**	660e	7.97				
Eucalyptus megacornuta	**15.40n**	660e	7.93				
Eucalyptus argyphea	**15.13n**	660e	7.79				
Melaleuca armillaris ssp. *armillaris*	**14.79**	576	7.02	43.0	12.5	4.8	
Acacia salicina	**14.11a**	648a	7.13	45.3			
Eucalyptus bridgesiana	**13.85n**	539	5.82	46.2	8.8	4.4	0.58
Eucalyptus rubida	**13.52n**	529	4.98	46.5	8.7	3.9	1.15
Eucalyptus dealbata	**12.98n**	772i	7.82				1.30
Eucalyptus polyanthemos	**12.55n**	783	7.67		15.3	4.0	1.13
Eucalyptus cosmophylla	**12.37n**	549	3.97	42.9	10.9	4.6	0.40
Eucalyptus microcarpa	**12.32n**	775	7.45		7.7	4.7	0.23
Eucalyptus maculata	**12.30n**	797i	7.64				0.65
Eucalyptus petiolaris	**12.25n**	664	6.22	47.1	10.1	4.3	2.10
Eucalyptus sideroxylon	**11.63n**	759	6.89		11.0	4.8	1.77
Eucalyptus fibrosa	**11.58n**	801	7.23		12.8	3.2	0.40
Eucalyptus sporadica	**11.40n**	554e	4.93				
Eucalyptus baxteri	**10.85**	490	3.15	46.0	8.0	4.6	0.55
Eucalyptus melliodora	**10.33n**	719	5.79		9.7	4.9	1.23

Table 14. Continued

Taxa	Stemwood production [m³/ha/year@500mm]	Basic density [kg/m³]	Woodchip production [bdt/ha/year@500mm]	Pulp yield [%dm@Kappa 18]	Water Solubles [%dm]	pH	Oil Yield [%dm]
Eucalyptus cneorifolia	**9.90**	854	6.53		8.5	4.5	1.45
Eucalyptus occidentalis	**9.85n**	554c	4.26	50.1c			
Codonocarpus cotinifolius	**9.74**	397w	3.29	46.5	9.0	5.7	
Callitris gracilis	**9.66**	529	4.40	<37	0.7	5.5	
Eucalyptus goniocalyx	**9.56n**	660	4.92	46.4	9.0	3.8	1.20
Eucalyptus siderophloia	**9.48n**	868i	6.42				0.15
Eucalyptus largiflorens	**9.41n**	883i	6.33		11.1	5.0	0.90
Eucalyptus dwyeri	**9.19n**	621e	4.45				2.05
Eucalyptus conica	**8.82n**	679	4.67	44.5	8.5	4.3	0.75
Eucalyptus odorata	**8.80n**	777	5.45		6.2	3.9	1.40
Eucalyptus nortonii	**8.78n**	660e	4.52	<39			0.70
Eucalyptus fasciculosa	**8.75**	704	3.80	43.7	10.2	4.8	0.16
Eucalyptus tereticornis	**8.71n**	781i	5.31				0.82
Eucalyptus macrorhyncha ssp. *macrorhyncha*	**8.68n**	668	4.52	40.4	10.6	3.5	0.30
Eucalyptus botryoides	**8.46n**	599c	3.95	47.9c			0.37
Eucalyptus viridis ssp. *wimmerensis*	**7.98n**	853	5.71		9.2	3.9	1.23
Eucalyptus leptophylla	**7.91**	779	4.90		3.6	5.4	0.80
Eucalyptus remota	**7.68**	700	4.19				0.68
Eucalyptus dives	**7.42**	603	3.49	39.4			3.81
Acacia stenophylla	**7.42**	868	5.03				
Eucalyptus blakelyi	**7.02**	543	2.97	44.7	3.4	5.2	1.60

Species with greatest bioenergy and essential oil potential have been indentified as those with high estimated productivities >6 m³/ha/year@500 mm in combination with with oil yields >1% (by dry weight), or slower growing species with high oil content (see Table 15).

6.4.3.5 Fodder

Of the species identified in Table 7 as having fodder potential, 55 were sampled for preliminary tests of crude protein, digestability and metabolisable energy (see Table 10). Actual feed quality (and preliminary test results) can be influenced by other leaf properties (e.g. mineral content). The feeding standards for ruminants states that most predictive equations should be restricted with feeds having ash (total mineral) contents in the range 90-120 g/kg DM. Forages growing on saline sites exceed this level (Dean Revell, pers comm.). Further testing must therefore include assessments of the fodder's mineral content. Also, crude protein (CP) results need to be treated with reservation as CP is mathematically derived from the nitrogen (N) content

Table 15. Selection of species with potential for wood (bioenergy) and essential oil production.

Additional results incorporated from Acacia Search (a), WA Search (w), Noel Clark (c), Jugo Ilic (i), Dean Nicolle contracted survey (n), & extrapolations from closely related species (e).

Taxa	Stemwood production [m³/ha/year@500mm]	Basic density [kg/m³]	Woodchip production [bdt/ha/year@500mm]	Pulp yield [%dm@ Kappa 18]	Water Solubles [%dm]	pH	Oil Yield [%dm]
Eucalyptus aromaphloia ssp. *sabulosa*	**25.49n**	540	7.85	44.5	7.7	4.5	**2.95**
Eucalyptus globulus ssp. *bicostata*	**22.43n**	656	9.61	46.7	8.0	4.6	**1.15**
Eucalyptus mannifera	**19.58n**	615i	9.39				**1.35**
Eucalyptus leucoxylon	**19.29n**	773	9.92	43.0	9.5	5.5	**1.65**
Eucalyptus camaldulensis	**19.24n**	502	7.53	38.3w	16.0	5.4	**1.50**
Eucalyptus viminalis ssp. *cygnetensis*	**17.50**	532	5.98	44.3	11.2	5.0	**1.36**
Eucalyptus rubida	**13.52n**	529	4.98	46.5	8.7	3.9	**1.15**
Eucalyptus dealbata	**12.98n**	772i	7.82				**1.30**
Eucalyptus polyanthemos	**12.55n**	783	7.67		15.3	4.0	**1.13**
Eucalyptus petiolaris	**12.25n**	664	6.22	47.1	10.1	4.3	**2.10**
Eucalyptus sideroxylon	**11.63n**	759	6.89		11.0	4.8	**1.77**
Eucalyptus melliodora	**10.33n**	719	5.79		9.7	4.9	**1.23**
Eucalyptus cneorifolia	**9.90**	854	6.53		8.5	4.5	**1.45**
Eucalyptus goniocalyx	**9.56n**	660	4.92	46.4	9.0	3.8	**1.20**
Eucalyptus dwyeri	**9.19n**	621e	4.45				**2.05**
Eucalyptus odorata	**8.80n**	777	5.45		6.2	3.9	**1.40**
Eucalyptus viridis ssp. *wimmerensis*	**7.98n**	853	5.71		9.2	3.9	**1.23**
Eucalyptus dives	**7.42n**	603i	3.49	39.4			**3.81**
Eucalyptus blakelyi	**7.02n**	543	2.97	44.7	3.4	5.2	**1.60**
Eucalyptus socialis	**6.62**	765	4.10		4.9	4.9	**1.60**
Eucalyptus brachycalyx	**6.59**	810	4.37				**1.30**
Eucalyptus porosa	**6.44n**	641	3.04	49.9	7.7	5.1	**2.10**
Eucalyptus incrassata	**5.04n**	768	3.14	48.6	4.6	5.9	**2.80**
Eucalyptus dumosa	**4.37n**	815e	2.78				**1.25**
Eucalyptus viridis	**3.85**	845	2.74		7.2	4.6	**1.23**
Eucalyptus oleosa	**3.28n**	954i	2.44				**3.10**
Eucalyptus pileata	**2.97n**	815e	1.89				**3.70**
Eucalyptus polybractea	**2.55n**	770	1.53	53.8	7.4	4.4	**2.35**
Eucalyptus radiata	**1.59n**	581i	0.72				**4.07**

of the fodder, but with some species CP does not give a true measure of protein as a high proportion of the N may be non-protein nitrogen (NPN; e.g. nitrate). NPN is utilised by rumen microbes less efficiently than protein N lowering the nutritive value of the N present. This suggests that a source of carbohydrate is required to enable rumen microbes to utilise a greater portion of the N as protein in such cases (P Milthorpe, pers. comm.)

Although the above reservations must be observed, the results of the FloraSearch species can be compared with those of commonly used feeds such as lucerne hay, cereal and legumes grains. Lucerne hay has an average CP of 20 % of dry matter and metabolisable energy (ME) of 9 MJ/kg dry matter; barley CP of 10% and ME of 12 MJ/kg dry matter; peas a CP of 24 % and ME of 13 MJ/kg dry matter (FeedTest Agriculture Victoria). Several FloraSearch species were recorded with a CP value exceeding 20% and ME exceeding 10 MJ/kg dry matter which compare favourably with traditional feeds. ME is the feed energy actually used by the animal calculated from digestible dry matter (DDM) and is the most important figure in the test report. It is used to calculate whether stocks are receiving adequate energy for production. The most promising FloraSearch species with high ME and CP levels, are listed in Table 16.

6.4.4 Conclusions

The initial phase of sample testing and collation of existing data for wood, essential oil and fodder value of priority species in the FloraSearch region has identified many species worthy of further examination. Yield is a key aspect of future crop systems. Estimation of annual rates of productivity for many species of interest (including most Eucalypts and sampled species) combined with product test results provide useful estimates of potential product yields for many FloraSearch species. These productivity and yield estimates are utilised in the following RIPA to examine the potential for industry development in the FloraSearch region.

Table 16. Top ranking fodder species occurring in the study area (sorted by Metabolisable Energy). Additional results incorporated from Acacia Search (a). #Stemwood values provide a relative indication of fodder productivity.

Taxa	Stemwood production # [m³/ha/year@500mm]	Crude Protein [%dm]	Digestibility [%dm]	Metabolisable Energy [MJ/kg dm]	Palatability [High Med Low Not]
Eremophila deserti	1.07	**14.0**	82.8	**12.2**	
Eremophila bignoniiflora	2.74	**12.0**	82.6	**12.2**	
Alstonia constricta	1.00	**17.7**	82.0	**12.1**	M
Santalum acuminatum	1.63	**5.4**	82.3	**12.1**	H
Nitraria billardierei	0.13	**18.5**	81.3	**12.0**	M
Canthium oleifolium	0.60	**10.4**	80.6	**11.9**	H
Chenopodium nitrariaceum		**20.8**	78.6	**11.5**	M
Atriplex nummularia	1.54	**20.4**	75.6	**11.1**	M
Eremophila longifolia	2.35	**13.2**	75.4	**11.0**	H
Petalostylis labicheoides var. *labicheoides*	1.44	**19.5**	74.0	**10.8**	N

Table 16. Continued

Taxa	Stemwood production # [m³/ha/year@500mm]	Crude Protein [%dm]	Digestibility [%dm]	Metabolisable Energy [MJ/kg dm]	Palatability [High Med Low Not]
Indigofera australis		**20.9**	70.2	**10.2**	H
Atriplex vesicaria	0.38	**20.1**	69.4	**10.1**	H
Maireana pyramidata		**25.8**	68.5	**9.9**	M
Rhagodia spinescens		**20.8**	67.0	**9.7**	M
Enchylaena tomentose	0.07	**18.5**	66.3	**9.6**	H
Acacia decora	0.69	**9.6**	65.4	**9.4**	
Maireana rohrlachii	0.09	**27.3**	64.7	**9.3**	H
Capparis mitchellii	5.11	**16.1**	64.6	**9.3**	H
Senna artemisioides	0.68	**10.6**	64.3	**9.3**	M
Acacia salicina	14.11a	**14.3**	62.3	**8.9**	L
Dodonaea viscosa ssp. *spatulata*	2.64	**10.3**	61.5	**8.8**	L
Geijera parviflora	2.30	**16.9**	60.7	**8.7**	H
Ventilago viminalis	6.90	**13.3**	61.1	**8.7**	H
Acacia pendula	0.78	**14.9**	55.8	**7.9**	H
Owenia acidula	2.56	**13.8**	55.8	**7.9**	H
Acacia implexa	2.15	**15.4**	55.0	**7.8**	L
Acacia omalophylla	1.13	**12.6**	53.7	**7.6**	
Acacia deanei ssp. *deanei*	1.83	**13.7**	52.7	**7.4**	M
Acacia retinodes var. *retinodes (swamp form)*	2.43a	**14.8**	52.0	**7.3**	
Acacia aneura	0.79	**12.6**	51.6	**7.2**	H
Acacia dealbata	4.11a	**17.2**	50.7	**7.1**	
Acacia retinodes var. *retinodes (hill form)*	22.50	**16.3**	50.6	**7.1**	
Apophyllum anomalum	0.35	**11.1**	50.7	**7.1**	H
Acacia victoriae ssp. *victoriae*	0.85a	**19.0**	50.1	**7.0**	M
Acacia decurrens	3.46a	**14.3**	50.0	**7.0**	
Brachychiton populneus	2.19	**13.9**	49.4	**6.9**	
Acacia leucoclada ssp. *leucoclada*	3.32a	**17.2**	49.1	**6.7**	
Acacia doratoxylon	4.88a	**13.5**	46.7	**6.4**	M
Acacia baileyana	1.71a	**13.3**	46.5	**6.4**	
Acacia pycnantha	1.42a	**12.2**	46.6	**6.4**	H
Atalaya hemiglauca	2.49	**13.8**	45.7	**6.3**	H
Acacia murrayana	2.66	**15.5**	44.9	**6.2**	M

7. Regional industry potential analysis

7.1 Introduction

The Regional Industry Potential Analysis (RIPA) is a methodology that integrates a geographic information system with species, environmental, industry and economic information to assist in the evaluation, prioritisation and selection of woody germplasm and appropriate industries in the FloraSearch region. The work reported here is an exploratory analysis of the RIPA process and utilises the industry knowledge, preliminary models of regional productivity and economic analyses for short-cycle woody crops conducted in 2004. These analyses will gain in predictive power, as more data becomes available from species trials and through more detailed examinations of prospective products and industries.

The RIPA required gathering a wide range of spatial data on the natural, infrastructure and human resources in the region to facilitate the decision making process. The condition, attributes and functions of natural resources influence decisions on landuse, resource management and future investment strategies by individuals, governments and industry. Industry development is dependent on access to natural, human and infrastructure resources, and hindered by the costs associated with any spatial distance from those resources.

Industry developments will be focussed on locations where the maximum economic, environmental and community benefits can be gained. Product groups and industries often have a number of common criteria relevant to their development. We have identified some of these criteria, such as feedstock requirements, transport infrastructure and minimum economical plant size, and gathered relevant datasets for spatial analysis.

The most prospective industries utilise short rotation woody crops, and are predominantly based on "chip-in-field" harvest technologies, as has been discussed in earlier sections of this report.

In summary these include:

- Pulp and paper (Australian production and woodchip export)
- Composite woods (e.g. MDF and other fibreboards, particleboard)
- Bioenergy (co-firing and renewables)
- Extractives (oil and tannins)
- Livestock fodder (in situ and processed).

Co-located industrial facilities for separate product types already exist in some agroforestry industry ventures, such as energy generation plants adjacent to sawmills or pulp mills that utilise waste stream for bioenergy benefits. Integrated tree processing plants, such as the one under construction for oil mallees in WA, will produce multiple products to increase profitability (e.g. oils, bioenergy and charcoal).

The viability of each of these industries in the FloraSearch study area depends on the degree of matching between existing resources and industries, commercially viable primary production and access to markets. RIPA currently provides a regional analysis that summarises:

- Industry infrastructure and non-biomass resources
- Existing industries and their facilities
- Primary production of total biomass (and fractions) using a representative species
- Generalised cost-benefit analysis for primary producers
- Evaluations of returns to primary producers to supply to existing industries
- Potential location for the investment in new facilities.

7.2 Industrial Resources and Requirements

Many of the biomass industries identified in FloraSearch have different resource needs and minimum requirements for processing facilities development. Feedstock volumes and qualities are critical components for each industry. Species evaluations described in Chapter 6 of this report provide information on the physical and chemical attributes of plant materials for each industry type. Relationships between observed productivity and spatial models of climate driven productivity are described in a later section. Table 17 provides a summary of key attributes that influence the location of processing facilities for a range of industry types.

7.2.1 Infrastructure and human resources

The following figures (Figure 10 – Figure 13) illustrate the spatial distribution of infrastructure and human resources that influence the location of a number of industries of interest to FloraSearch.

7.2.2 Existing industries

The spatial distribution of focal points for existing industries is illustrated in the following figures (Figure 14 – Figure 16).

7.3 Regional Species Productivity

Stemwood, twig and leaf production rates (m^3/ha/year) from FloraSearch, Currency Creek Arboretum and Acacia Search survey sites have been correlated to spatial data on primary productivity predicted by the BiosEquil model (Raupach *et al.* 2001). BiosEquil utilises meteorological, soil and vegetation data to determine water, carbon, nitrogen and phosphorus flows in the landscape to predict primary productivity. The model has been used to predict the accumulation of carbon (tonnes/ha/year) for Australian landscapes.

The correlations between BiosEquil predictions and field observations of plant productivity for individual species allow us to cautiously predict the yield of total biomass and wood, bark, twig and leaf components across the FloraSearch study area. We have chosen faster growing individual species (or their variants) which have suitable characteristics (e.g. pulp yield, wood density, calorific value, extractive yields, livestock nutritional value) for each product type for our primary productivity models. For each product type there are often species with similar plant characteristics that may be more suited to our climatic zones or soil types. Table 18 below provides representative species for each product type and indicates species used in RIPA simulations.

Table 17. Summary of feedstock requirement, product output and infrastructure requirements for "typical" production facilities for some of the target products considered in RIPA.

Product	Market trend and size	Typical plant output	Feedstock requirement	Transport requirement	Substantial Water
Kraft pulp mill	Increase	240,000 - 750,000 t/yr	2,000,000-3,000,000 green t/yr	Port within approximately 150 km [SE Aust obs: 5 mills, range 120-270 km Avg 180 km]	High demand 7-30 GL/yr
Export woodchip	Increase	Smaller operation at Ballast head, KI 470,000 t/yr ranging to 1,000,000 t/yr in WA		Port within approximately 150 km	No
Panel Products (e.g. MDF, Particleboard)	Increase	150,000	100,000 for this output but up to 300,000 dry t/yr	Port within approximately 150 km [SE Aust obs. 9 mills, range 18-250 km Avg 115 km]	No
Wood plastic composites	Increase 300,000 tonnes in 2002 (USA). Potential of 50,000 tonnes in Aust. by 2010	Minimum of 2,000 t/yr Large plant in USA output of 120,000 t/yr	500 dry t/yr for minimal plant ranging up to 74,000 t/yr	Access to port if an export market is required	No
Electricity from co-firing	Prospective Market of 200,000 GWh growing at 2 %	5 - 10 % mix with coal	> 1,000,000 t/yr		
Electricity from biomass	Prospective	1 MW represents a small plant for rural location	10,000 dry t/yr		No
Integrated tree processing	Prospective		100,000 green t/yr		No

Figure 10. Population centres and size.

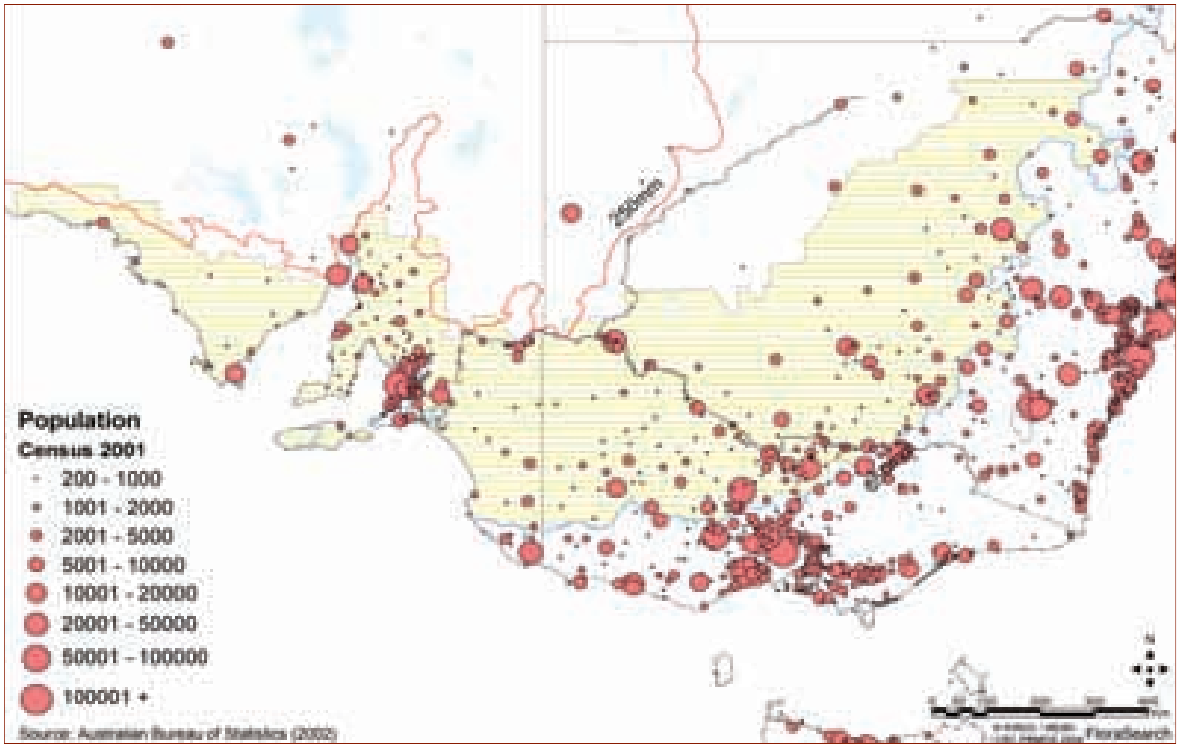


Figure 11. Bulk handling ports.

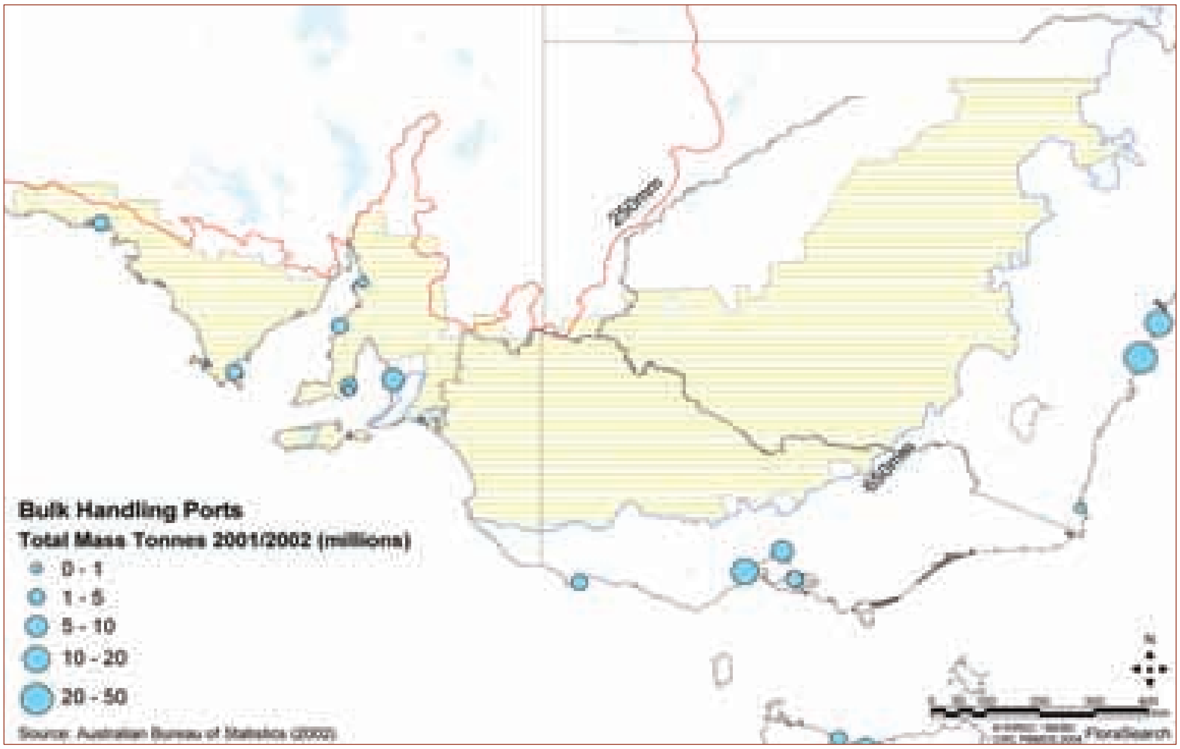


Figure 12. Road transportation network.

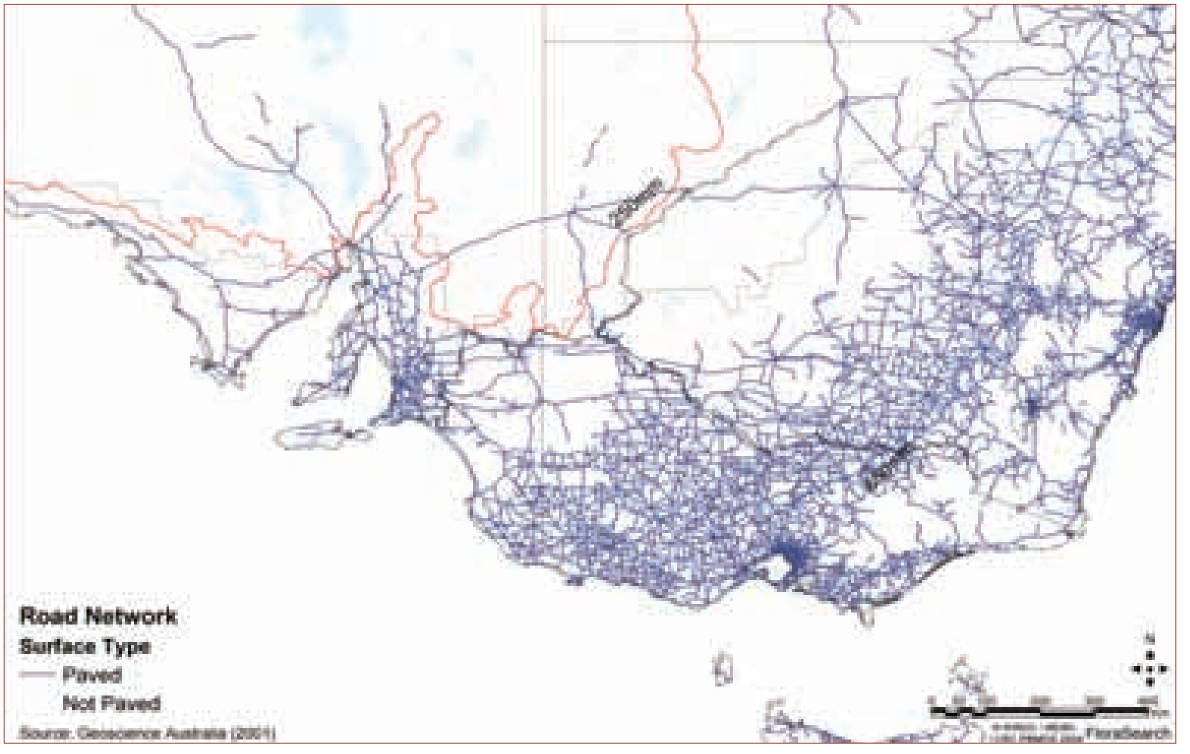


Figure 13. Electricity generation capacity.

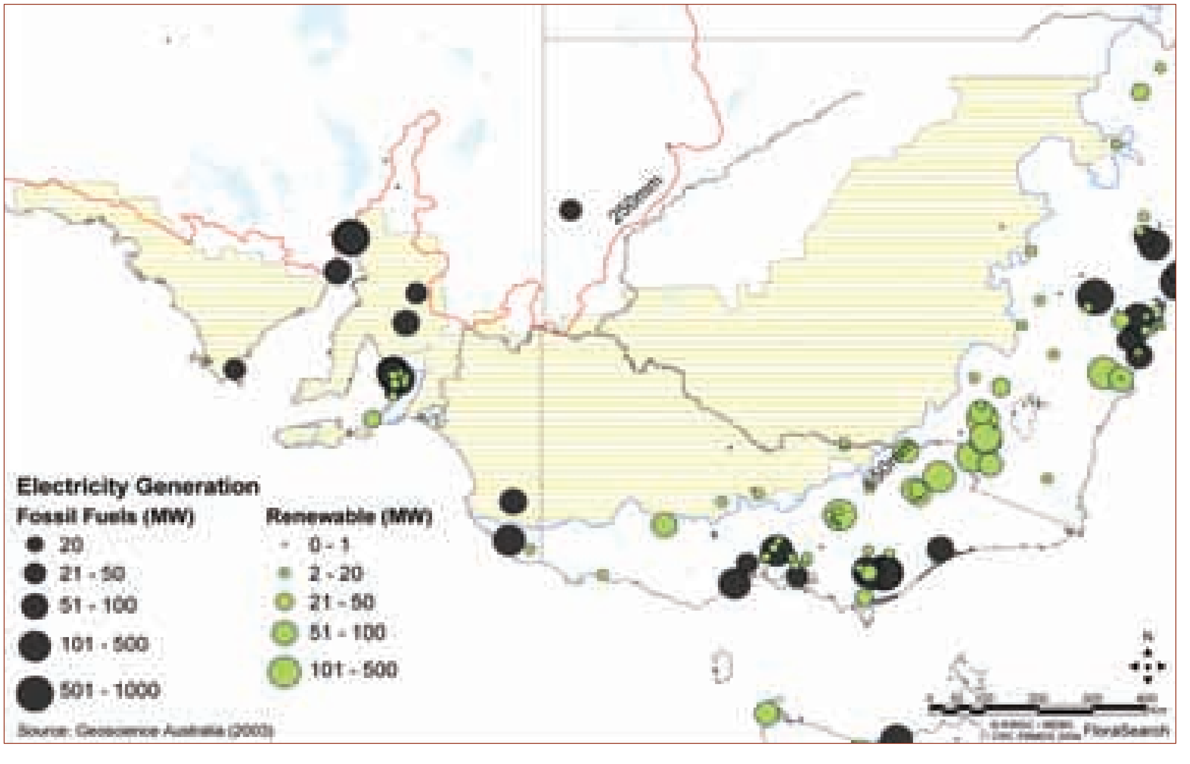


Figure 14. Existing wood fibre processing facilities.

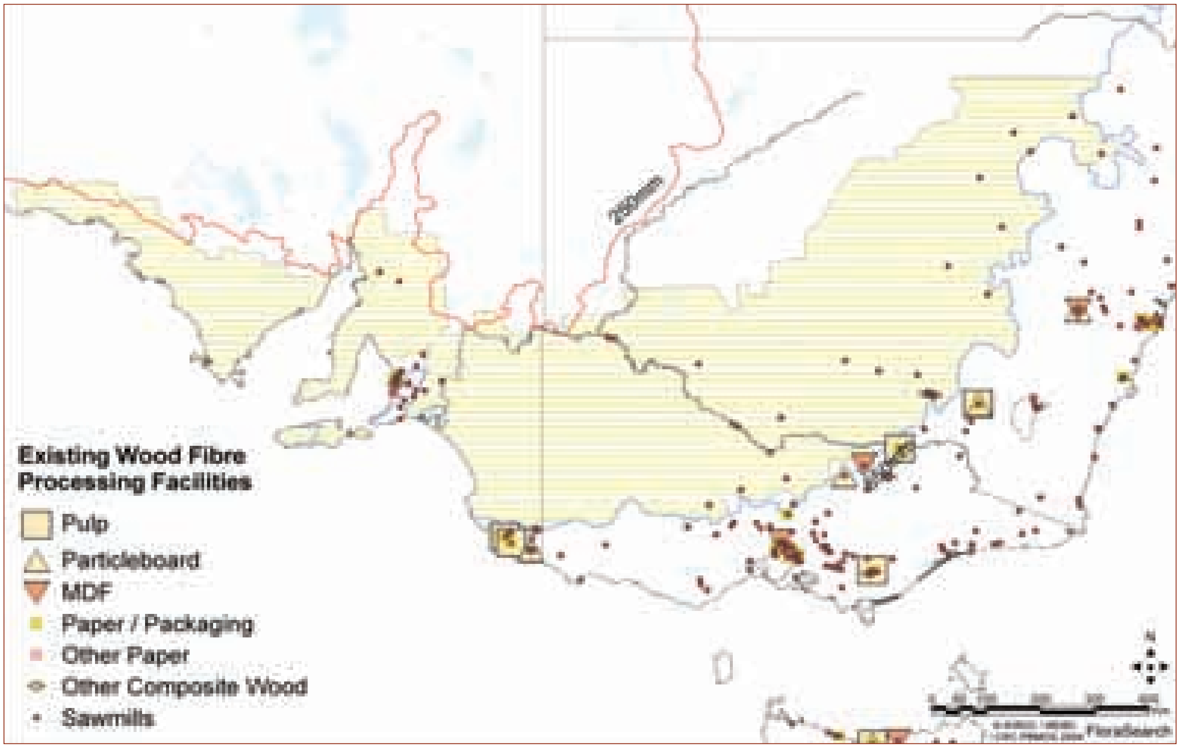


Figure 15. Existing solid fuel electricity generation sites.

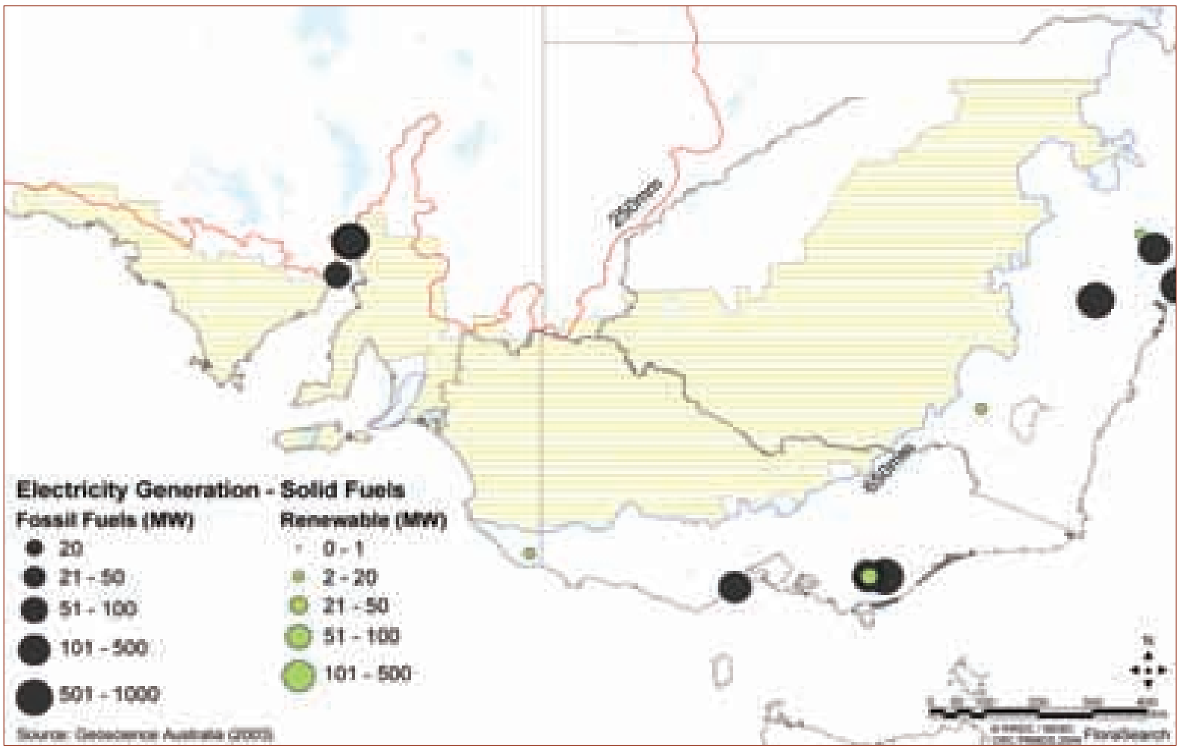
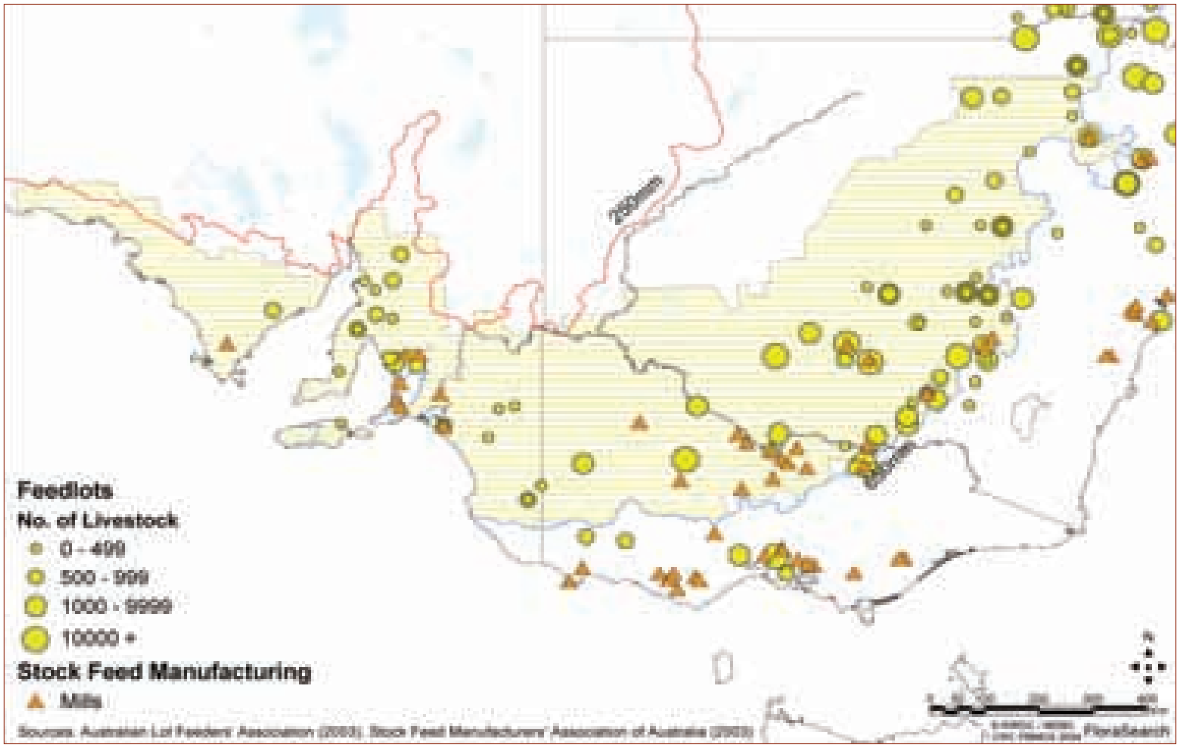


Figure 16. Existing feedlots and stock feed manufacturing facilities.



7.4 Regional Industry Analysis 2004

The regional industry analysis combines data on plant productivity, species' attributes, establishment and maintenance costs, delivered prices for industry feedstocks, and harvest and transport costs, to estimate the economic viability of biomass industries for primary producers by analysing expected cash flows resulting from the agroforestry project. These projects have typically high costs of setup and establishment the initial years, followed by several years of modest maintenance costs, before crop maturity, harvest and finally income from the sale of plantation products. The financial viability of the agroforestry enterprise depends on its ability to create a positive cash flow over the life of the project. To determine whether a new investment in farm forestry is more profitable than an existing enterprise it is necessary to compare the expected economic performance of each enterprise.

7.4.1 Investment analysis

Discounted Cash Flow (DCF) analysis is a commonly used evaluation technique for economic comparisons of different commercial enterprises (Abadi *et al.* 2006). It is an approach that converts projected costs and returns of each enterprise into present day values and factors in different time preferences and financing charges. In our analyses the financing charges of the new enterprise is expressed as the "Discount Rate", that is the cost of raising and servicing the capital required for the investment. Choosing an appropriate discount rate is crucial to the calculation of the Net Present Value (NPV) of the enterprise. In our analyses we have used a discount rate of 7% which approximates the current commercial rate for borrowing, less the inflation rate, for farm forestry enterprises (Abadi *et al.* 2006, Peirson *et al.* 2002). The expected cash flows of each agroforestry enterprise has been discounted back to its present value and summed to determine its NPV using the formula:

Table 18. Prospective species for major product types.

Species and attributes highlighted in **bold** are ones used for RIPA simulations.

Taxa	Stemwood production [m^3/ha/year@500mm]	Basic density [kg/m^3]	Woodchip production [bdt/ha/year@500mm]	Pulp yield [%dm@Kappa 18]	Water Solubles [%dm]	pH	Oil Yield [%dm]	Crude Protein [%dm]	Digestibility [%dm]	Metabolisable Energy [MJ/kg dm]	Palatability [High Med Low Not]
Pulp, Fibre/Particleboards											
Eucalyptus viminalis* ssp. *cygnetensis	**17.50**	**532**	**5.98**	**44.3**	**11.2**	**5.0**	**1.36**				
Eucalyptus globulus ssp. *bicostata*	22.43	656	9.61	46.7	8.0	4.6	1.15				
Eucalyptus ovata	18.73	504	6.13	49.5	8.2	4.5	0.95				
Eucalyptus bridgesiana	13.85	539	5.82	46.2	8.8	4.4	0.58				
Eucalyptus porosa	6.44	641	3.04	49.9	7.7	5.1	2.10				
Pulp, Fibre/Particleboards & Fodder											
Acacia retinodes	**22.50**	**639**	**11.36**	**49.1**	**8.3**	**5.2**		**15.6**	**51.3**	**7.2**	
Acacia salicina	14.11	648	7.13	45.3				14.3	62.3	8.9	L
Bioenergy											
Eucalyptus cladocalyx	**22.05**	**753**	**12.11**	**49.6**	**8.4**	**4.3**	**0.05**				
Acacia retinodes	22.50	639	11.36	49.1	8.3	5.2		15.6	51.3	7.2	
Eucalyptus leucoxylon	19.29	773	9.92	43.0	9.5	5.5	1.65				
Eucalyptus chloroclada	20.31	621	9.84	39.9	14.0	4.0					
Eucalyptus globulus ssp. *bicostata*	22.43	656	9.61	46.7	8.0	4.6	1.15				
Eucalyptus camaldulensis	19.24	502	7.53	38.3	16.0	5.4	1.50				
Eucalyptus viminalis ssp. *cygnetensis*	17.50	532	5.98	44.3	11.2	5.0	1.36				
Oil & Bioenergy/Pulp											
Eucalyptus porosa	**6.44**	**641**	**3.04**	**49.9**	**7.7**	**5.1**	**2.10**				
Eucalyptus incrassata	5.04	768	3.14	48.6	4.6	5.9	2.80				
Eucalyptus polybractea	2.55	770	1.53	54.0	7.4	4.4	2.35				
Fodder Only											
Atriplex nummularia	**1.54**	**450**	**0.54**					**20.4**	**75.6**	**11.1**	**M**
Eremophila longifolia	2.35	672	1.23	<38	8.8	5.2		13.2	75.4	11.0	H

$$NPV = \sum_{t=1}^{n} \frac{C_t}{(1 + r)^t} - C_0$$

Where

t = the time of the cash flow

n = the total time of the project

r = the discount rate

C_t = the net cash flow (the amount of cash) at time t

C_0 = the capital outlay at the beginning of the investment time (t = 0)

To allow economic comparisons across the range of potential agroforestry options, and with current annual-based cereal and and livestock industries in the region, we have explored the expected Annual Equivalent Return (AER) for the first 20 years of each enterprise. AERs can be thought of as an annuity where the NPV is spread evenly across the life of the enterprise. This approach addresses the issue that first and subsequent harvest cycles of the each agroforestry enterprise varies according to the industry selected, specifications of the raw materials harvested, and plantation growth rates of different species used in each region. AER analyses allow meaningful comparisons of investments having longer or variable period returns (e.g. agroforestry crops) with those having annual returns (e.g. annual crops).

The economic analyses used in our regional industry analysis approach are all based on contractor rates for site planning and preparation, planting, maintenance, harvesting and transport. They specifically exclude direct landholder investments in capital items such as new land by tenure/lease, and machinery used to undertake site preparations, maintenance, harvesting or transport. The analysis also excludes any values derived from government financial incentives or taxation subsidies, environmental credits and services or other on-farm economic benefits of perennial revegetation. At this stage, the analyses do not factor in the opportunity costs of land being assigned to new woody crops.

Figure 17. Estimated outer bark stemwood productivity of *Eucalyptus viminalis* ssp. *cygnetensis*.

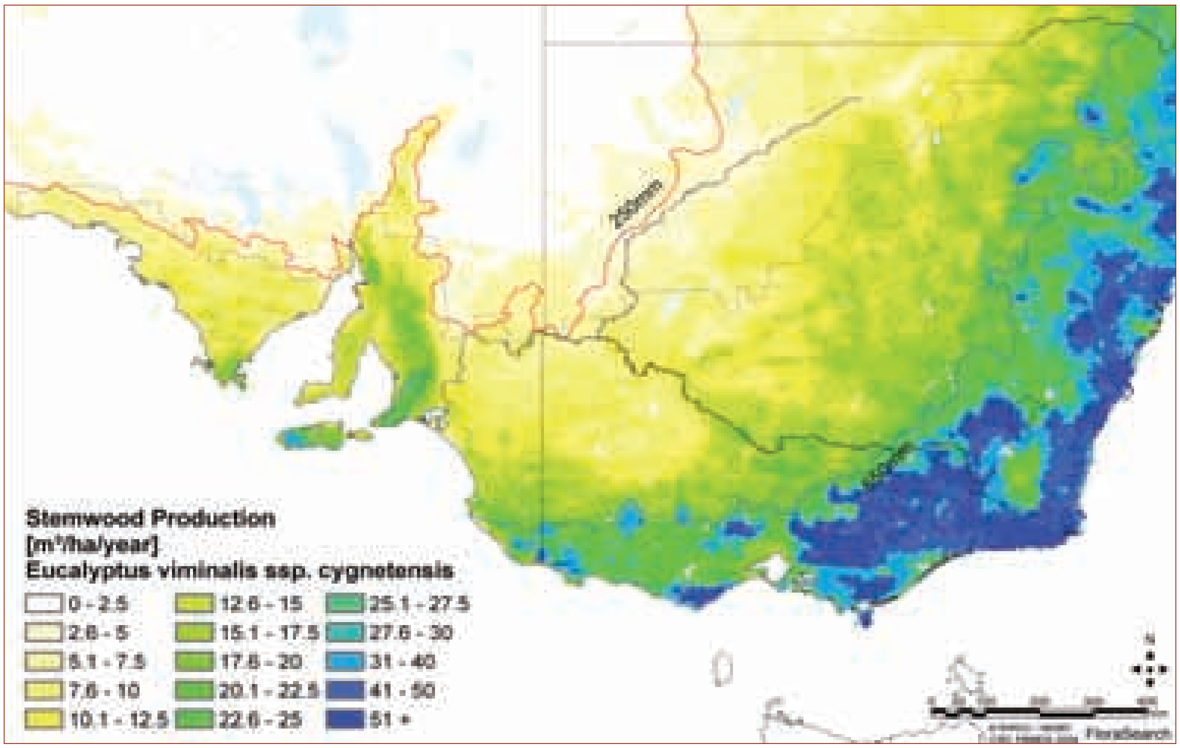


Figure 18. Estimated outer bark stemwood productivity of *Eucalyptus cladocalyx*.

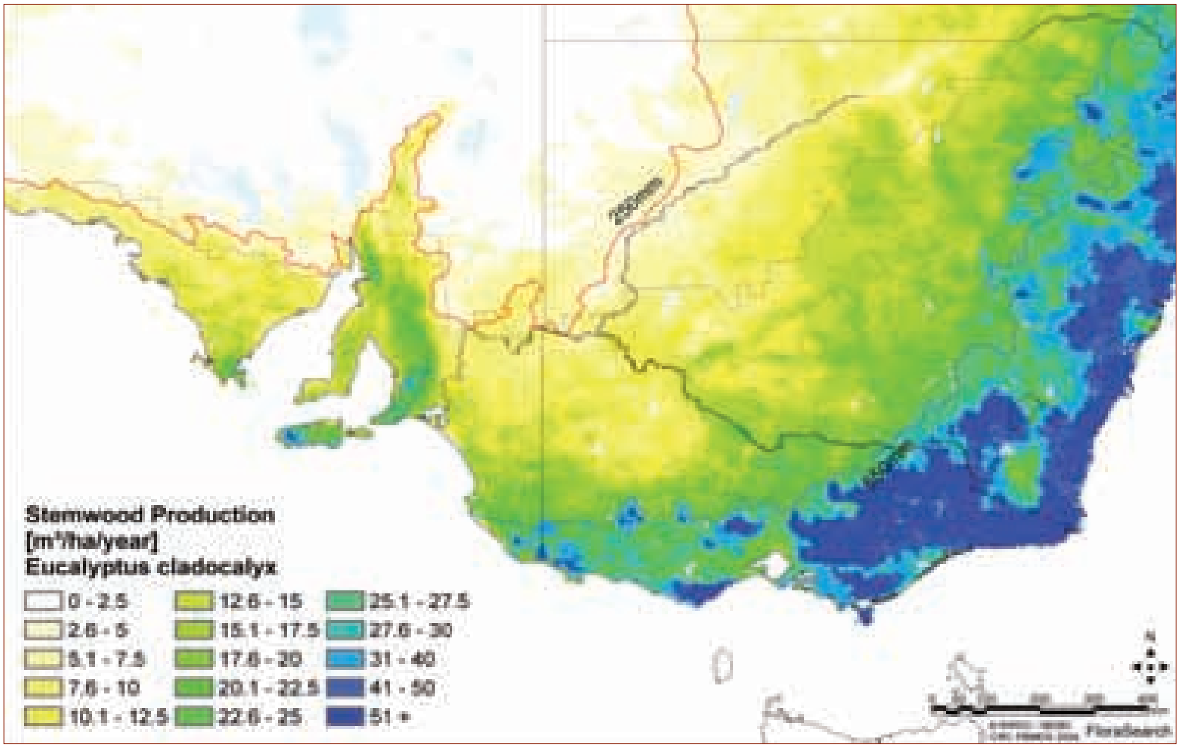


Figure 19. Estimated outer bark stemwood productivity of *Eucalyptus porosa*.

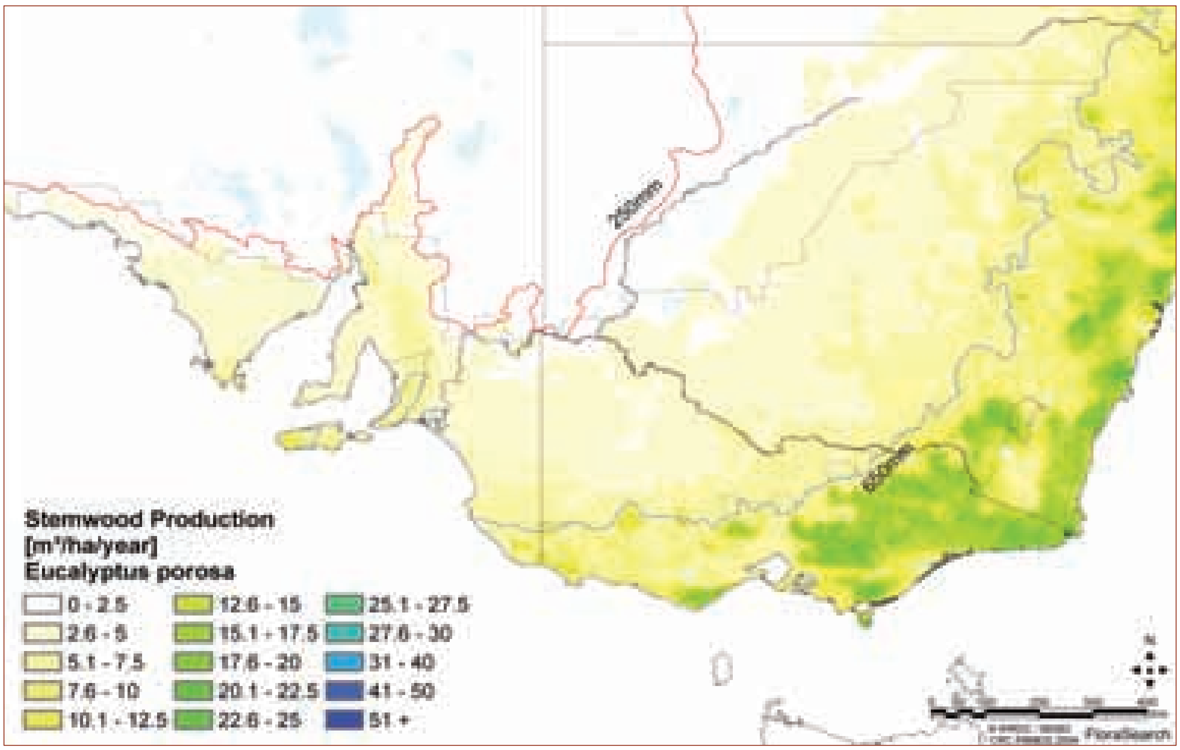


Figure 20. Estimated outer bark stemwood productivity of *Acacia retinodes*.

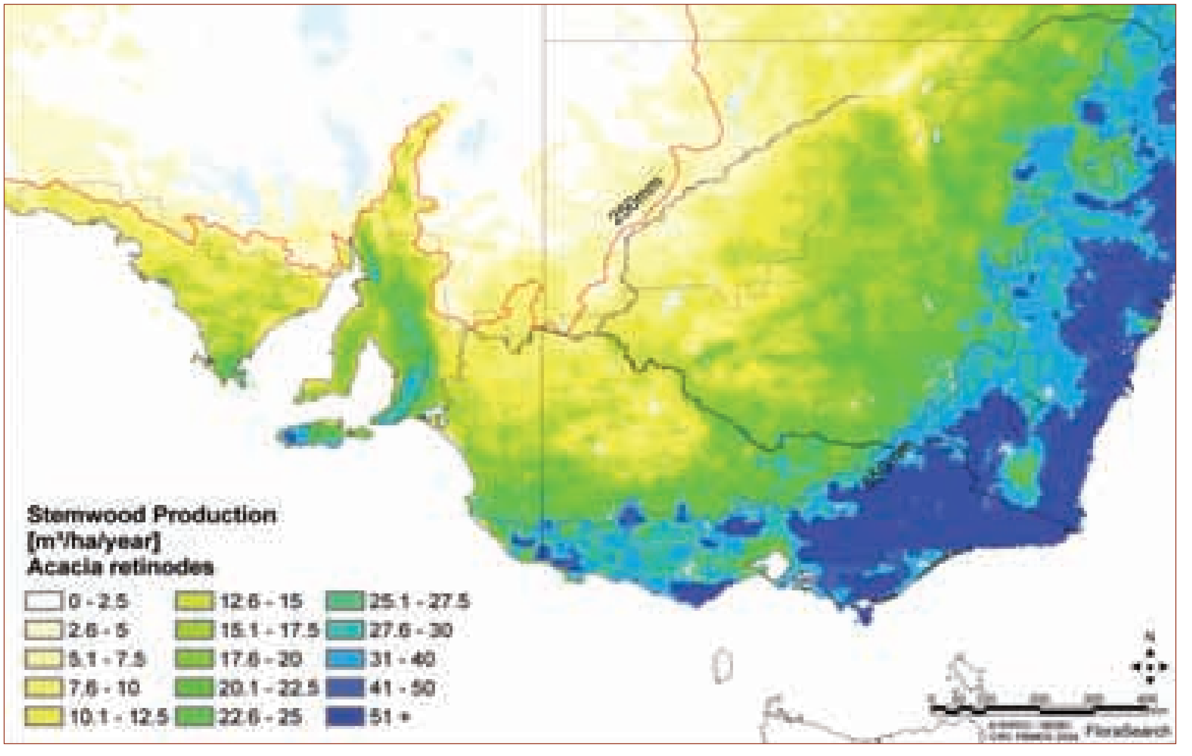
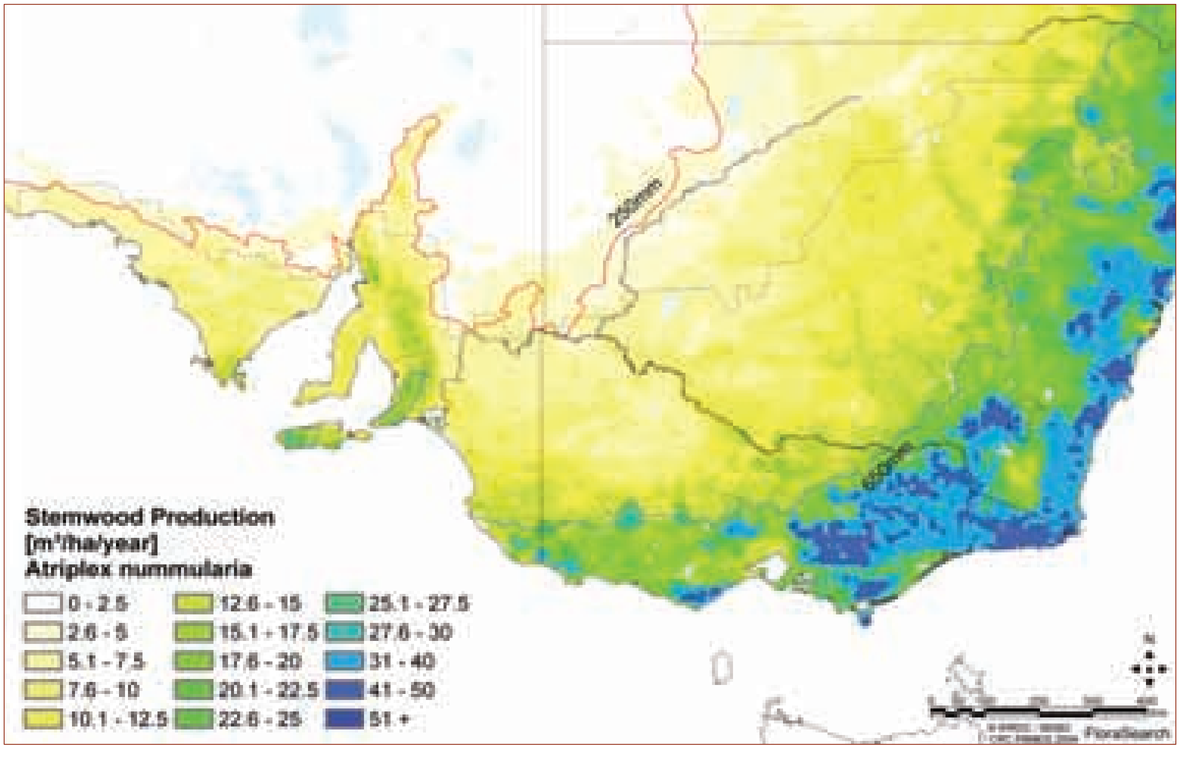


Figure 21. Estimated outer bark stemwood productivity of *Atriplex nummularia*.



7.4.2 Primary productivity

Five representative FloraSearch species have been used in RIPA simulations and regional productivity mapping: *Eucalyptus viminalis* ssp. *cygnetensis* (pulp/fibreboards/particleboard); *Eucalyptus cladocalyx* (bioenergy only); *Eucalyptus porosa* (Eucalyptus oils/bioenergy); *Acacia retinodes* (pulp/fodder combinations); and *Atriplex nummularia* (fodder only). Biomass fractions (wood, leaf, twig and bark) and their proportional changes with plant age, were determined and tracked over 20-year simulations for six outer bark stemwood productivity classes (5, 10, 15, 20, 25, 30 m³/ha/year). For coppicing production systems the RIPA simulations use a 50% increase in productivity after the first harvest. Using relationships established between site observation of productivity and BiosEquil indices the productivity surfaces for each of the five species (and biomass fractions) were mapped across Australia (Figure 17 – Figure 21). The primary productivity models used in the RIPA are based on currently limited field observations, and are considered by the authors to be an indicative measure of productivity. Further research is required to produce more reliable models.

7.4.3 Establishment, maintenance and harvest costs

Abadi *et al*. (2006) have undertaken a detailed study of the profitability of medium to low rainfall agroforestry in the cropping zone. They provide several case studies (including NSW Blue Mallee, WA Oil Mallee and WA Acacia phase crops) where they provide details on the costs associated with the establishment, maintenance and harvest of wood biomass industries. These parameters have been further refined using information from Tasmanian Bluegum industries in SA and WA (Don McGuire and Mick Underdown [Forestry SA], Graeme Olsen and Don Cooper [WA CALM], pers. comms.). A summary of the parameters used in our analysis is contained in Table 19.

7.4.4 Delivered price of feedstock

The delivered price of biomass feedstocks per tonne varies greatly depending on the end use of the raw material. Prices range from approximately $145 per bone dry tonne for export wood chips to around $20 per green tonne used for bioenergy generation (see Table 19). Wood fibre values have been provided by CSIRO Forestry and Forest Products (N. Clark and G. Freischmidt, pers. comms.). Export woodchips values of $72.5 per green tonne are based on a current export value of $145 per bone dry tonne. Bioenergy values are based on comparisons between wood calorific value versus coal calorific value and price (CSIRO Biofuel database 2003; World Bank 2003). Fodder values are based on the relative nutritional value of Oldman Saltbush (*Atriplex nummularia*) by weight to commercial fodder species (FeedTest Agriculture Victoria). All FloraSearch feedstocks are based on products from "chip-in-field" technologies, forage harvesters, or in situ fodder use.

7.4.5 Transport

The delivery distance, weight of the product and cost per kilometre, determines the cost of transporting products from the farmgate to a port, mill or processing plant. Road freight is the most appropriate method of transport for mechanically chipped wood, bark, twig and leaf products from FloraSearch industries. Semi-fluid chipped products, with lower combined transport and handling costs, should have a competitive cost advantage over expensive conventional forestry practices of solid log harvesting, handling and transport. Commercial carriers of semi-fluid crops (e.g. grains and cereals) charge between $1.20-1.50/km return for a 26 tonne single tray vehicle and $1.50-2.00/km return for a 40 tonne B Double vehicle (2003 prices – Shane Gail, Ausbulk Transport Manager, pers. comm.). The resulting road transport cost equates to price range $0.037-0.058/t/km. For this study we have used a baseline value of $0.046/t/km for major roads, with costs increasing by +20% for minor roads and +40% for minor tracks.

Table 19. Primary production and freight costs, and commodity values used in RIPA 2004 simulations and sensitivity analyses.

	Plant density & type / ha	Site planning, setup & land preparation [$/ha]	Seedlings, planting, fertiliser & watering [$/ha]	Weed/Pest management & control [$/ha]	Harvest costs [$/green t]
Primary Production Costs	1,000 trees 2,000 shrubs	305 300	350 500	85 50	10 (5-25.5)[#1]
[#1] Harvest cost (using "chip-in-field" or fodder harvest technologies) variations per green tonne of total biomass: $10 bioenergy; $15 pulpwood, fibre/particleboards; $25.5 oil (including oil extraction, based on Abadi et al. 2006); $5 off-farm fodder; $0 in situ fodder; +$10/g tonne for biomass requiring sorting. Other costs: $10/ha annual maintenance costs; $90/ha post-harvest cleanup & fertilizer application cost for phase crops.					

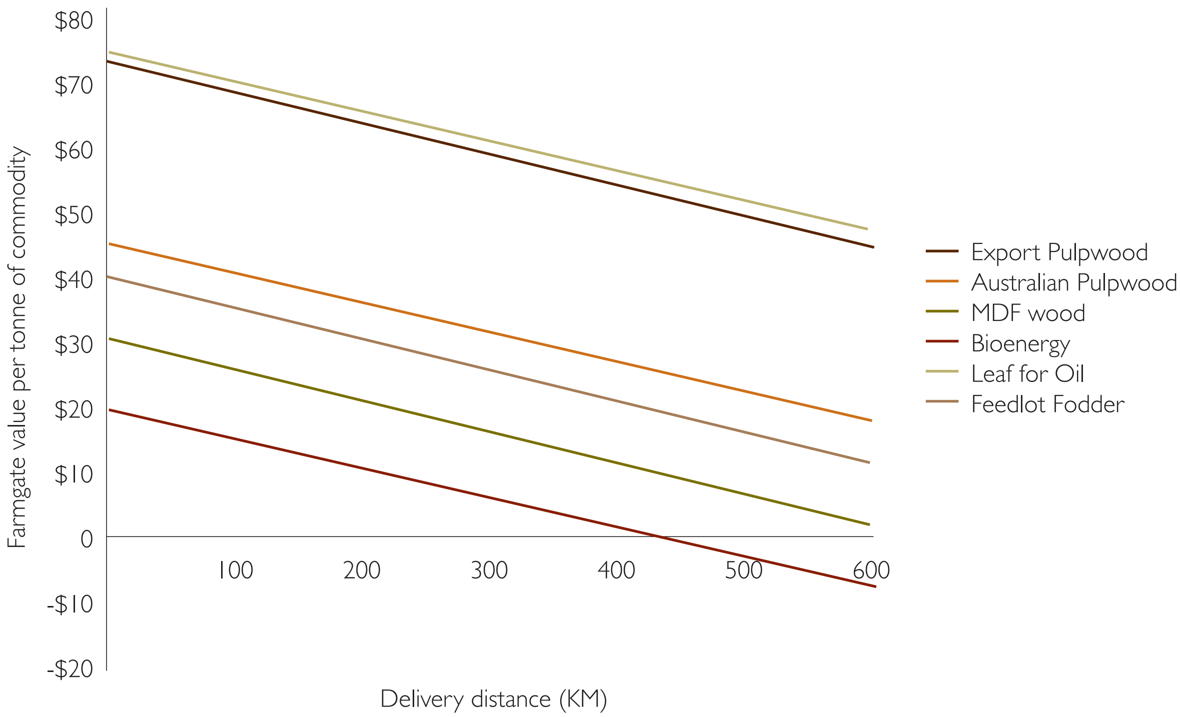
Freight costs ($/t/km)	0.046 - 0.065 depending on road/track surface					
	Export Pulpwood	Australian Pulpwood	Fibre/ Particleboards	Bioenergy	Leaf for Oil	Leaf for Fodder
Commodity value ($/green t)	72.5	45	30	20	75[#2]	40
[#2] Processed in field by mobile processing plant, oil value of $2.50/kg (cf. $7/kg reported by Abadi et al. 2006).						
Discount rate	7%					
Sensitivity Analysis Parameters/Industry Type	Export Pulpwood	Australian Pulpwood	Fibre/ Particleboards	Bioenergy	Eucalyptus Oil	Fodder
Establishment costs ($/ha)	370 - 1110					425 - 1275
Maintenance costs ($/ha)	5 - 15					
Harvest Costs ($/green t)	7.5 - 22.5			5 - 15	12.8 - 38.3	0 - 2.5 - 7.5
Freight distance (km)	25 - 75 - 100 - 200 - 300					
Freight costs ($/t/km)	0.023 - 0.069 - 0.092 - 0.184 - 0.276					
Commodity value ($/green t)	36.3 - 108.8	22.5 - 67.5	15 - 45	10 - 30	37.5 - 112.5	20 - 60

The farmgate value of the product diminishes with increasing delivery distances (Figure 22). High value products (e.g. export woodchip) can be delivered greater distances than low value (bioenergy) as transportation costs for high value products are a relatively low fraction of the product value. Harvest costs range from $4/green t (feedlot fodder) to $25.5/green t for some multipurpose crops. Establishment and maintenance costs vary from crop to crop and harvest intervals.

7.4.6 Productivity, harvest times and optimising returns

An analysis of the variable costs and returns for primary producers was undertaken for a 20-year period and conducted in two parts: 1/ Initial Harvest and 2/ Subsequent Harvests. For each harvest type simulations of costs and benefits (using the parameters outlined in Table 18 and Table 19) was conducted for each industry feedstock type (and combinations) and six stemwood productivity levels (5, 10, 15, 20, 25, 30

Figure 22. Influence of transportation costs on the value of commodity produced.



m³/ha/year) for a farm at a distance of 50 km from a processing facility. The first harvest (and single-phase crop only) scenarios were conducted for each year as if it was the first harvest to determine the period to first harvest break-even point and maximum AER under a discount rate of 7%. The subsequent harvest scenarios (for coppicing systems) were conducted in an identical way to the first harvest scenario to identify the next harvest interval to maximum AER with coppicing species' stemwood productivity rates increased by 50%. A series of figures in the next section (Figure 23 – Figure 34) demonstrate the relationship between times to first harvest and subsequent harvests for each product type on NPVs and AERs at a distance of 50 km from an existing processing facility. Summaries of those results, and a comparison with 100 km from a processing facility scenario, are presented in Table 20 and Table 21.

The optimum intervals and their AERs for first and subsequent harvests were identified (see Table 20 and Table 21). Optimums for phase crops were determined for the first harvest interval only. Times to harvest and AERs from first and subsequent harvest were combined for coppicing crop types (Eucalypts and Oldman Saltbush). The maximum allowable first harvest period was set at 15 years for tree-based systems, and six years for fodder shrub systems. AERs over the first 20 years of each agroforestry system were calculated using a discount rate of 7% (Table 22).

Table 22 presents estimates of times to first harvest and primary producers' AERs per hectare for six productivity classes and two distances from processing facilities. Distance from processing facility is not a relevant for "on-farm fodder" and "Eucalyptus oil" components processed on-site. Figure 36 provides a summary of maximised AERs by potential product types for the first twenty years of primary production at sites 50km from a processing facility.

Figure 23. Net Present Value and Annual Equivalent Return ($) per hectare of export pulpwood chips by stemwood productivity class [m³/ha/year]: *Eucalyptus viminalis* ssp. *cygnetensis*.

Export Pulpwood Only

First Harvest

Subsequent Harvest

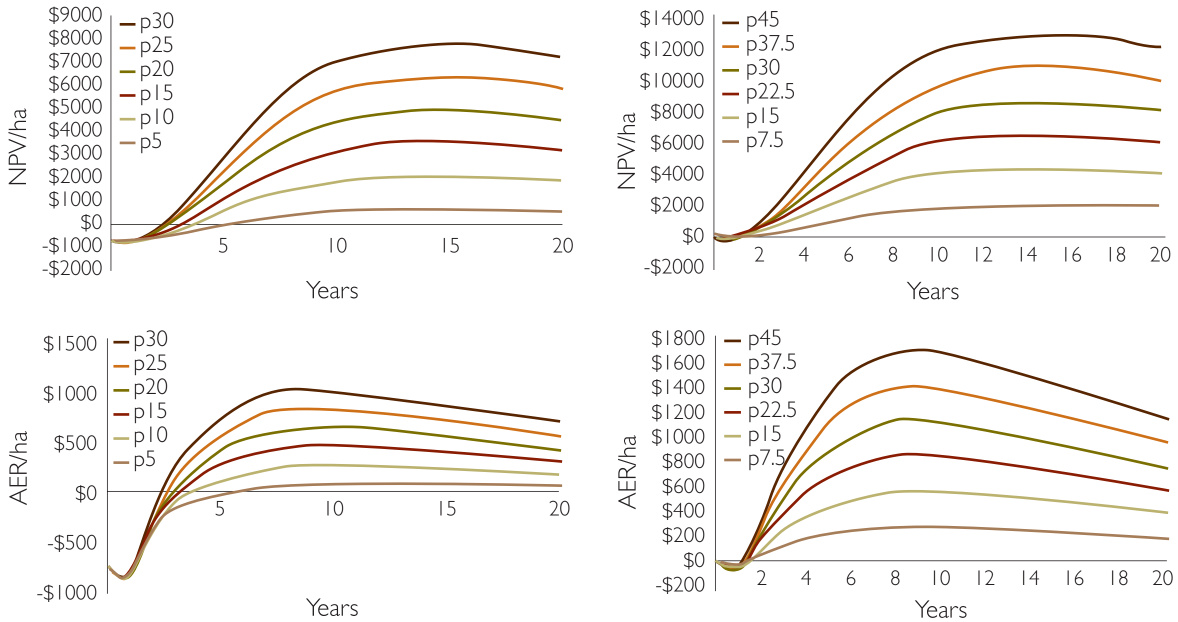


Figure 24. Net Present Value and Annual Equivalent Return ($) per hectare of Australian pulpwood chips by stemwood productivity class [m³/ha/year]: *Eucalyptus viminalis* ssp. *cygnetensis*.

Australian Pulpwood Only

First Harvest

Subsequent Harvest

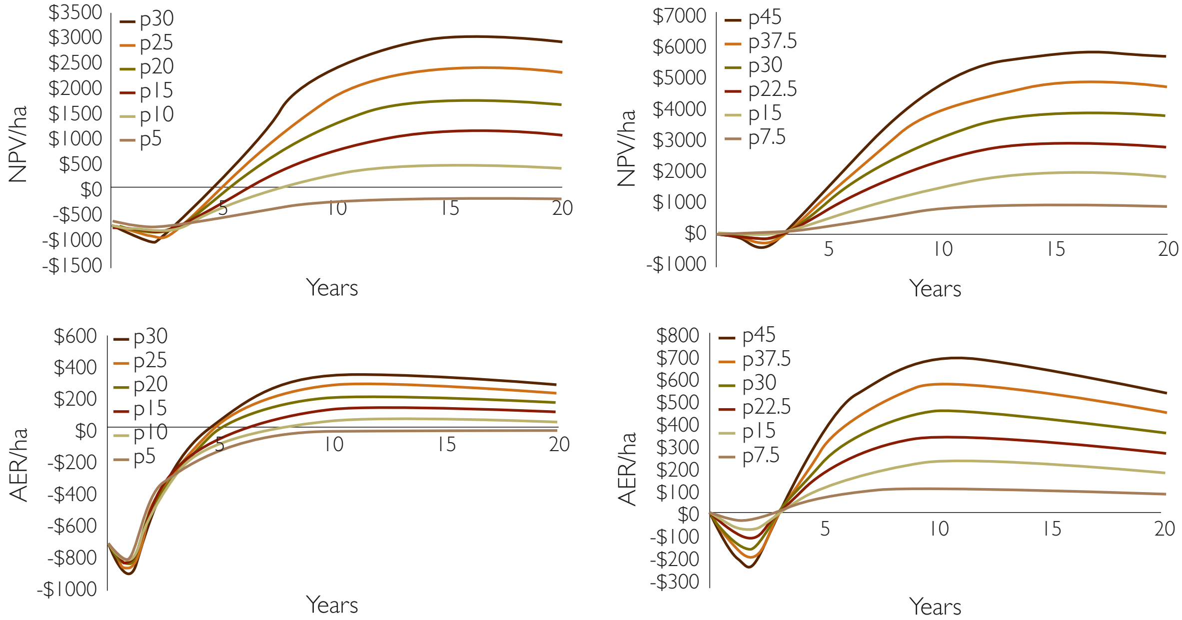


Figure 25. Net Present Value ($) per hectare of MDF, fibre/particleboard chips by stemwood productivity class [m³/ha/year]: *Eucalyptus viminalis* ssp. *cygnetensis*.

Fibreboard/Particleboard Only

First Harvest

Subsequent Harvest

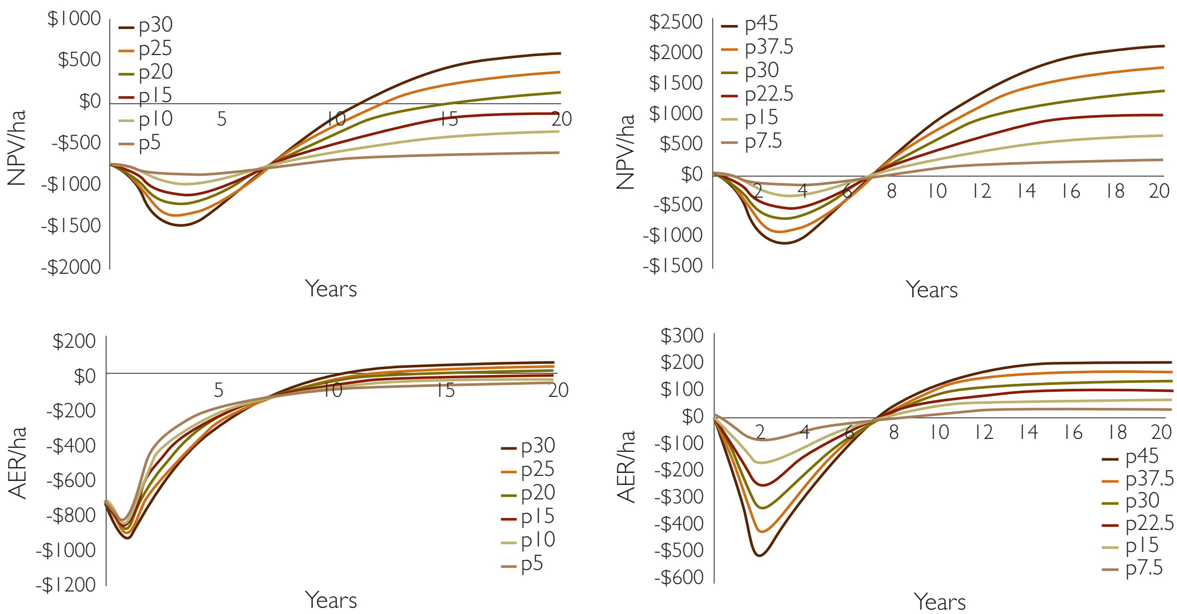


Figure 26. Net Present Value and Annual Equivalent Return ($) per hectare of biomass for electricity generation by stemwood productivity class [m³/ha/year]: *Eucalyptus cladocalyx*.

Bioenergy Only

First Harvest

Subsequent Harvest

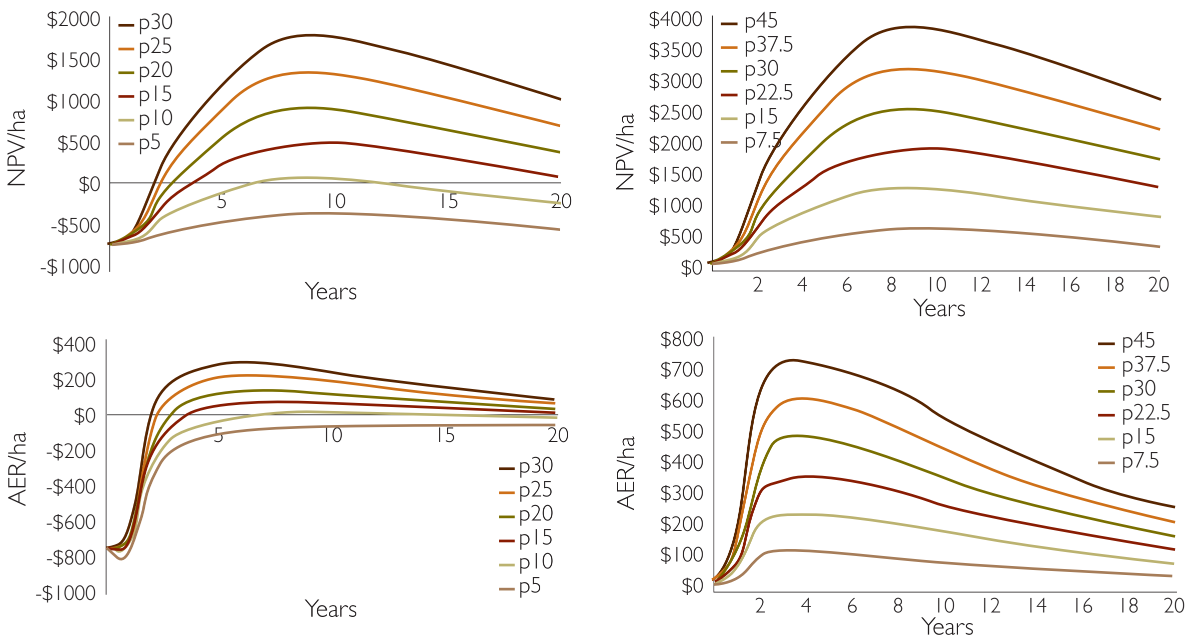


Figure 27. Net Present Value ($) and Annual Equivalent Return per hectare of leaf to oil, processed on-site, by stemwood productivity class [m³/ha/year]: *Eucalyptus porosa.*

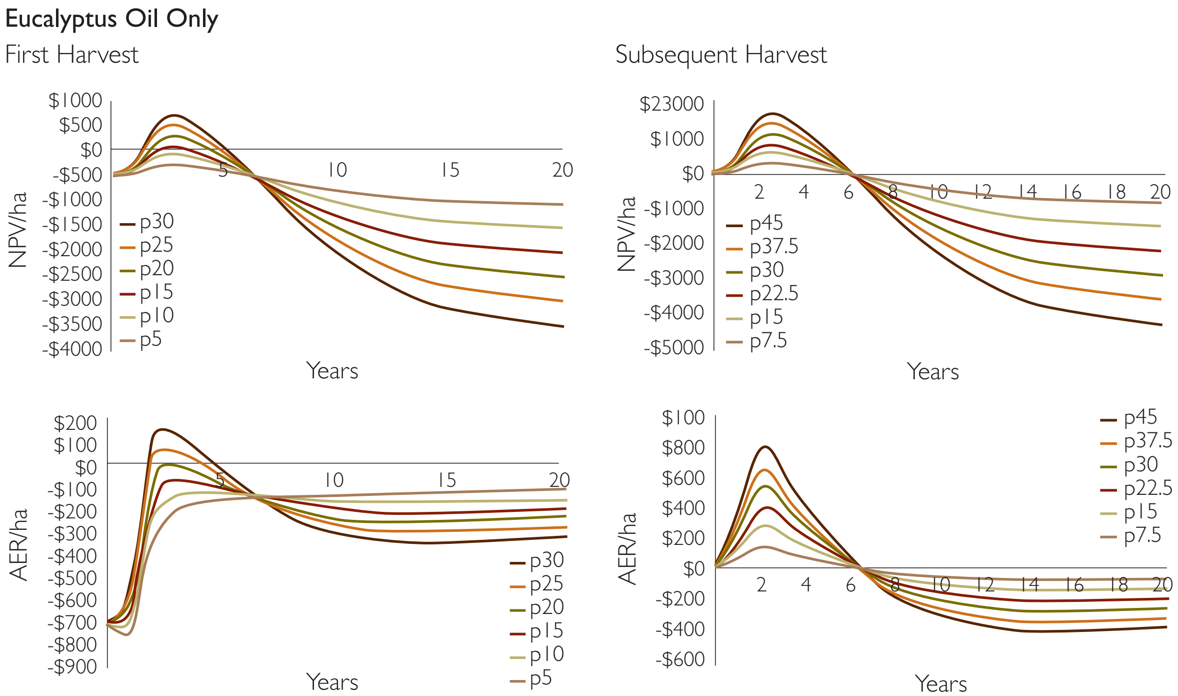


Figure 28. Net Present Value and Annual Equivalent Return ($) per hectare of leaf and fine twig for farm fodder by stemwood productivity class [m³/ha/year]: continuous *Atriplex nummularia.*

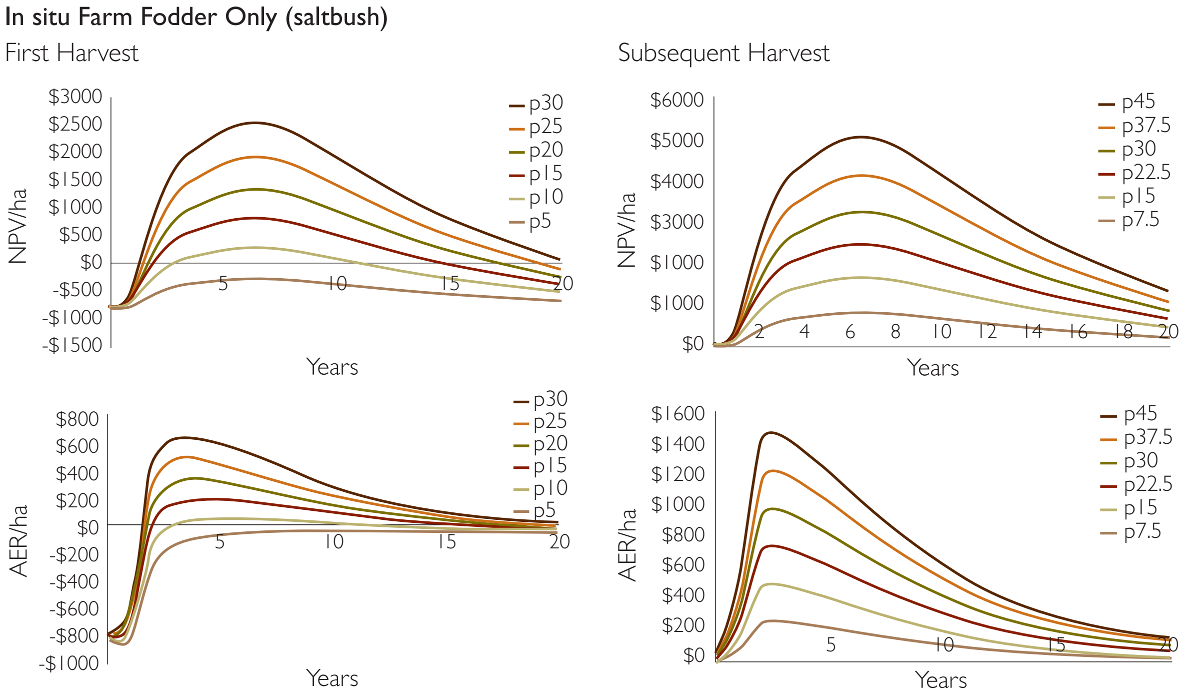


Figure 29. Net Present Value and Annual Equivalent Return ($) per hectare of leaf and fine twig for feedlot and processed fodder by stemwood productivity class [m³/ha/year]: continuous *Atriplex nummularia*.

Off-farm Fodder Only (saltbush)

First Harvest

Subsequent Harvest

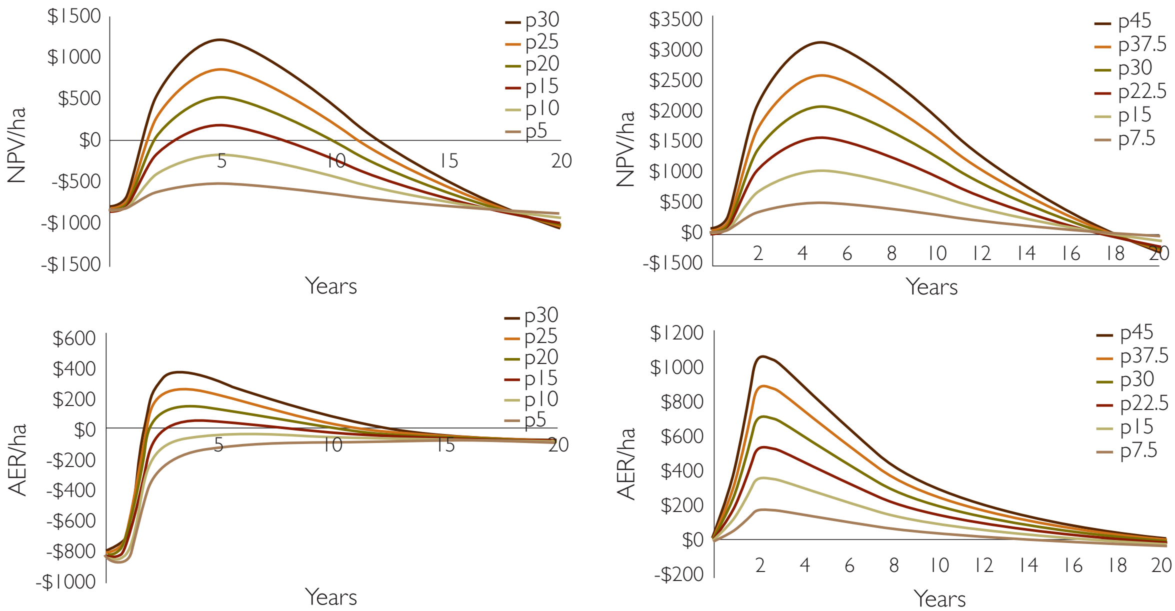


Figure 30. Net Present Value ($) per hectare of Australian pulpwood chips, and residual biomass used for electricity generation, by stemwood productivity class [m³/ha/year]: *Eucalyptus viminalis ssp. cygnetensis*.

Australian Pulpwood and Bioenergy

First Harvest

Subsequent Harvest

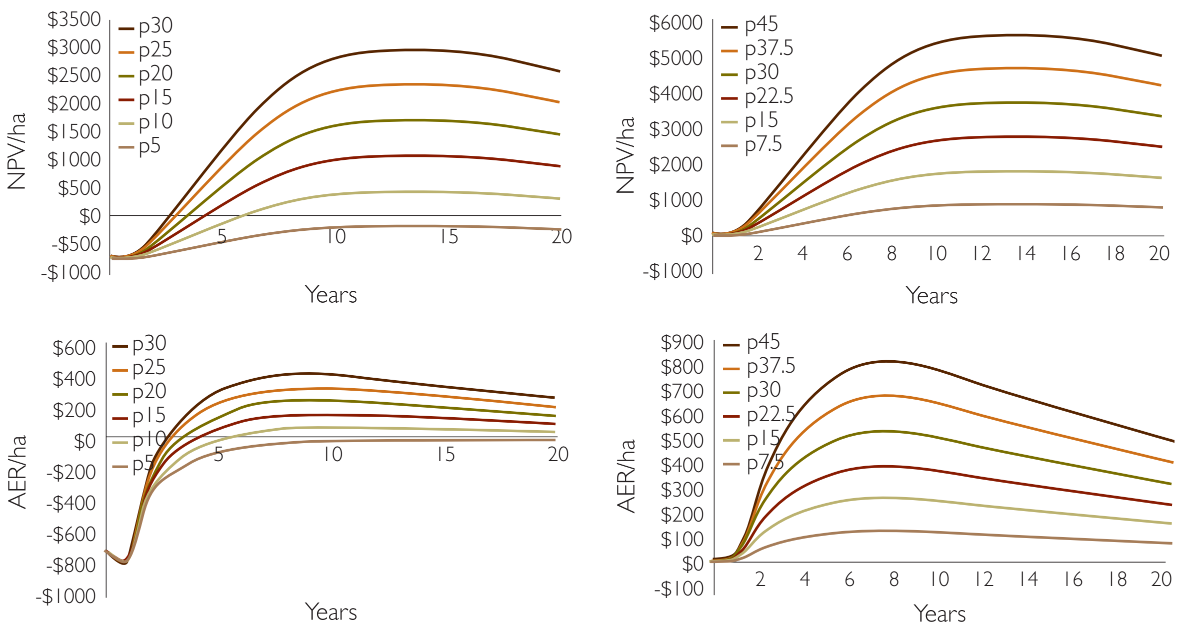


Figure 31. Net Present Value ($) per hectare of MDF chips, and residual biomass used for electricity generation, by stemwood productivity class [m³/ha/year]: *Eucalyptus viminalis* ssp. *cygnetensis*.

Fibreboard/Particleboard and Bioenergy

First Harvest

Subsequent Harvest

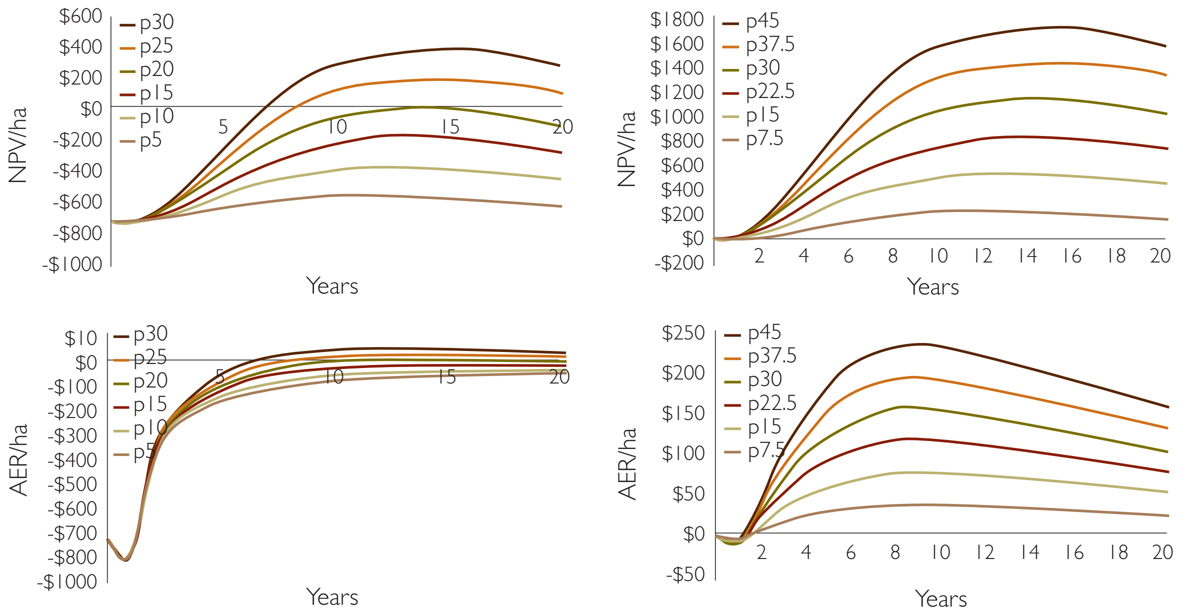


Figure 32. Net Present Value ($) per hectare of Australian pulpwood chips, leaf to farm fodder and residual biomass used for electricity generation, by stemwood productivity class [m³/ha/year]: *Acacia retinodes* var. *retinodes*.

Australian Pulpwood, On-farm Fodder and Bioenergy

First Harvest and Subsequent Harvest

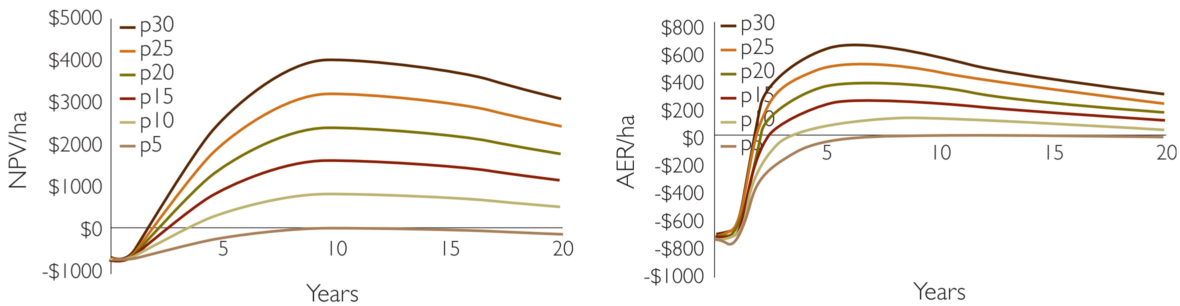


Figure 33. Net Present Value ($) per hectare of Australian pulpwood chips, leaf to off-farm fodder and residual biomass used for electricity generation, by stemwood productivity class [m³/ha/year]: *Acacia retinodes* var. *retinodes*.

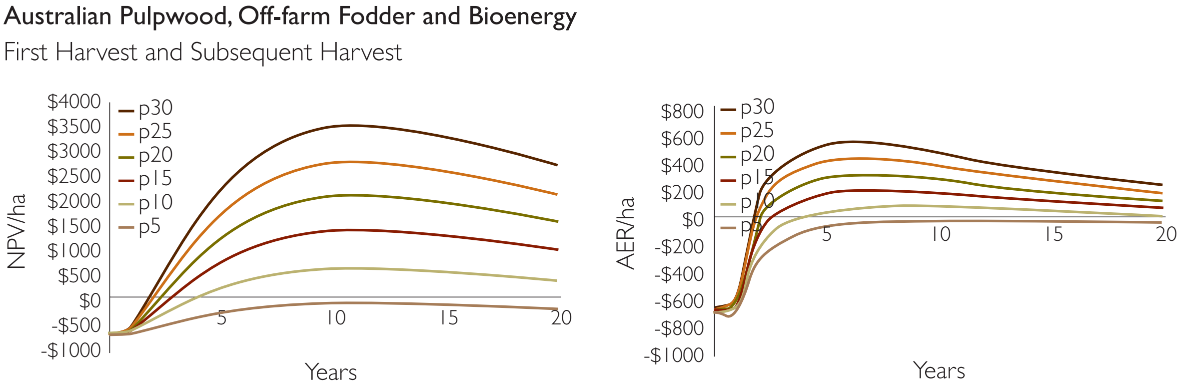


Figure 34. Net Present Value ($) and Annual Equivalent Return per hectare of leaf to oil, and residual biomass used for electricity generation, by stemwood productivity class [m³/ha/year]: *Eucalyptus porosa*.

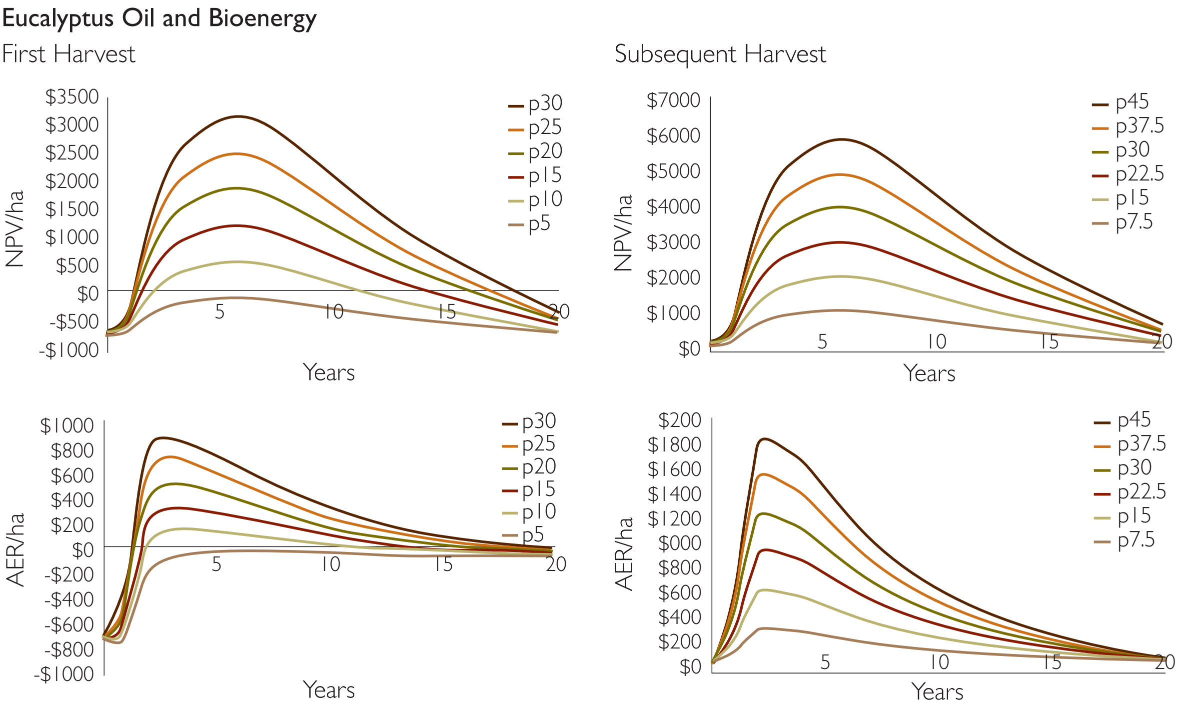


Table 20. Maximised Annual Equivalent Returns by potential product types for First Harvest (or phase crop only) at sites 50 km and 100 km from a processing facility.

Product Type	Distance	Max. AER	Stemwood productivity classes (m^3/ha/year)					
			p5	p10	p15	p20	p25	p30
Export Pulpwood Only	50 km	Year	12	9	9	9	9	9
		AER	$71	$253	$442	$630	$818	$1,006
	100 km	Year	12	10	9	9	9	9
		AER	$59	$226	$396	$569	$742	$915
Australian Pulpwood Only	50 km	Year	18	14	13	13	12	12
		AER	-$19	$49	$122	$195	$269	$343
	100 km	Year	19	16	15	14	14	14
		AER	-$27	$31	$91	$152	$214	$275
Fibre/Particleboards Only	50 km	Year	20	20	20	20	19	19
		AER	-$57	-$34	-$11	$11	$34	$57
	100 km	Year	20	20	20	20	20	20
		AER	-$64	-$47	-$31	-$15	$1	$17
Bioenergy Only	50 km	Year	16	9	8	7	7	6
		AER	-$49	$9	$79	$151	$225	$302
	100 km	Year	20	10	9	8	8	7
		AER	-$59	-$30	$16	$65	$114	$166
Eucalyptus Oil Only	50 km	Year	20	4	3	3	3	3
		AER	-$123	-$136	-$83	-$14	$55	$123
	100 km	Year	20	4	3	3	3	3
		AER	-$123	-$137	-$83	-$15	$53	$122
In situ Farm Fodder Only# (saltbush)	50 km	Year	8	5	4	4	4	4
		AER	-$61	$49	$183	$331	$478	$625
	100 km	Year	8	5	4	4	4	4
		AER	-$61	$49	$183	$331	$478	$625

Table 20. Continued

Product Type	Distance	Max. AER	Stemwood productivity classes (m³/ha/year)					
			p5	p10	p15	p20	p25	p30
Off-farm Fodder Only (saltbush)	50 km	Year	20	6	4	4	4	3
		AER	-$92	-$45	$39	$138	$237	$342
	100 km	Year	20	6	5	4	4	3
		AER	-$97	-$74	-$7	$77	$161	$254
Australian Pulpwood and Bioenergy	50 km	Year	15	10	9	9	9	9
		AER	-$22	$56	$144	$233	$322	$411
	100 km	Year	17	12	10	9	9	9
		AER	-$31	$31	$100	$173	$246	$320
Fibre/Particleboards and Bioenergy	50 km	Year	20	20	16	14	13	12
		AER	-$62	-$44	-$25	-$3	$20	$44
	100 km	Year	20	20	20	20	19	18
		AER	-$69	-$58	-$47	-$36	-$25	-$13
Australian Pulpwood, On-farm Fodder# and Bioenergy (phase crop)	50 km	Year	10	8	8	7	7	7
		AER	-$1	$123	$252	$381	$513	$644
	100 km	Year	10	8	8	8	7	7
		AER	-$11	$101	$217	$334	$454	$574
Australian Pulpwood, Off-farm Fodder and Bioenergy (phase crop)	50 km	Year	11	9	8	8	8	7
		AER	-$14	$91	$203	$315	$427	$540
	100 km	Year	13	9	8	8	8	8
		AER	-$24	$64	$158	$255	$352	$450
Eucalyptus Oil and Bioenergy	50 km	Year	6	4	4	3	3	3
		AER	-$28	$133	$313	$506	$705	$903
	100 km	Year	6	4	4	3	3	3
		AER	-$45	$98	$260	$437	$619	$800

#No transport costs for on-farm fodder.

Table 21. Maximised Annual Equivalent Returns by potential product types for Subsequent Harvests (coppicing systems) at sites 50 km and 100 km from a processing facility.

Product Type	Distance	Max. AER	Stemwood productivity classes (m^3/ha/year)					
			p5	p10	p15	p20	p25	p30
Export Pulpwood Only	50 km	Year	9	9	9	9	9	9
		AER	$273	$555	$837	$1,120	$1,402	$1,684
	100 km	Year	9	9	9	9	9	9
		AER	$250	$510	$769	$1,029	$1,288	$1,548
Australian Pulpwood Only	50 km	Year	11	11	11	11	11	11
		AER	$103	$215	$327	$439	$551	$663
	100 km	Year	12	12	12	12	12	12
		AER	$84	$178	$271	$365	$459	$552
Fibre/Particleboards Only	50 km	Year	17	17	17	17	17	17
		AER	$25	$61	$96	$131	$166	$201
	100 km	Year	20	20	20	20	20	20
		AER	$14	$38	$63	$87	$111	$135
Bioenergy Only	50 km	Year	4	4	4	4	4	4
		AER	$115	$237	$359	$481	$604	$726
	100 km	Year	4	4	4	4	4	4
		AER	$78	$164	$250	$335	$421	$507
Eucalyptus Oil Only	50 km	Year	2	2	2	2	2	2
		AER	$126	$257	$388	$519	$650	$781
	100 km	Year	2	2	2	2	2	2
		AER	$126	$256	$387	$518	$648	$779
In situ Farm Fodder Only# (saltbush)	50 km	Year	3	3	3	3	3	3
		AER	$232	$470	$709	$948	$1,186	$1,425
	100 km	Year	3	3	3	3	3	3
		AER	$232	$470	$709	$948	$1,186	$1,425
Off-farm Fodder Only (saltbush)	50 km	Year	2	2	2	2	2	2
		AER	$167	$339	$510	$682	$854	$1,026
	100 km	Year	2	2	2	2	2	2
		AER	$148	$300	$453	$606	$758	$911

Table 21. Continued

Product Type	Distance	Max. AER	Stemwood productivity classes (m³/ha/year)					
			p5	p10	p15	p20	p25	p30
Australian Pulpwood and Bioenergy	50 km	Year	8	8	8	8	8	8
		AER	$126	$262	$397	$532	$667	$803
	100 km	Year	8	8	8	8	8	8
		AER	$102	$213	$324	$435	$546	$657
Fibre/Particleboards and Bioenergy	50 km	Year	9	9	9	9	9	9
		AER	$31	$70	$110	$150	$190	$229
	100 km	Year	13	13	13	13	13	13
		AER	$9	$28	$47	$66	$85	$104
Eucalyptus Oil and Bioenergy	50 km	Year	2	2	3	3	3	3
		AER	$292	$590	$887	$1,185	$1,483	$1,781
	100 km	Year	2	2	2	2	2	2
		AER	$270	$546	$821	$1,096	$1,372	$1,647

#No transport costs for on-farm fodder.

Table 22. Maximised Annual Equivalent Returns by potential product types, for the first 20 years of primary production at sites 50 km and 100 km from a processing facility, including years to first harvest and [next optimal harvest].

Product Type	Distance	Max. AER	Stemwood productivity classes (m³/ha/year)					
			p5	p10	p15	p20	p25	p30
Export Pulpwood Only	50 km	Year	12 [9]	9 [9]	9 [9]	9 [9]	9 [9]	9 [9]
		AER	$124	$377	$605	$834	$1,062	$1,291
	100 km	Year	12 [9]	10 [9]	9 [9]	9 [9]	9 [9]	9 [9]
		AER	$115	$341	$577	$797	$1,016	$1,235
Australian Pulpwood Only	50 km	Year	15 [11]	14 [11]	13 [11]	13 [11]	12 [11]	12 [11]
		AER	$0	$86	$176	$261	$355	$442
	100 km	Year	15 [11]	15 [11]	15 [11]	14 [11]	14 [11]	14 [11]
		AER	-$8	$64	$135	$218	$292	$367

Table 22. Continued

Product Type	Distance	Max. AER	Stemwood productivity classes (m³/ha/year) p5	p10	p15	p20	p25	p30
Fibre/Particleboards Only	50 km	Year	15 [15]	15 [15]	15 [15]	15 [15]	15 [15]	15 [15]
		AER	-$53	-$26	$1	$27	$54	$81
	100 km	Year	15 [15]	15 [15]	15 [15]	15 [15]	15 [15]	15 [15]
		AER	-$61	-$43	-$24	-$5	$13	$32
Bioenergy Only	50 km	Year	15 [4]	9 [4]	8 [4]	7 [4]	7 [4]	6 [4]
		AER	-$24	$89	$200	$326	$428	$536
	100 km	Year	15 [4]	10 [4]	9 [4]	8 [4]	8 [4]	7 [4]
		AER	-$34	$60	$138	$245	$326	$461
Eucalyptus Oil Only	50 km	Year	6 [2]	4 [2]	3 [2]	3 [2]	3 [2]	3 [2]
		AER	-$5	$127	$267	$383	$499	$614
	100 km	Year	6 [2]	4 [2]	3 [2]	3 [2]	3 [2]	3 [2]
		AER	-$5	$127	$267	$383	$498	$614
In situ Farm Fodder Only# (saltbush)	50 km	Year	3 [2]	3 [2]	3 [2]	3 [2]	3 [2]	3 [2]
		AER	$124	$339	$554	$768	$983	$1,198
	100 km	Year	3 [2]	3 [2]	3 [2]	3 [2]	3 [2]	3 [2]
		AER	$124	$339	$554	$768	$983	$1,198
Off-farm Fodder Only (saltbush)	50 km	Year	6 [2]	6 [2]	4 [2]	4 [2]	4 [2]	3 [2]
		AER	$36	$163	$356	$504	$653	$853
	100 km	Year	6 [2]	6 [2]	5 [2]	4 [2]	4 [2]	3 [2]
		AER	$30	$150	$307	$485	$628	$831
Australian Pulpwood and Bioenergy	50 km	Year	15 [8]	10 [8]	9 [8]	9 [8]	9 [8]	9 [8]
		AER	$1	$128	$247	$356	$465	$573
	100 km	Year	15 [8]	12 [8]	10 [8]	9 [8]	9 [8]	9 [8]
		AER	-$7	$88	$204	$318	$418	$518
Fibre/Particleboards and Bioenergy	50 km	Year	15 [9]	15 [9]	15 [9]	14 [9]	13 [9]	12 [9]
		AER	-$55	-$29	-$4	$26	$59	$92
	100 km	Year	15 [9]	15 [9]	15 [9]	15 [9]	15 [9]	15 [9]
		AER	-$63	-$46	-$28	-$11	$6	$23

Table 22. Continued

Product Type	Distance	Max. AER	p5	p10	p15	p20	p25	p30
			Stemwood productivity classes (m³/ha/year)					
Australian Pulpwood, On-farm Fodder# and Bioenergy (phase)	50 km	Year	10 [10]	8 [8]	8 [8]	7 [7]	7 [7]	7 [7]
		AER	$34	$181	$311	$387	$504	$620
	100 km	Year	10 [10]	8 [8]	8 [8]	8 [7]	7 [7]	7 [7]
		AER	$27	$168	$292	$371	$474	$584
Australian Pulpwood, Off-farm Fodder and Bioenergy (phase)	50 km	Year	11 [11]	9 [9]	8 [8]	8 [8]	8 [8]	7 [7]
		AER	$17	$137	$262	$375	$489	$528
	100 km	Year	13 [11]	9 [9]	8 [8]	8 [8]	8 [8]	8 [7]
		AER	$1	$120	$236	$342	$447	$493
Eucalyptus Oil and Bioenergy	50 km	Year	6 [2]	4 [2]	4 [3]	3 [3]	3 [3]	3 [3]
		AER	$145	$440	$702	$1,016	$1,290	$1,564
	100 km	Year	6 [2]	4 [2]	4 [3]	3 [3]	3 [3]	3 [3]
		AER	$137	$428	$685	$999	$1,269	$1,538

#No transport costs for on-farm fodder.

7.4.7 Sensitivity analyses

Sensitivity analyses were conducted to investigate the influence of stemwood productivity classes, primary production and transport costs, and delivered feedstock values on optimum harvest times and potential profitability per hectare (see Appendix H). They demonstrate the high degree of sensitivity that exists with many low value feedstocks in relation to transport, establishment and harvest costs especially in areas with lowest primary productivity. Many high value products can be freighted substantial distances before the transport costs negate the delivered price to the mill. Production systems which utilise products on site (fodder) or undertake refining in the field to reduce transport costs (oils) provide options for more distant locations.

Figure 35 provides an example sensitivity summary for the first harvest of an Australian Pulpwood planting located 50 km from a pulp mill. It illustrates the significant influence of delivered commodity price, harvest costs and greater transportation distances on farmer returns. Sensitivity analyses for other industry types and harvest cycles are presented in Appendix H. More sophisticated sensitivity analyses and reviews of outputs will be conducted as part of future FloraSearch research.

7.4.8 Feedstocks to existing industries

Results from the sensitivity analysis for each product type and productivity class have identified the likely optimal harvest periods for each product type and productivity class. By utilising spatial productivity data for representative species, primary production establishment and harvest parameters, delivered product prices and transport distances from existing processing facilities, we can identify locations in southeastern Australia that can provide a commercially viable feedstock to existing industries in the region. Results of the spatial analyses are presented in Section 7.5.

Figure 35. A Sensitivity Analysis for the First Harvest scenario of Australian Pulpwood Only (at maximum annual equivalent return rate): *Eucalyptus viminalis* ssp. *cygnetensis*.

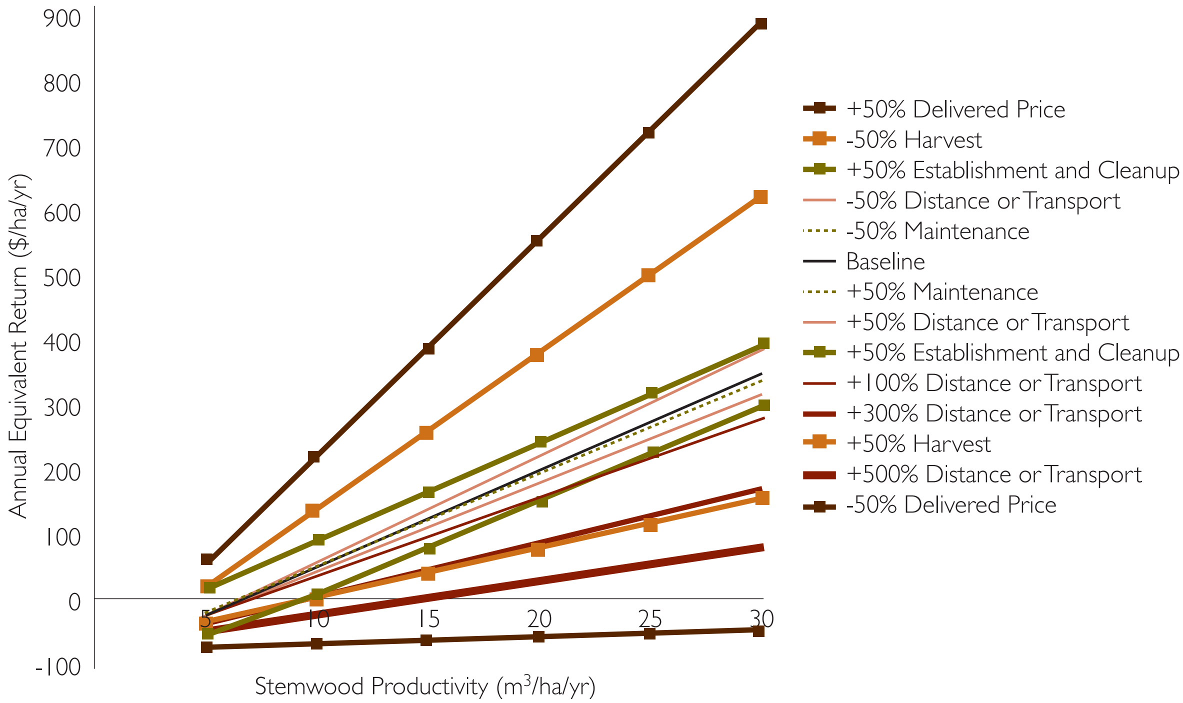
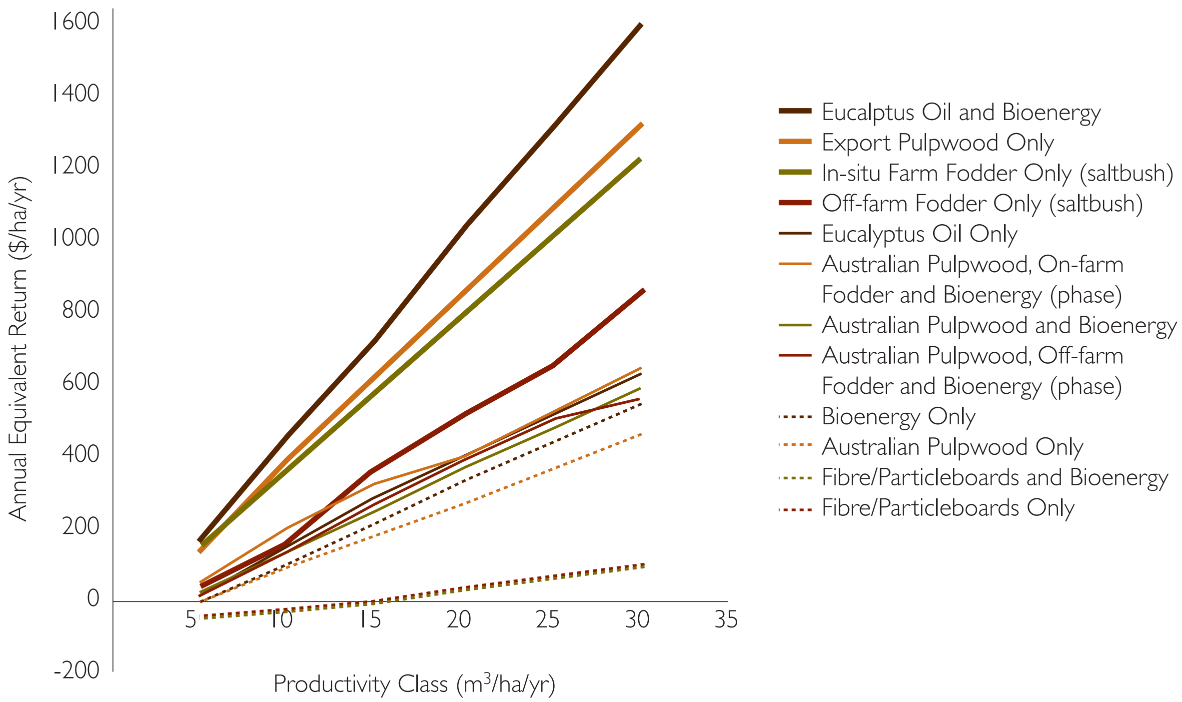


Figure 36. Summary of maximised Annual Equivalent Returns by potential product types for the first twenty years of primary production at sites 50km from a processing facility (no transport costs for on-farm fodder).



7.4.9 Potential industry feedstocks

Simulations have also been conducted for a number of industry types to determine where commercially viable feedstock can be produced in southeastern Australia. These simulations use productivity surface generated for our representative species, parameters used in the sensitivity analyses, and optimal first harvest period and a distance of 50 km from a potential processing facility to identify regions that can produce a commercially viable feedstock for industry and indicate potential location of new processing facilities. The results of these analyses are presented in Section 7.5. This section also provides further information on limitations to development of new industry facilities, which, when combined with spatial data on commercially viable primary production, allows the identification of areas with the greatest potential for developing new processing facilities.

7.5 Regional Industry Evaluations and Potential 2004

The following figures (Figure 37 – Figure 55) provide a summary of preliminary economic analysis for all single product options and some higher priority integrated product options conducted in 2004. Included are maps identifying areas with potential for producing commercially viable feedstock to existing industrial facilities and prospective facility development. For most scenarios both existing and potential feedstock are mapped, except for the supply of export wood chips to established bulk handling ports, and in situ farm fodder only and Eucalyptus oil only scenarios, where the resource is eaten or processed on-site.

Figure 37. Estimated primary producer returns from Export Pulpwood Only scenario to existing facilities.

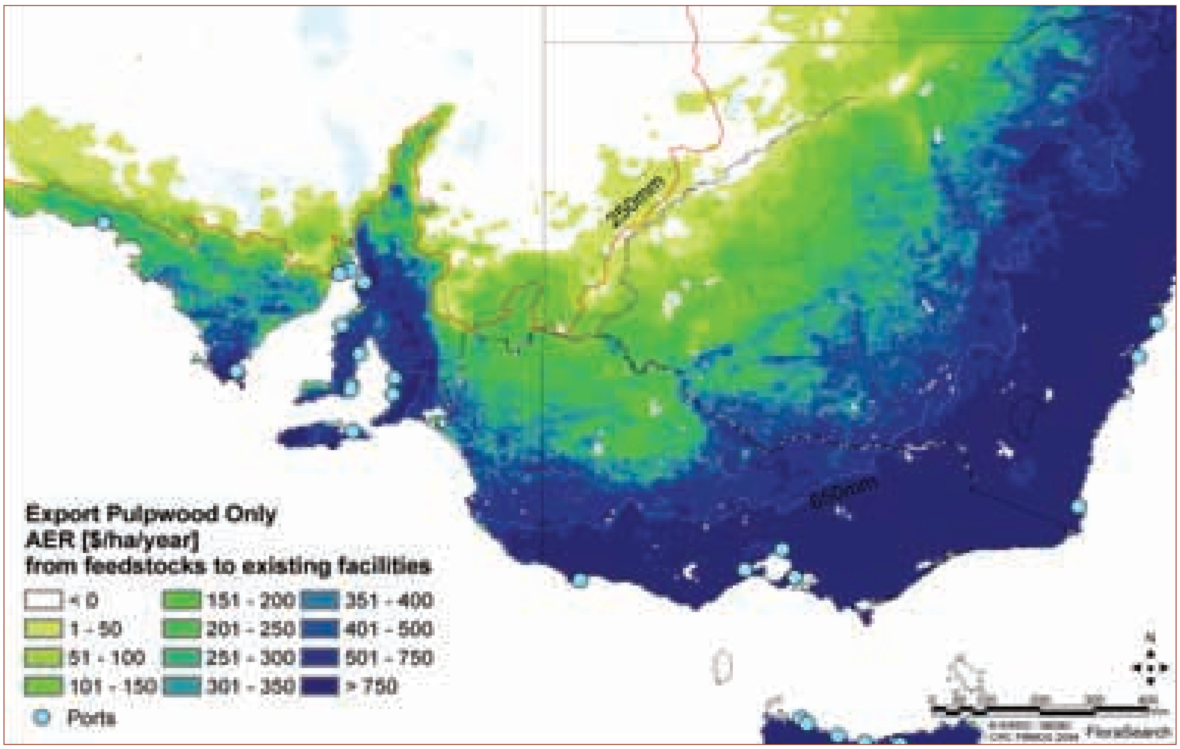


Figure 38. Estimated primary producer returns from Australian Pulpwood Only scenario to existing facilities.

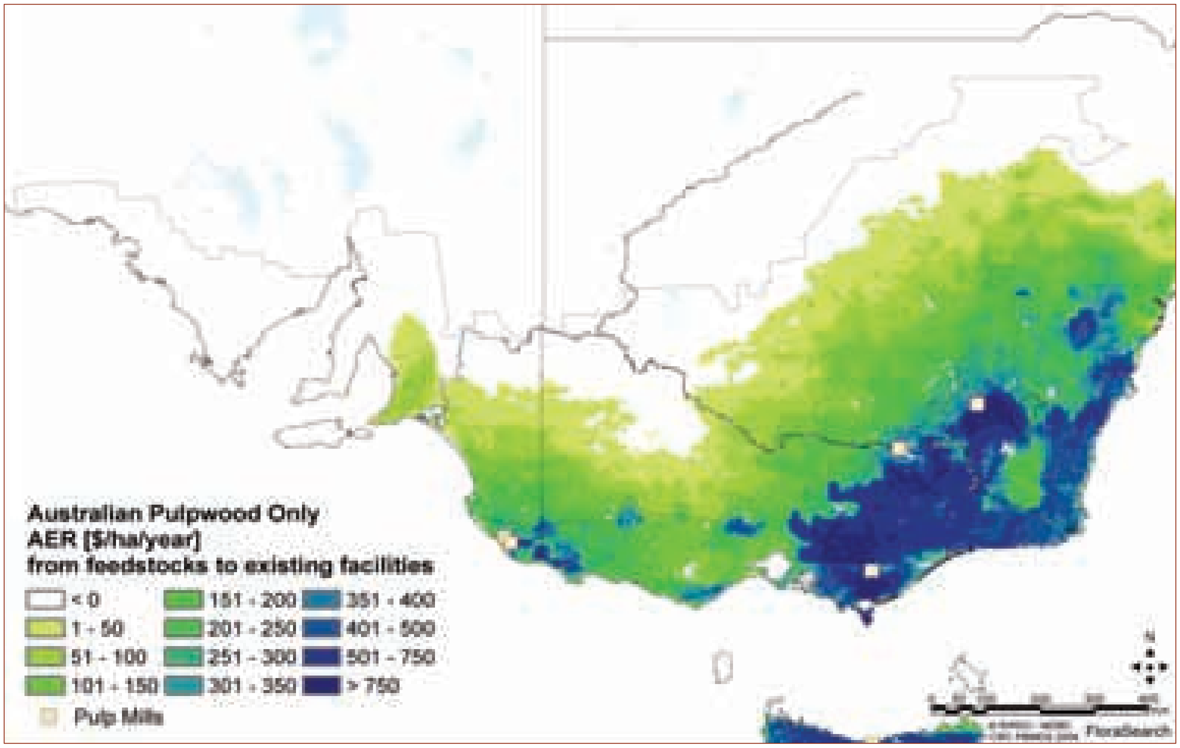


Figure 39. Estimated primary producer returns from Australian Pulpwood Only scenario for farms located within 50 kilometres of potential processing facility.

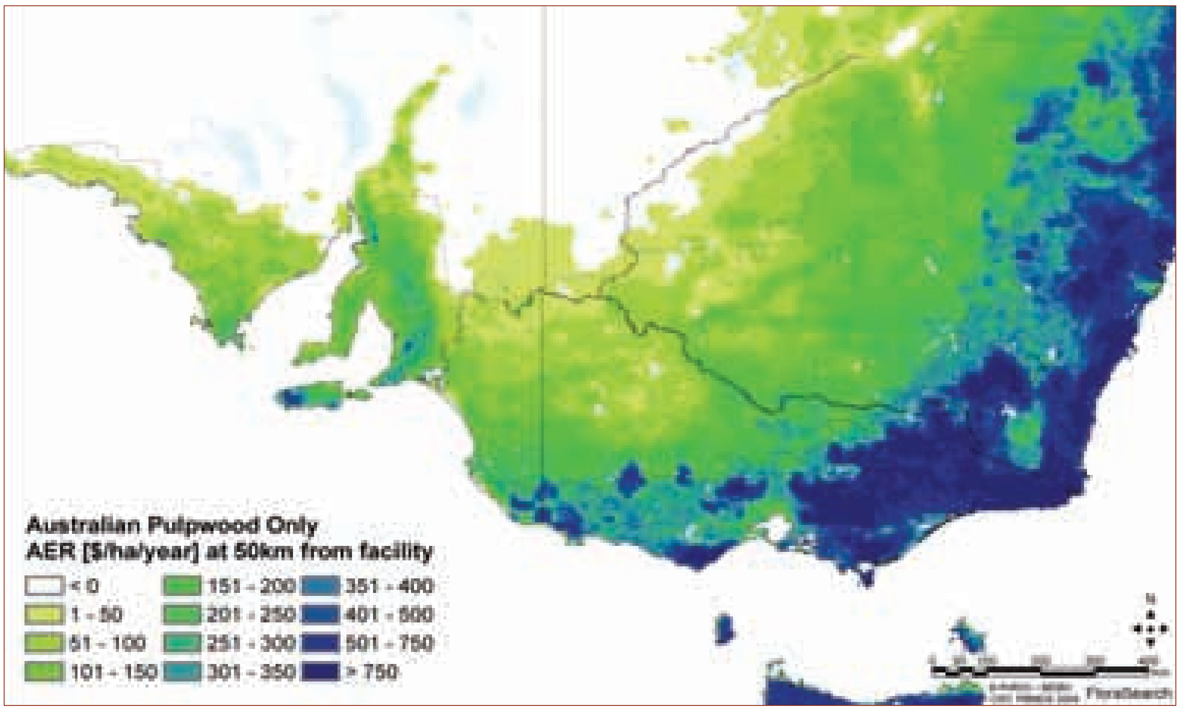


Figure 40. Estimated primary producer returns from Fibreboard/Particleboard Only scenario to existing facilities.

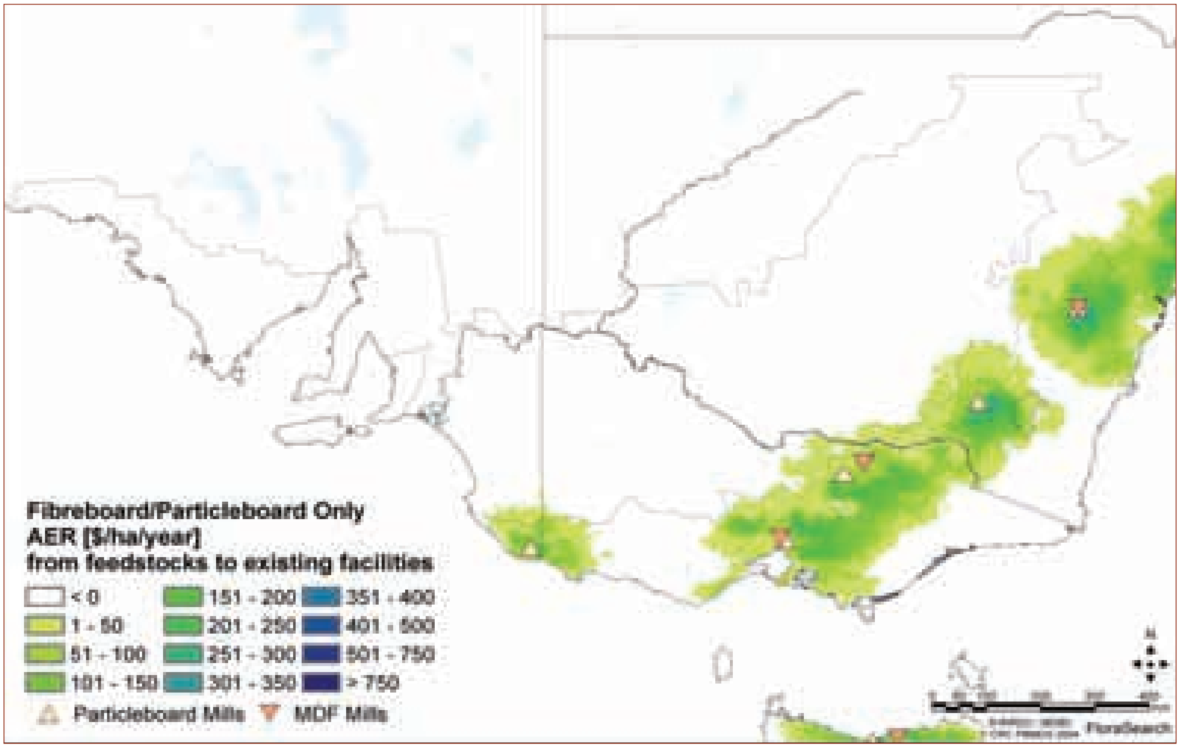


Figure 41. Potential Industry – Estimated primary producer returns from Fibreboard/ Particleboard Only scenario for farms located within 50 kilometres of potential processing facility.

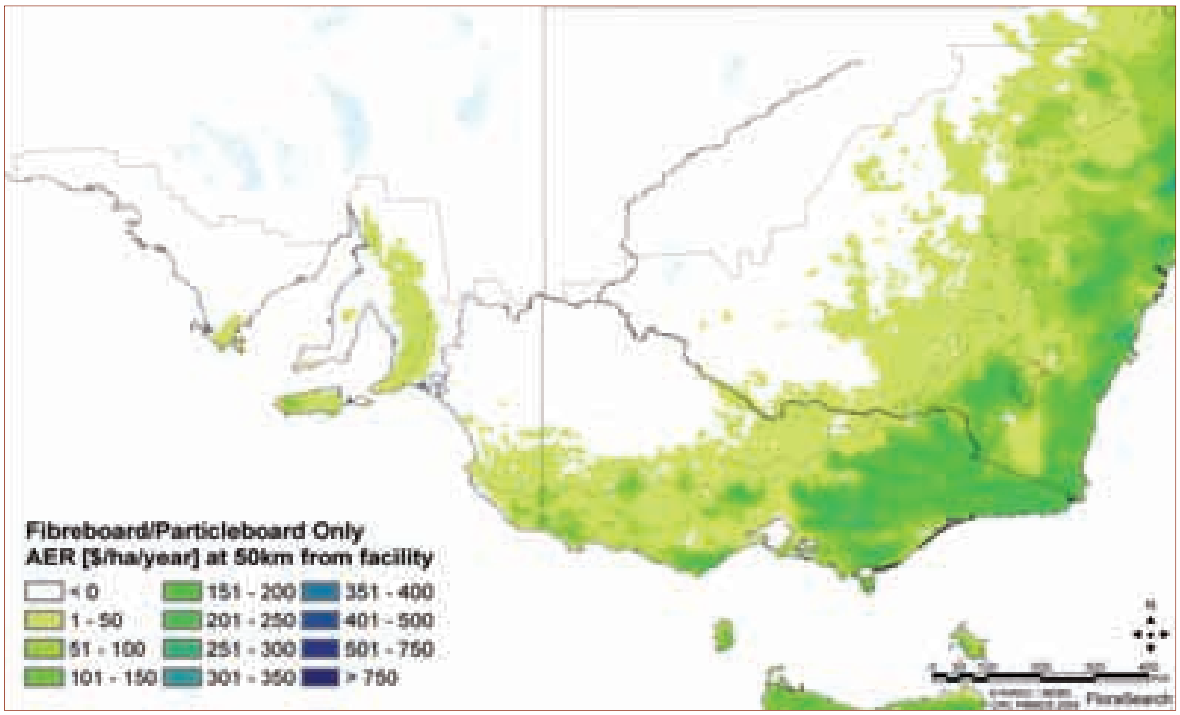


Figure 42. Estimated primary producer returns from Bioenergy Only scenario to existing facilities.

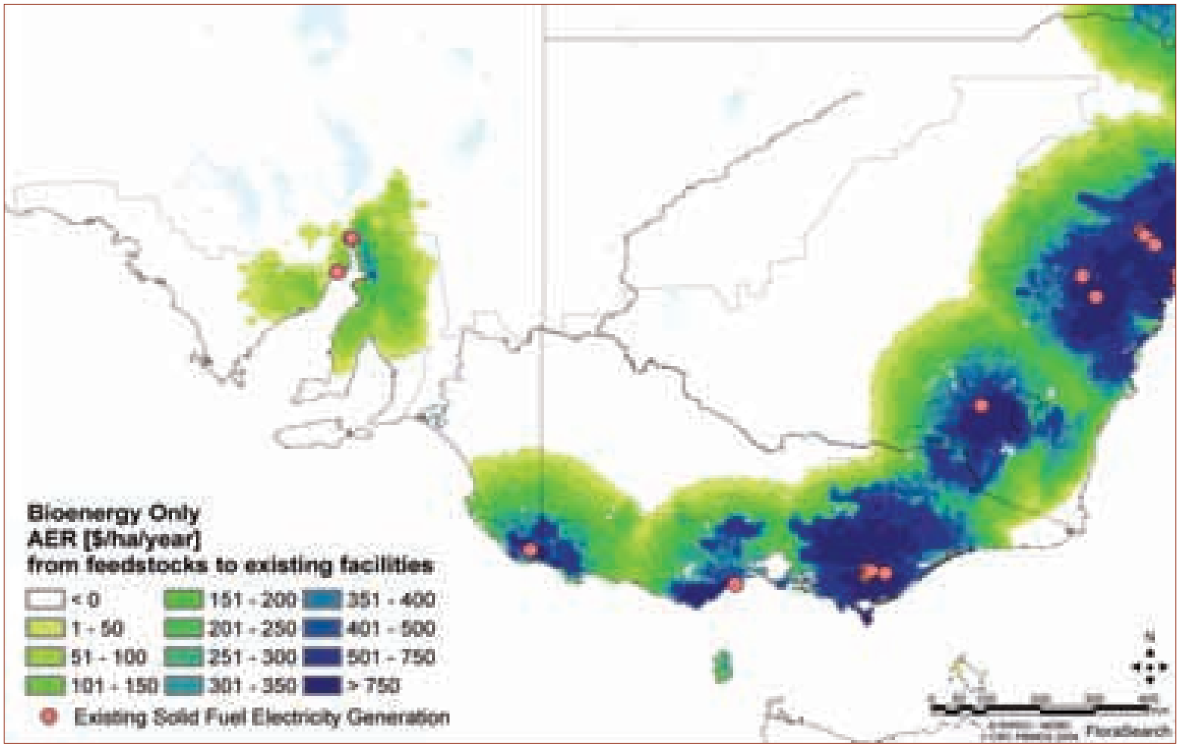


Figure 43. Estimated primary producer returns from Bioenergy Only scenario for farms located within 50 kilometres of potential processing facility.

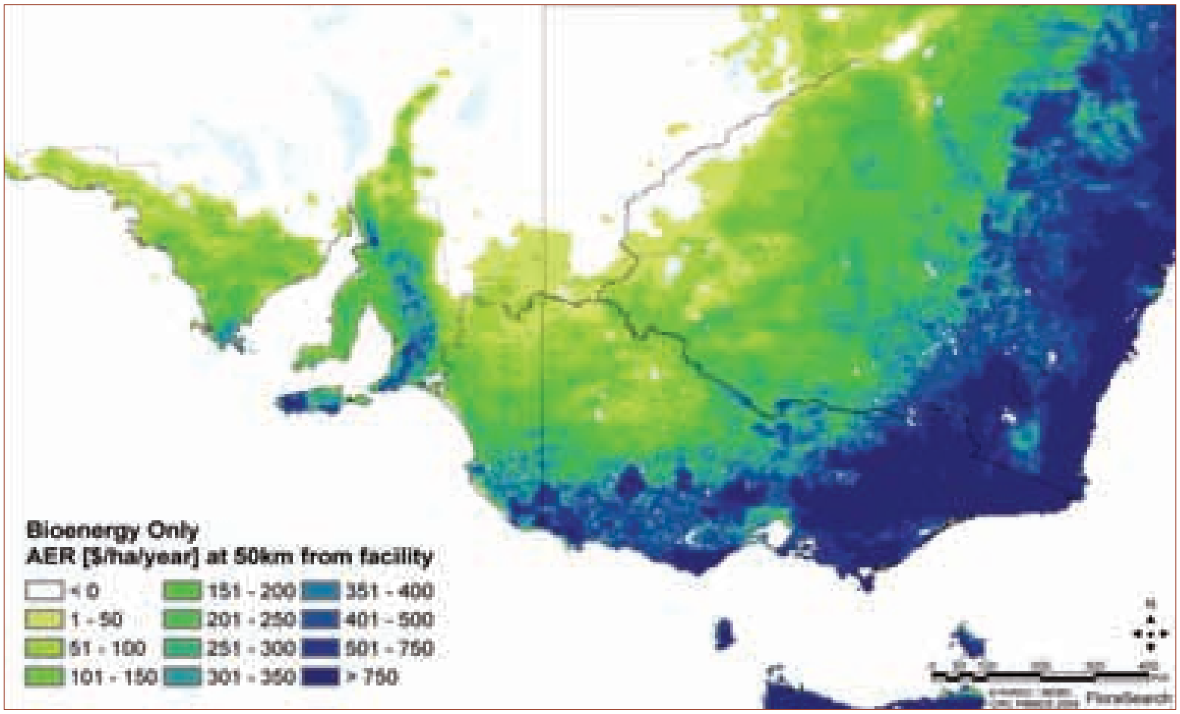


Figure 44. Estimated primary producer returns from Eucalyptus Oil Only scenario (on site oil processing, oil transported to existing ports).

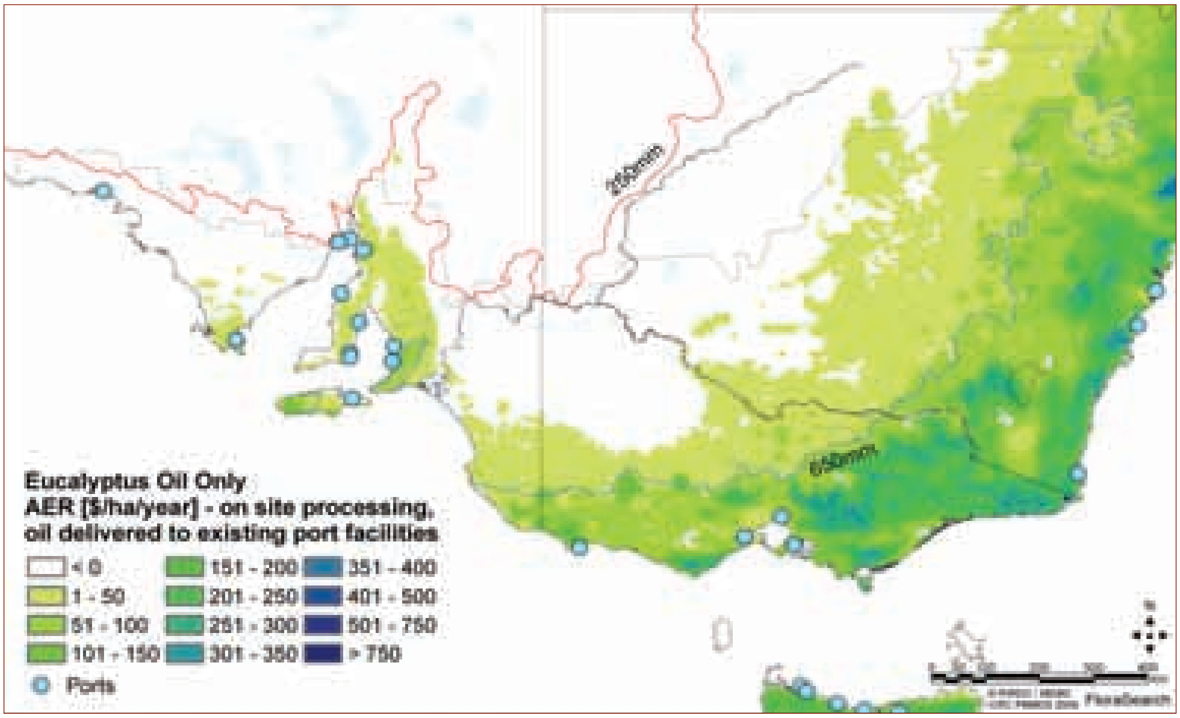


Figure 45. Estimated primary producer returns from In situ Farm Fodder Only scenario (on site utilisation).

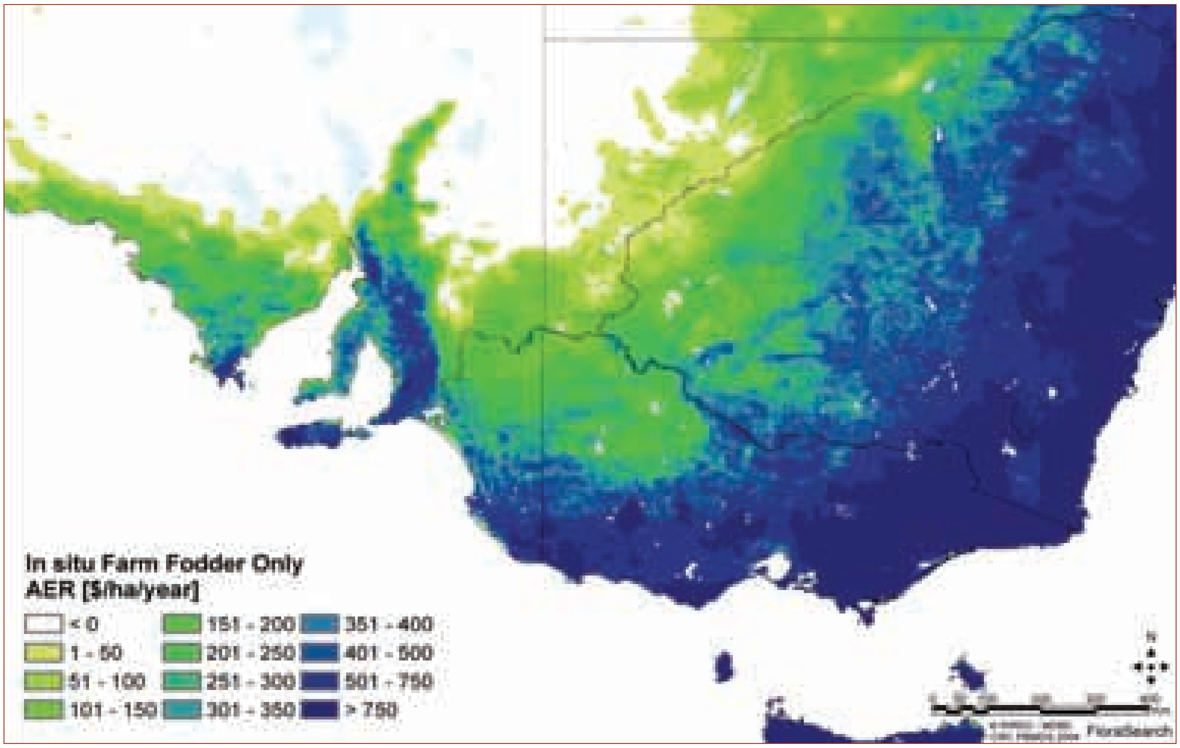


Figure 46. Estimated primary producer returns from Off-farm Fodder Only scenario to existing facilities.

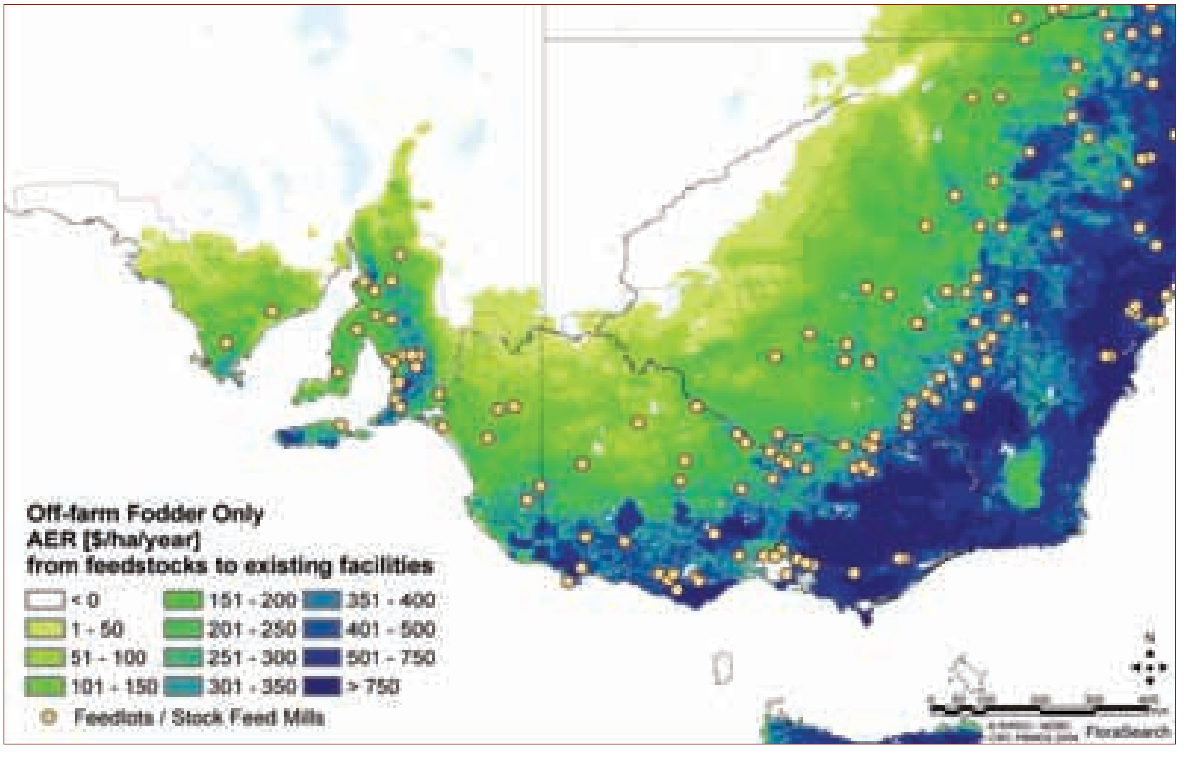


Figure 47. Estimated primary producer returns from Off-farm Fodder Only scenario for farms located within 50 kilometres of potential processing facility.

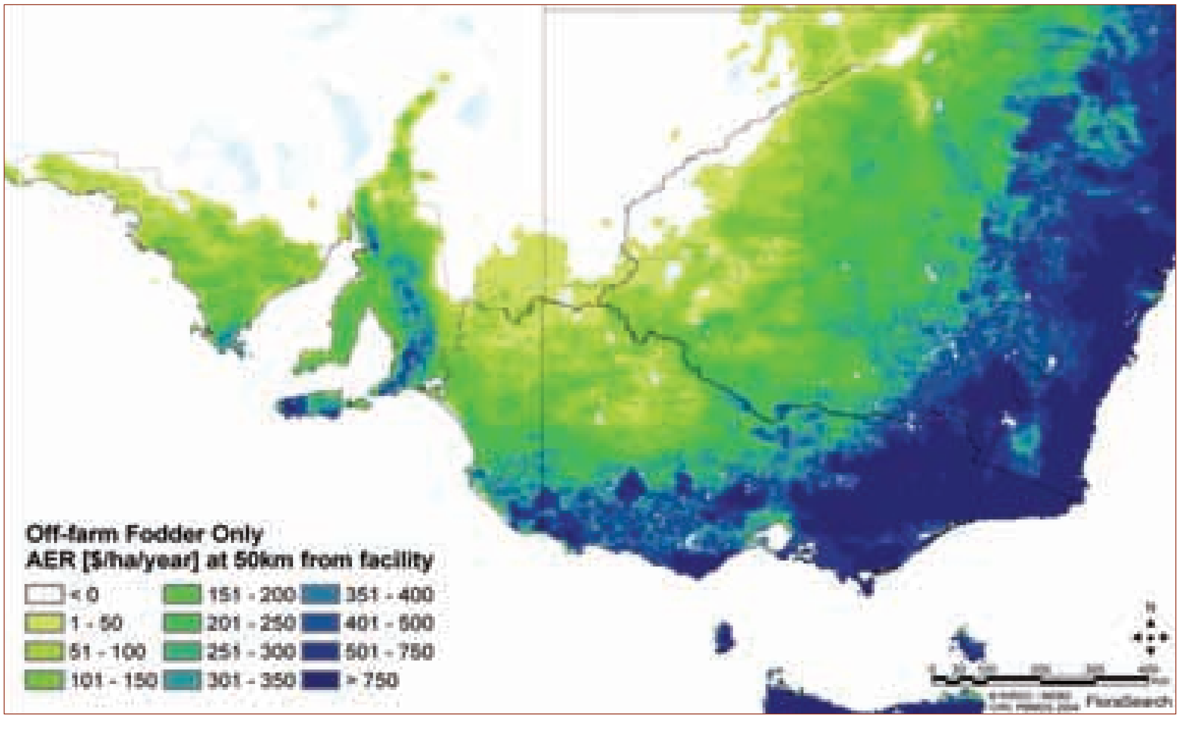


Figure 48. Estimated primary producer returns from Australian Pulpwood and Bioenergy scenario to existing facilities.

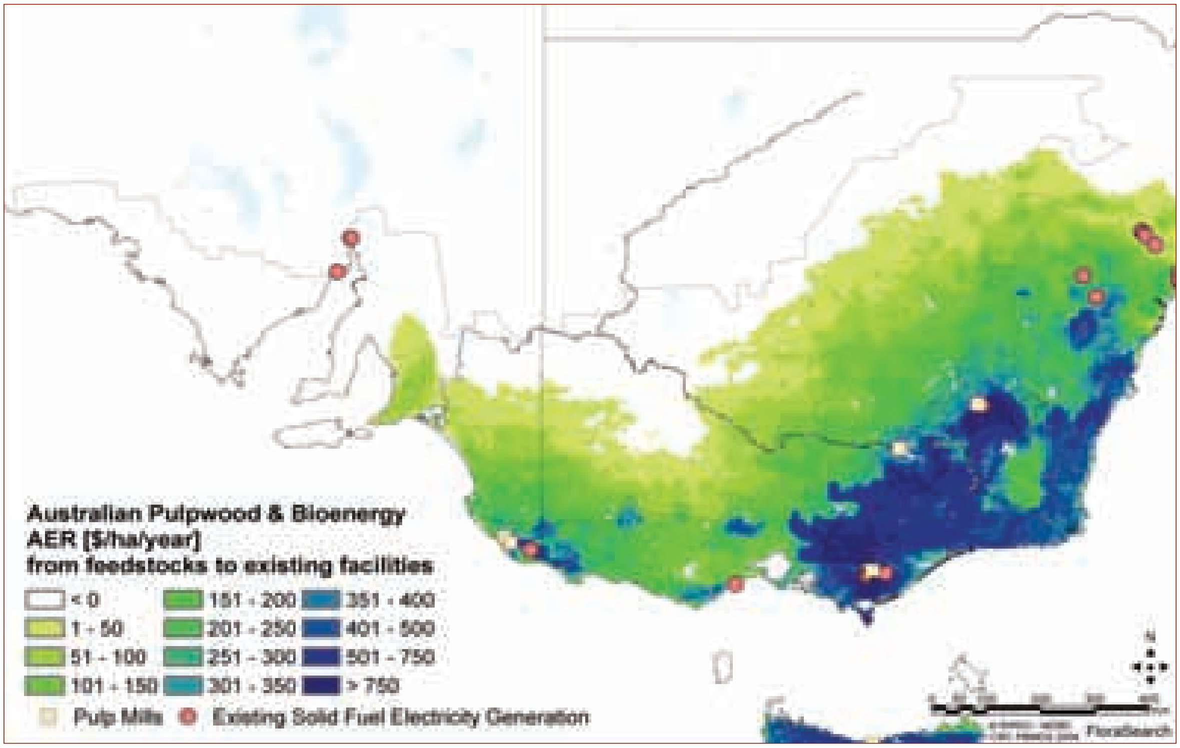


Figure 49. Estimated primary producer returns from Australian Pulpwood and Bioenergy scenario for farms located within 50 kilometres of potential processing facility.

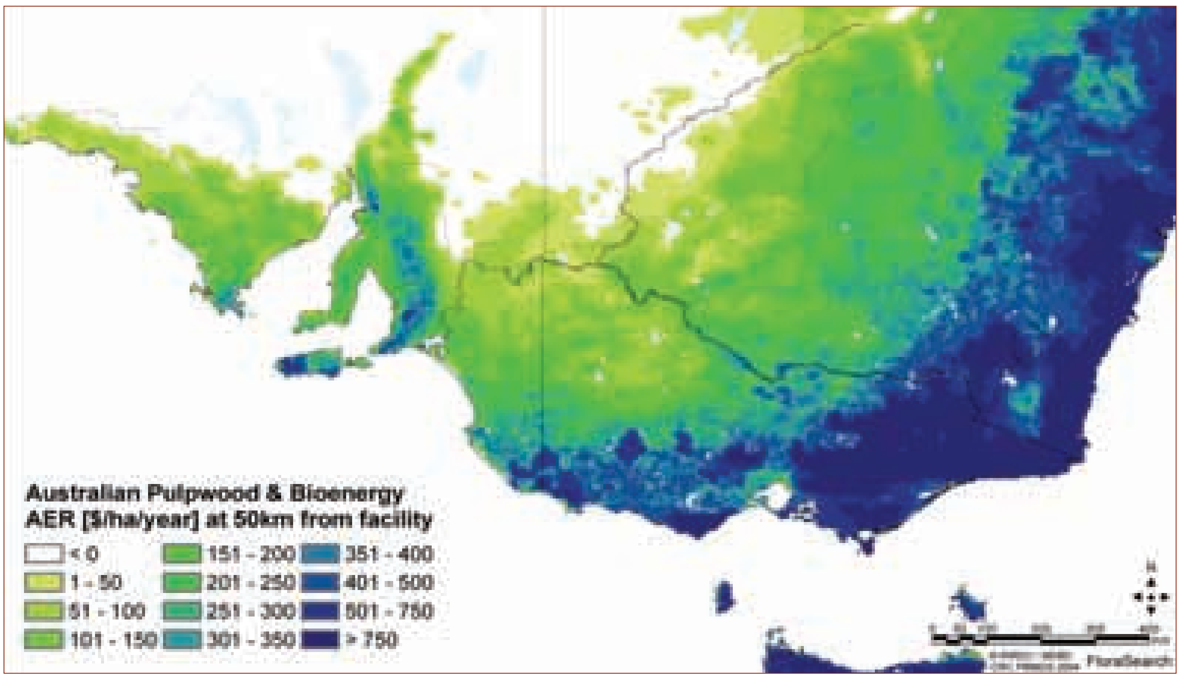


Figure 50. Estimated primary producer returns from Fibreboard/Particleboard and Bioenergy scenario to existing facilities.

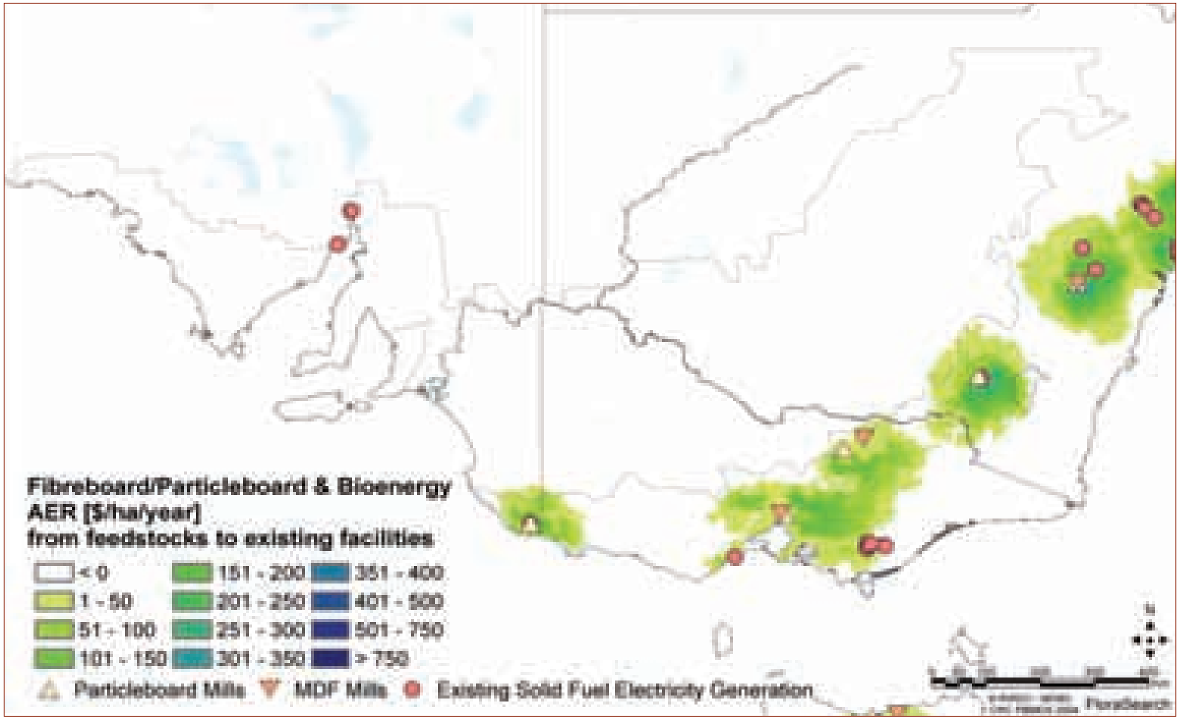


Figure 51. Estimated primary producer returns from Fibreboard/Particleboard and Bioenergy scenario for farms located within 50 kilometres of potential processing facility.

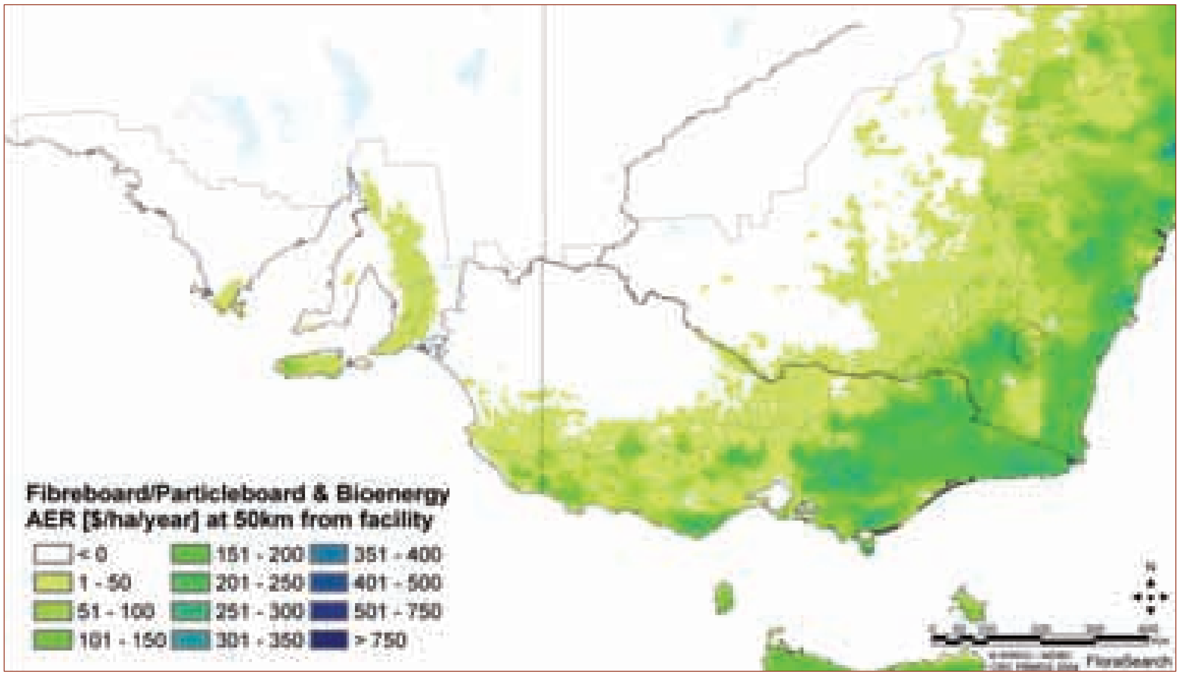


Figure 52. Estimated primary producer returns from Australian Pulpwood, On-farm Fodder and Bioenergy scenario to existing facilities.

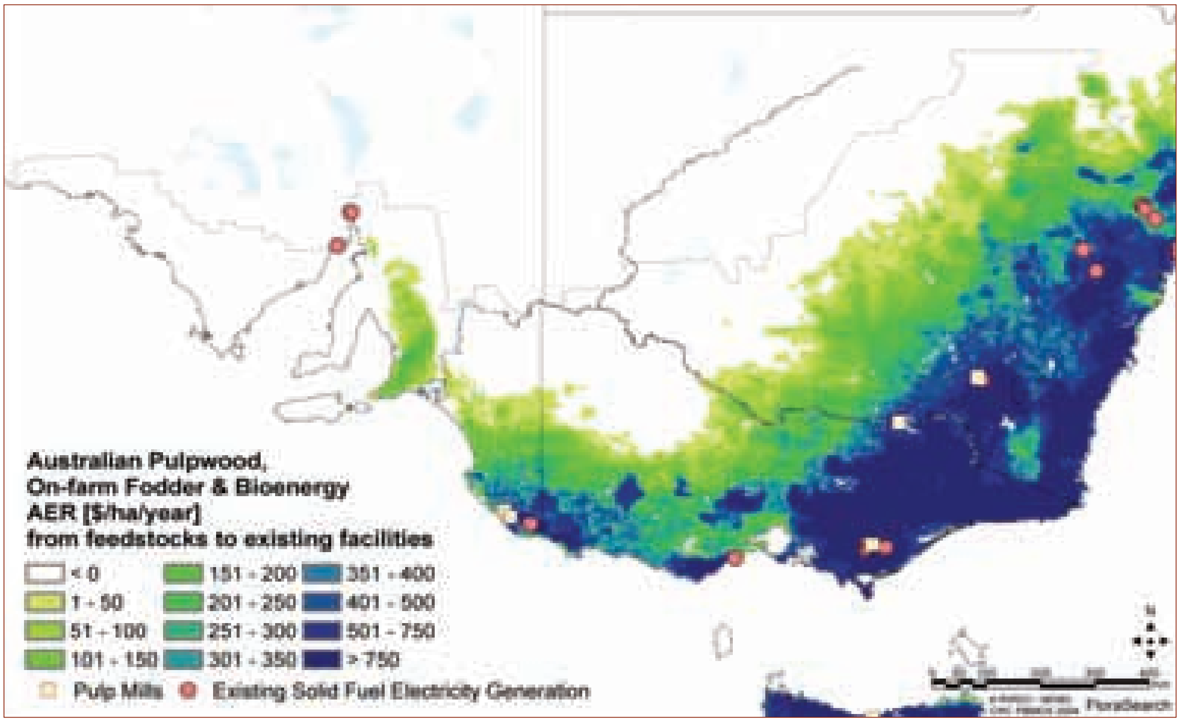


Figure 53. Estimated primary producer returns from Australian Pulpwood, On-farm Fodder and Bioenergy scenario for farms located within 50 kilometres of potential processing facility.

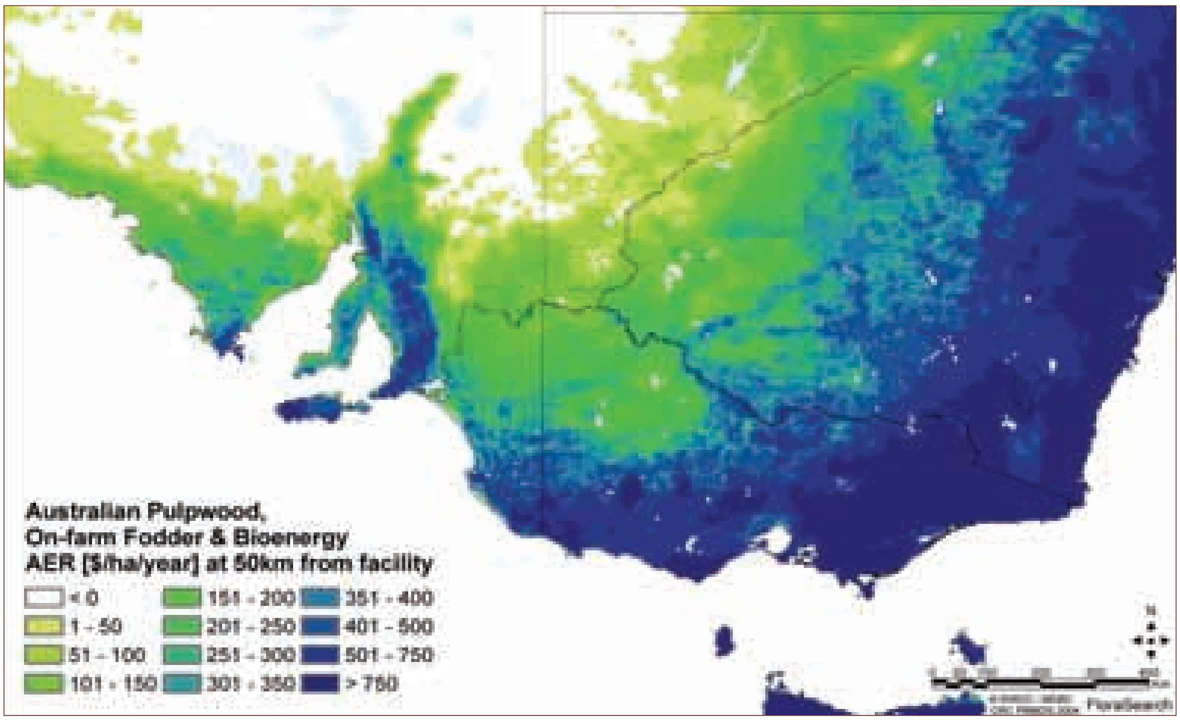


Figure 54. Estimated primary producer returns from Eucalyptus Oil and Bioenergy scenario to existing facilities.

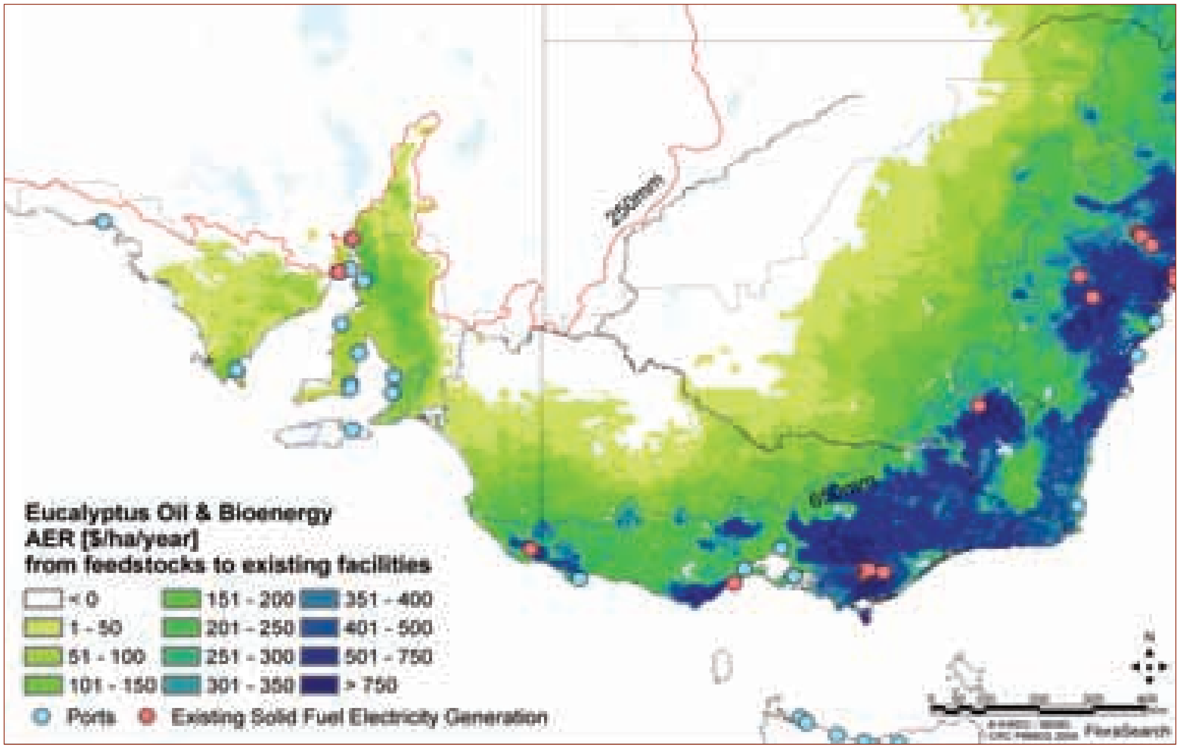
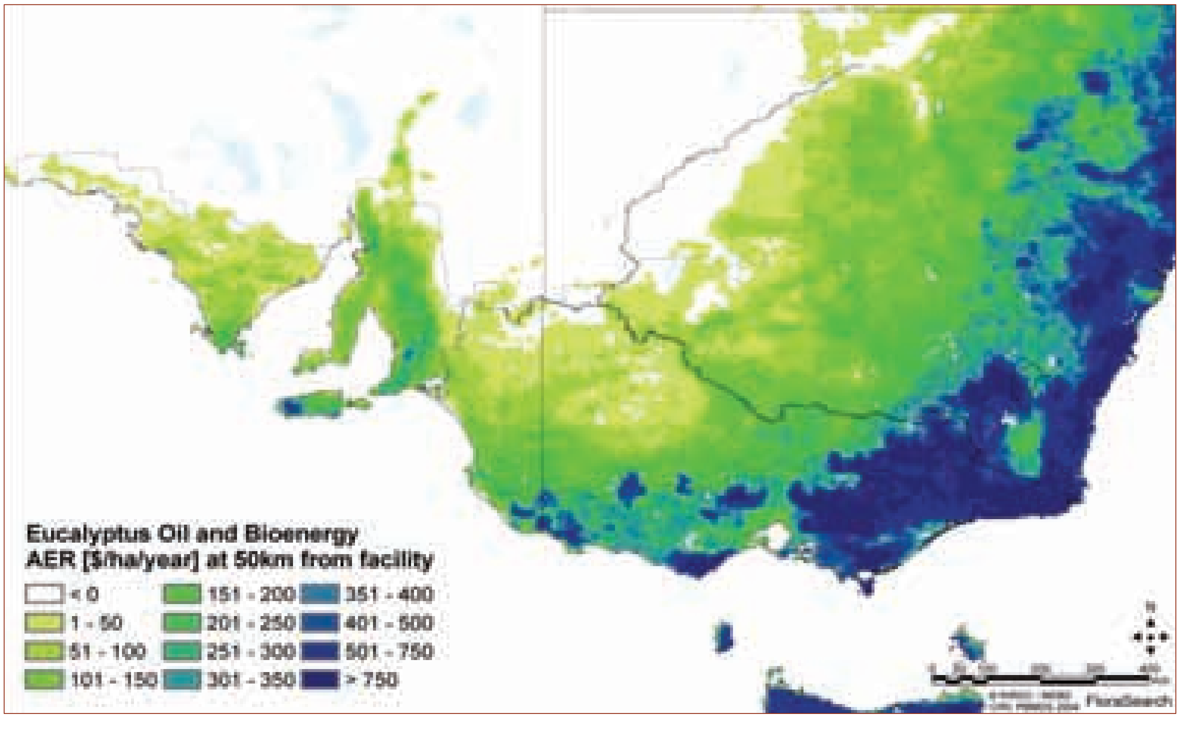


Figure 55. Estimated primary producer returns from Eucalyptus Oil and Bioenergy scenario for farms located within 50 kilometres of potential processing facility.



7.6 Potential Location of New Infrastructure

The potential location of new industry infrastructure is driven by many factors. Generally, these include the availability of commercially viable biomass feedstock from the farming systems in the surrounding area, the availability of other resources (e.g. other raw materials, energy, allied infrastructure, workforce), and proximity to markets. The following sections outline some of the key factors that influence the spatial location of potential new industry infrastructure.

7.6.1 Opportunities and constraints

7.6.1.1 All industries

All biomass industry facilities require differing levels of access to feedstocks, energy, allied infrastructure, workforce and support services. The previous section (Regional Industry Evaluations and Potential) highlights areas which can provide commercially viable feedstocks for a range of biomass industries. Figure 56 provides a map of areas within 25 km of population centres with greater than 200 persons, and provides an indicative map of access to workforces and support services, energy supplies and other infrastructure (or the potential to develop existing resources). Figure 57 illustrates the location of bulk handling ports for the export of products and the road freight transportation distances. Distances to major local markets in Sydney, Melbourne and Adelaide are reflected in mapped distance to their corresponding ports. Energy supplies and access to freshwater issues are discussed further in following sections. More detailed analysis of accurately quantified levels of access to resources is required before any new facility development. This section is aimed at identifying areas within the region which have potential for further investigation.

7.6.1.2 Bioenergy

Potential bioenergy generation sites are best located in areas where there is a high demand for electricity supply, a lack of local generation supplies, and high electrical energy losses due to greater distances from existing major power generation facilities. To determine potential sites we have calculated the ratio between population density and electricity generation density multiplied by the distance from existing 20 MW+ generation facilities (see Figure 58). Population densities within 50 km were derived from point source population data from the Australian Bureau of Statistics (2002). Electricity generation densities (in MW) within 50 km were derived from all electricity generation site data from Geoscience Australia (2003a and 2003b). Electricity distribution network data (location and capacity) is necessary to accurately determine electrical energy losses with distance. Although this data is available from most NSW and Victorian utility companies, it is not available from the SA utility. Therefore to approximate energy losses with distance we simply calculated linear distances from major generation (20 MW+) facilities. We have highlighted areas with greater potential for utilising bioenergy but this does not exclude the option of providing bioenergy to the transmission grid for utilisation in other areas.

7.6.1.3 Pulp mills

Water quantity and quality are critical issues for the paper and pulp industry. After capital investment and feedstock availability, water supply is the next major limitation to the establishment of a pulp mill. Fresh water availability in the region is dependent on dams capturing local runoff in high rainfall locations, proximity to perennial river systems, or high yielding underground aquifers. To indicate areas with potential access to freshwater supplies we have integrated maps of higher annual rainfall (>550 mm), areas within 20 km of reliable perennial rivers and high yielding (>50 L/s) shallowest aquifers (Figure 59).

Figure 56. Distance from populations with greater than 200 persons.

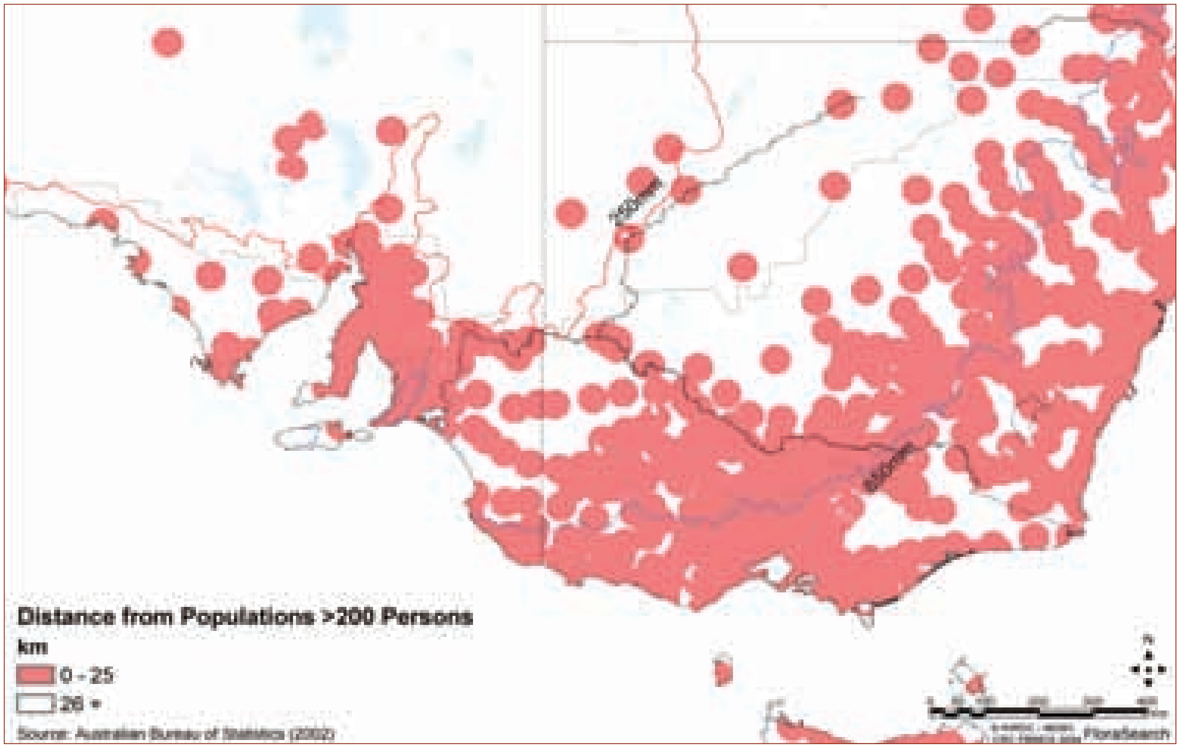
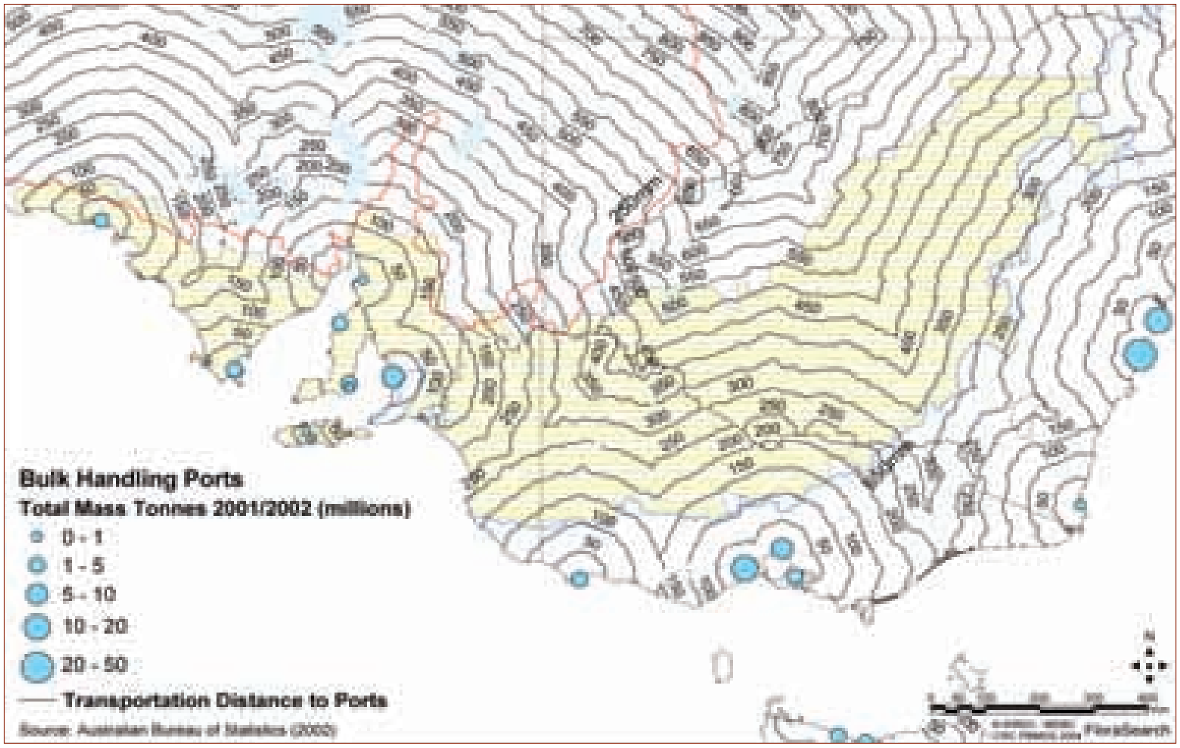


Figure 57. Location and road freight distances from bulk handling ports.



7.6.1.4 Other fibre products, particleboard, extractives and fodder processing

These product classes have fewer limitations to facility development than pulp mills. Although other fibre products and particleboards do have significant energy requirements they are much less than pulp mills. Products like oils, which are typically a fraction of the raw material, can be extracted with few non-biomass resources in mobile processing plants in the field or as part of integrated processing facilities in static locations. Fodder processing facilities typically have few non-biomass resource limitations.

7.6.2 Environmental benefits

Replacing annual cropping and pasture systems with perennial-based systems can provide numerous environmental benefits, including salinity reduction, soil conservation and biodiversity. Our work within the CRC for Plant-based Management of Dryland Salinity is focussed on the benefits of perennial crops on salinity. Other benefits are not discussed in this report apart from their potential to provide financial benefits to an enterprise (e.g. incentives, taxes, carbon credits, etc.).

Much research has been conducted on the issue of dryland salinity, groundwater recharge and saline discharge into rivers. Major work on dryland salinity risk and forecasting was conducted as part of the National Land and Water Resources Audit (2001). Groundwater recharge research conducted by Peter Cook (CSIRO Land and Water) has been incorporated to simulations of groundwater discharges into the River Murray by SA Department of Environment and Heritage (Miles, *et al*. 2001). Matt Miles (SA DEH) has kindly provided preliminary forecasts of river discharge from contributing recharge areas. These forecasts have been combined with National Land and Water Resources Audit dryland salinity risk 2050 data to provide an indicative map of areas that would provide salinity reduction benefits if planted with perennial vegetation (Figure 60).

Figure 58. Electricity demand versus supply distance from existing 20MW generating facilities.

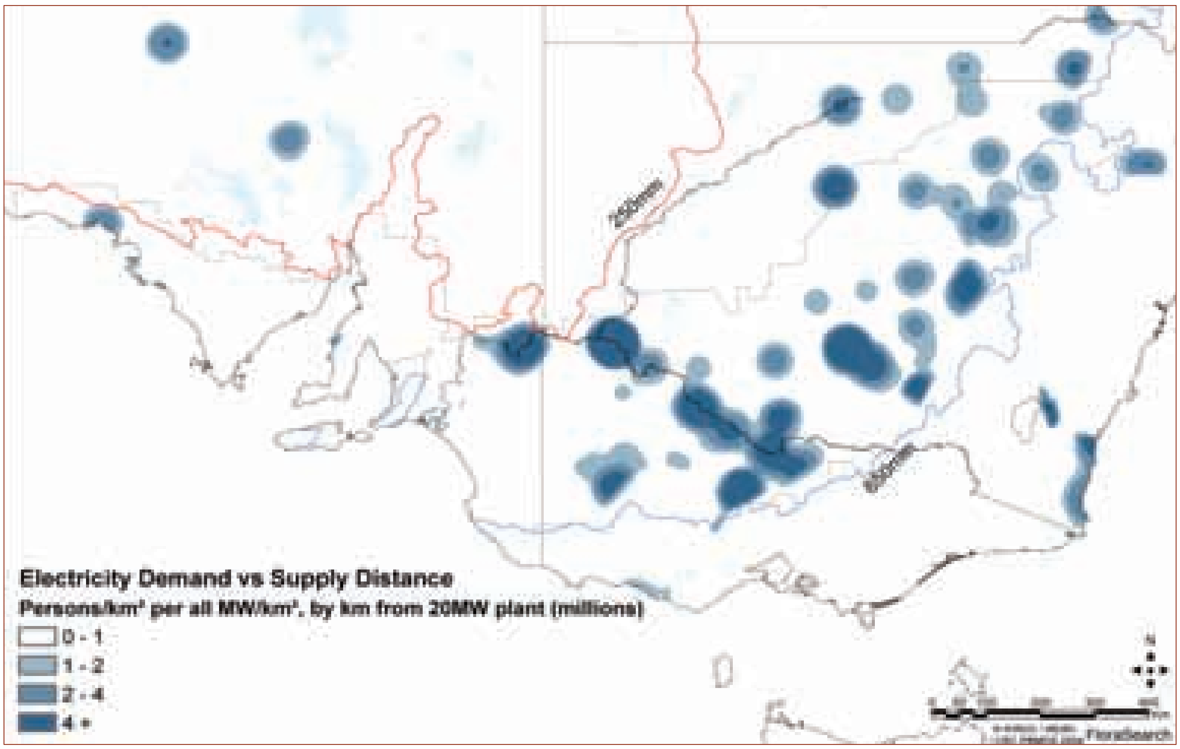


Figure 59. Areas with potential access to freshwater supplies.

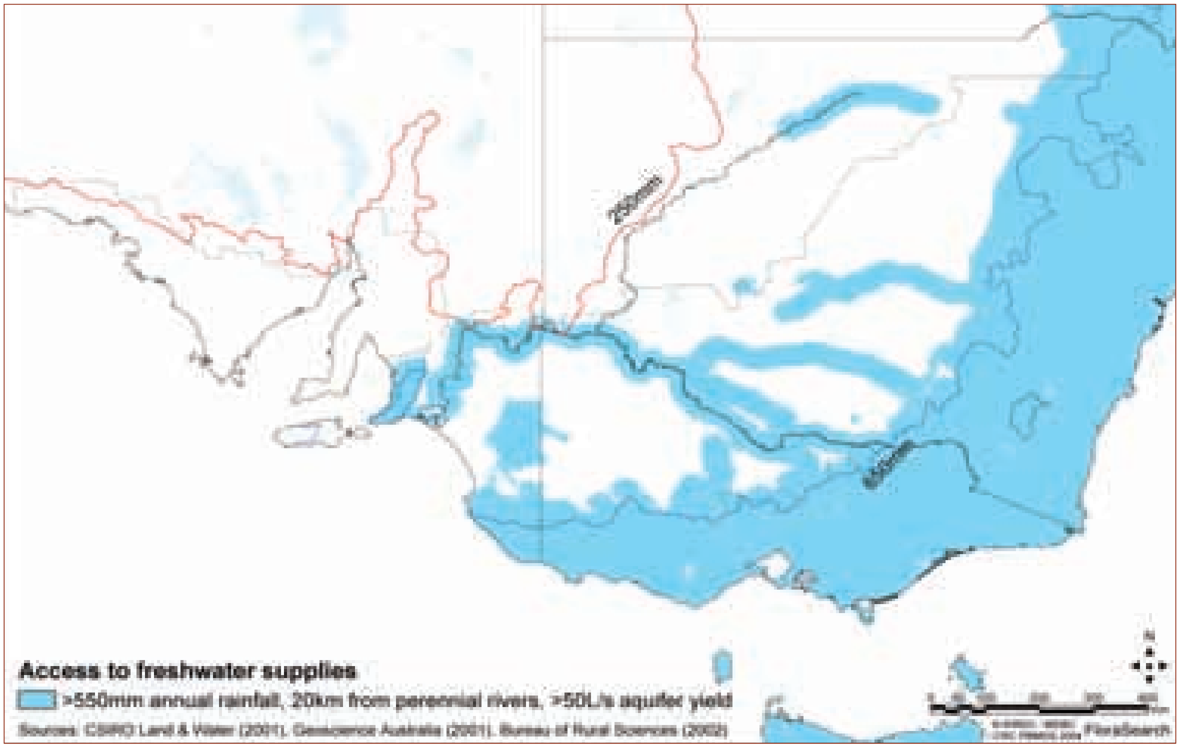
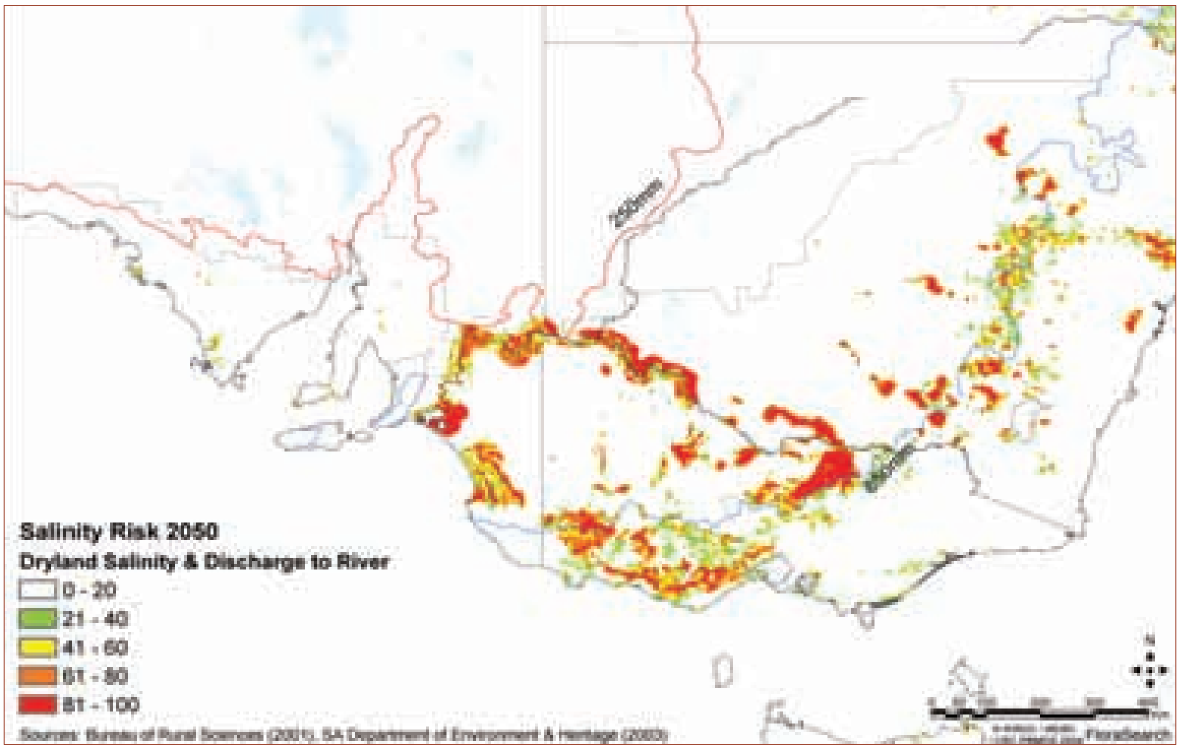


Figure 60. Salinity risk in 2050 from dryland salinity and discharges to river from saline groundwater flows.



8. Conclusions and future directions

8.1 Introduction

This chapter aims to link the outcomes of proceeding chapters that consider product selection, species selection and evaluation, agroforestry systems and the RIPA. In many respects this work is at a preliminary stage and the final section of this chapter outlines a direction for future work and lists species that require ongoing evaluation. However, the project has achieved its goals of:

- Selecting priority products to provide the focus of ongoing work
- Identifying a group of species having attributes suitable for feedstock standards of large-scale industries (pulp and paper, reconstituted fibreboard and fodder) and that can be potentially highly productive within the FloraSearch region using short-cycle crop systems (phase or coppice)
- Undertaking the regional analysis of current and potential industry based on these products and species.

The RIPA describes the potential returns of principal product areas (pulp and paper, wood composite, bioenergy, essential oil and fodder) both alone and as co-products. The potential returns from the options can be ranked to allow selection of the most likely to be able to compete with existing land use and be adopted by landowners. The results of this analysis are based on species suited to the product area. These species have widely ranging estimated productivities that in turn impact on the likely returns of production. This work also mapped the infrastructure locations of industry currently utilising biomass (wood processing, fodder and bioenergy) and likely future locations of most prospective industries, and describes the extent of the region that can economically supply feedstock to these sites. This process helps to define productive regions and allows matching to the species based on attributes and distributions defined by bioclimatic modelling.

8.2 Selection of "Best Bet" Species

The consideration of species assumes a hierarchal process as follows:

- Feedstock for pulp and paper may provide highest returns through export or local pulp and paper production and has the greatest potential for driving large-scale revegetation. The attributes of species grown to supply feedstock for pulp are closely defined and a relatively small group of species will be suitable.
- Feedstock for composite wood products can be met by species suitable for pulp but not vice versa.

- Therefore, in regions where feedstock production for pulp is identified in RIPA as being possible species selection will be targeted primarily to this product and selection based on these parameters.
- Composite wood industries often occur adjacent to pulp industries but have less stringent feedstock and industry siting requirements (low water requirements and smaller feedstock amounts) and so may be more flexible in placement but most likely within areas suitable for pulp.
- Bioenergy may be sited over the study region within and outside the wood processing industry. Feedstock needs are not stringent and more defined by meeting economic targets through co-products such as oil/fodder in areas outside of wood processing regions or will be an ancillary product within the wood regions.
- Fodder may be an ancillary product but most likely species are to be developed as part of in situ grazing systems that show high potential returns in the RIPA.

A summary of most likely species selected and grouped onto product areas are listed in Table 23. The species identified as being suited for pulp and paper, and wood composites in Chapter 6 are further sorted on the following criteria: pulp yield >45 %; high productivity >6 m³/ha/year at 500 mm mean annual rainfall; and density < 700 kg/m³.

Table 23. Summary of the most prospective species evaluated grouped into target product areas and providing key evaluation data.

Taxa	Species No.	Stemwood production [m³/ha/year@500mm]	Basic density [kg/m³]	Wood chip production [bdt/ha/year@500mm]	Pulp yield [%dm@ Kappa 18]	Water Solubles [%dm]	pH	Oil Yield [%dm]	Crude Protein [%dm]	Digestibility [%dm]	Metabolisable Energy [MJ/kg dm]	Palatability [High Med Low Not]
Pulp, Fibre/Particleboards												
Eucalyptus viminalis ssp. *cygnetensis*	1	17.5	532	6.0	44.3	11.2	5.0	1.36				
Eucalyptus globulus ssp. *bicostata*	2	22.4	656	9.6	46.7	8.0	4.6	1.15				
Eucalyptus ovata	3	18.7	504	6.1	49.5	8.2	4.5	0.95				
Eucalyptus bridgesiana	4	13.8	539	5.8	46.2	8.8	4.4	0.58				
Eucalyptus porosa	5	6.4	641	3.0	49.9	7.7	5.1	2.10				
Codonocarpus cotinifolius	6	9.7	397	3.3	46.5							
Eucalyptus goniocalyx	7	9.5	660	4.9	46.4							
Eucalyptus botryoides	8	8.4	599	3.9	47.9							
See Table 12 for additional species												
Fibre/Particleboards, Pulp, Fodder												
Acacia retinodes	9	22.5	639	11.3	49.1	8.3	5.2		15.6	51.3	7.2	
Acacia salicina	10	14.1	648	7.1	45.3				14.3	62.3	8.9	L

Table 23. Continued

Taxa	Species No.	Stemwood production [m^3/ha/year@500mm]	Basic density [kg/m^3]	Wood chip production [bdt/ha/year@500mm]	Pulp yield [%dm@ Kappa 18]	Water Solubles [%dm]	pH	Oil Yield [%dm]	Crude Protein [%dm]	Digestibility [%dm]	Metabolisable Energy [MJ/kg dm]	Palatability [High Med Low Not]
Bioenergy												
Eucalyptus cladocalyx	11	22.0	753	12.1	49.6	8.4	4.3	0.05				
Acacia retinodes	12	22.5	639	11.4	49.1	8.3	5.2		15.6	51.3	7.2	
Eucalyptus leucoxylon	13	19.3	773	9.9	43.0	9.5	5.5	1.65				
Eucalyptus chloroclada	14	20.3	621	9.8	39.9	14.0	4.0					
Eucalyptus globulus ssp. *bicostata*	15	22.4	656	9.6	46.7	8.0	4.6	1.15				
Eucalyptus viminalis ssp. *cygnetensis*	16	17.5	532	6.0	44.3	11.2	5.0	1.36				
Eucalyptus camaldulensis	17	19.2	502	7.5	38.3	16.0	5.4	1.50				
See Table 14 for additional species												
Oil/Bioenergy												
Eucalyptus porosa	18	6.4	641	3.0	49.9	7.7	5.1	2.10				
Eucalyptus incrassata	19	5.0	768	3.1	48.6	4.6	5.9	2.80				
Eucalyptus aromaphloia ssp. *sabulosa*	20	25.5	540	7.8	44.5			2.95				
Eucalyptus dives	21	7.4	603	3.5	39.4			3.81				
Eucalyptus polybractea	22	2.5	770	1.5	54.0	7.4	4.4	2.35				
See Table 15 for additional species												
Fodder Only												
Atriplex nummularia	23	1.5	450	0.5					20.4	75.6	11.1	M
Eremophila longifolia	24	2.3	672	1.2	<38	8.8	5.2		13.2	75.4	11.0	H
Chenopodium nitrariaceum	25								20.8	78.6	11.5	M
Indigofera australis	26								20.9	70.2	10.2	H
Atriplex vesicaria	27	0.4							20.1	69.4	10.1	H
Maireana pyramidata	28								25.8	68.5	9.9	M
Rhagodia spinescens	29								20.8	67	9.7	M
See Table 16 additional species												

Table 24. List of species with high productive potential and basic density <700 kg/m³ that are worthy of testing and evaluation in ongoing FloraSearch work.

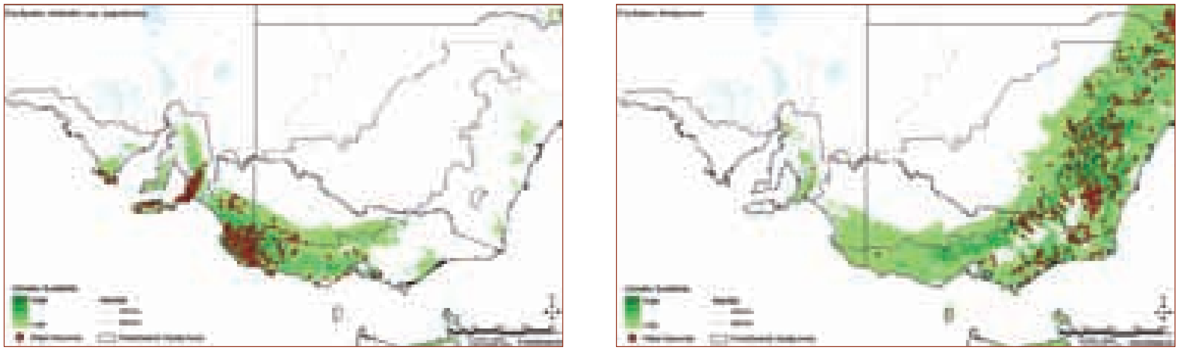
Taxa	Basic density [kg/m³]	Stemwood production [m³/ha/year@500mm]	Taxa	Basic density [kg/m³]	Stemwood production [m³/ha/year@500mm]
Eucalyptus banksii	660	32.7	*Eucalyptus dwyeri*	621	9.1
Eucalyptus mannifera	615	19.5	*Eucalyptus conica*	679	8.8
Eucalyptus alaticaulis	660	15.4	*Eucalyptus nortonii*	660	8.7
Eucalyptus megacornuta	660	15.4	*Eucalyptus macrorhyncha*	668	8.6
Eucalyptus argyphea	660	15.1	*Eucalyptus dives*	603	7.4
Acacia salicina	648	14.1	*Eucalyptus blakelyi*	543	7.0
Eucalyptus rubida	529	13.5	*Eucalyptus diversifolia*	674	6.8
Eucalyptus cosmophylla	549	12.3	*Eucalyptus utilis*	554	6.4
Eucalyptus petiolaris	664	12.3	*Melaleuca halmaturorum*	690	6.1
Eucalyptus sporadica	554	11.4	*Viminaria juncea*	478	na
Eucalyptus baxteri	490	10.8	*na =not available*		

A group of species selected in Chapter 6 as being suitable for composite wood products with density < 700 kg/m³ and estimated stemwood productivity > 6 m³/ha/year at 500 mm mean annual rainfall still remain to be sampled and evaluated for wood processing attributes. Those with known poor pulp are deleted (see Table 24). This table shows a significant group of species with high estimated productivity, suitable density for wood processed products, but which have not been pulp tested at this stage. Testing for fibreboard manufacture remains to be undertaken for all species. There is an emphasis on eucalypts because of the availability of growth data from the Currency Creek Arboretum site and published density information that has meant they have been retained in the species evaluation lists. Other species in the original selection lists but for which no information is currently available may be added in the future.

For regions where wood processing is not identified the next option is bioenergy/oil combination. Bioenergy has well understood technical requirements and a policy incentive through the MRET. Essential oil on an industrial scale has been identified by WA research but has price limits that require the evolution of processing technology to allow cheap field processing to reduce costs. The RIPA shows this to be a highly prospective option if cineole was to realise its market potential and on-site production could be developed. This is not on the current horizon and there is disagreement from experienced people in the field (Eric Lassak, pers comm.) whether an industrial market can be realised. However uncertainty applies to all the FloraSearch options and this should not be considered as a constraint at this time.

In situ grazing of perennial fodder systems is identified in the RIPA as having the potential to provide high rates of return. Additional value can be attributed to

Figure 61. Occurrence and predicted potential distribution of *Eucalyptus viminalis* ssp. *cygnetensis* (left) and *Eucalyptus bridgesiana* (right).



these systems, as green feed out-of-season (summer/autumn) is more valuable than the same feed in spring, due to higher market prices for the commodity being produced out-of-season. The value of off-season feed is illustrated by Warner *et al*. (1998) who state that "Grazing mature crops of lupins and field peas to produce prime lambs out of season generated greater gross margins per hectare than would have been achieved had these crops been harvested for sale of grain." Table 18 lists several species with high tested feed values equivalent to those of lucerne hay. Matching these species to suitable climate and soil conditions within the FloraSearch region is a crucial next step. Natural distributions of the species provide information on climate and soil affiliations which have been utilised in bioclimatic modelling giving strong indications as to where these species are most likely to perform. This data is provided in Hobbs and Bennell (2008) for all species selected in Chapter 6. To report on each "best bet" species would be too cumbersome but considering the actual and modelled potential distributions for *Eucalyptus viminalis* ssp. *cygnetensis* and *Eucalyptus bridgesiana* (see Figure 61) provides an illustration of the usefulness of this data. The distinct ranges for each species are clear. Both are suited to higher rainfall parts of the FloraSearch region with *E bridgesiana* suited to the western ranges of NSW and Victoria whilst *E. viminalis* ssp. *cygnetensis* is suited to the south part.

Ultimately, field trials of a priority species derived from the primary species selection process, tested over a range of rainfall zones, landscapes, plantation designs and management practices, will be necessary to determine optimal species and production system designs suitable for development into commercial perennial crops in the wheat-sheep zone of southeastern Australia. This work is currently being prepared as part of the CRC for Plant-based Management of Dryland Salinity (CRC PBMDS) project "Field evaluation of woody germplasm" which will include many of the selected FloraSearch species.

8.3 Conclusions

Opportunities lie in all phases of the product lifecycles whether embryonic, growth, mature or declining. Industries based on potential products such as transport fuels, some forms of biomass electricity, chemical production, and industrialised essential oil production are largely embryonic. Composite wood products and some bioenergy methods (e.g. co-firing existing coal-based power stations) are in growth sectors and supplied by current industries, some that will also be in competition with supplies from FloraSearch sources. Pulp and paper and woodchips production appear to be mature industries dominated by a relatively small number of key companies employing relatively stable technologies. A few dominant players control most of the pulpwood production and associated infrastructure in highly productive forestry regions. Significant barriers can be expected for new players into the pulp and paper markets, but potential exists for providing feedstocks into existing infrastructure. Although these product areas are predicted to grow steadily, new supply sources will have to demonstrate that they can meet quality and price standards.

Product groups and industries often have a number of common criteria relevant to their development. We have identified some of these criteria, such as feedstock requirements, transport infrastructure and minimum economical plant size, and gathered relevant datasets for spatial analysis. Industry facilities for separate product types already exist in some industry ventures identified above including pulp and paper, composite wood products and bioenergy including co-located plants such as energy generation adjacent to sawmills or pulp mills that utilise waste stream for bioenergy benefits. Integrated tree processing plants, such as the one under construction for oil mallees in WA will produce multiple products to increase profitability (e.g. oils, bioenergy and charcoal).

The viability of each of these industries in the FloraSearch study area depends on the degree of matching between existing resources and industries, commercially viable primary production and access to markets. The RIPA provides a wealth of information on many key components that influence the potential for commercial agroforestry development in the region, including:

- Industry infrastructure and non-biomass resources
- Existing industries and their facilities
- Primary production of total biomass (and fractions) using a representative species
- Generalised cost-benefit analysis for primary producers
- Evaluations of returns to primary producers to supply to existing industries
- Potential location for the investment in new facilities.

The RIPA is a powerful analytical tool that merges spatial information on species productivity, short-cycle woody crop yields, environmental conditions and industries to provide an evaluation of the spatial and economic potential of new woody crops and industries in the FloraSearch region. As more information becomes available, from species trials, more detailed economic analyses and further industrial research, the accuracy and reliability of these spatial analyses will increase substantially, and thereby provide more confident predictions of product yields, economic returns and locations for industrial development in the FloraSearch region.

An important aspect of production economics is harvesting technology. Clark and Rawlins (1999) suggest three factors need to be considered when assessing quality of export wood chip (i.e. suitable for pulp and paper): 1/ level of contaminants (bark, rot, soil and charcoal); 2/ chip size uniformity; and 3/ pulping quality. Pulping quality includes pulp yield and paper making properties and is a reflection of species properties and growing conditions. The first two factors point to the need for substantial technology development to suit harvest of short rotation woody crops and coppice crops. The WA Search project has focused on wood products and there is an underlying assumption of development of continuous flow harvesting that produces chip-in-field off the stump and is capable of producing the quality needed for processing. If successful, these developments will deliver significant cost benefits for many products over traditional forest harvest methods using single stem handling techniques.

The plants' attributes defined by these cropping systems, the likely product outcomes and the environmental conditions (rainfall and soil type) where these crops will be produced combine to provide a matrix of parameters into which the species selected and tested by FloraSearch must fit (see Table 25). For each option a set of selection criteria can be developed integrating growing conditions, production system, species and product.

Table 25. Example product/crop system matrix for prospective products and the three described agroforestry crop systems with suitable species shown.

Production system	Product / Species (Species numbers refer to Table 23)				
	Pulp / Paper	Fibreboards	Bioenergy	Fodder	Oil
Phase crop - Short term between 4 - 12 years.	1, 2, 3, 4, 5, 6, 7, 8	1, 2, 3, 4, 5, 6, 7, 8, 9 11	11, 12, 13, 14, 15, 16, 17		18, 19, 20, 21, 22
Continuous - Coppice with short harvest cycle	1, 2, 3, 4, 5, 6, 8	1, 2, 3, 4, 5, 6, 8, 9 11	11, 12, 13, 14, 15, 16, 17	23, 24, 25, 26, 27, 28, 29	18, 19, 20, 21, 22
Continuous - Long cycle	Not considered	Not considered	Not considered	Not considered	Not considered

8.4 Future Directions

Of the initial group of 392 species selected in Chapter 5 a significant number remain to be fully evaluated. Many of these species, particularly the Eucalypts and Acacias, have some basic growth information that indicates they are productive species and worthy of FloraSearch testing and evaluation. Hobbs *et al.* (2008) does provide significant new data on product testing results for previously untested species and some additional data on plant growth rates. Readily available published information on wood densities, essential oils and fodder values for a few FloraSearch species has been incorporated into our databases and reported in Table 10. This published data is very limited, highlighting the need to undertake realistic and more detailed evaluations of many more species native to the FloraSearch region.

Wood product evaluation has not been fully completed for some species. Hobbs *et al.* (2008) provides additional paper product testing on a small group of species having good initial pulp yields. The growth potential and expected adaptability to cultivation for many species is still largely unknown. Several species selected from the current evaluation round also need to be tested for their composite wood products (fibreboards) and combustion (bioenergy) properties. These evaluations will be undertaken as a priority in future research.

The potential of species from the FloraSearch region containing interesting secondary plant compounds has been raised by researchers from the CRC Bioproducts and University of Adelaide. Nuclear magnetic resonance testing of plant samples has been suggested as a means of identifying the relative amount and chemical grouping of compounds that may be present. This work would complement oil testing and ultimately allow the identification of compounds that may play a positive role in the future commercial development of a species. Other potential screening methods for secondary compounds will be investigated and evaluated in the near future. Screenings for secondary compounds is planned for most of the sampled FloraSearch species but particularly for those selected for further development.

Technology development is required for harvest of short rotation woody crops and coppice crops. The focus on wood products for WA Search and FloraSearch has an underlying assumption of the development of continuous flow harvesting that produces chip in the field, directly off the stump, and is capable of meeting the quality requirements of industry.

Field trials of priority species over a range of rainfall zones and soil types are necessary to determine optimal species and to provide more accurate data on productivity. This work has commenced as part of the CRC PBMDS's "Field Trials of Woody Germplasm" project and includes many of the selected FloraSearch species but will require future support for maintenance, measurements and analysis. This will include further productivity evaluations of target species including assessments of biomass partitioning into wood, leaf and bark fractions to more accurately determine yields of biomass components for each industry type. All species reviewed, both indigenous and non-indigenous, will need to be assessed for their weed risk potential in later stages of the project.

It is expected that species identified here will be the subject of much genetic improvement and crop development research in the future, and will include farming system design studies through current and future CRC PBMDS/Future Farm Industries CRC and JVAP sponsored work on the development of woody perennial crops.

Continued development of the RIPA work will be undertaken, and will incorporate more accurate assessments of productivity, economics, farming systems and industries.

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Appendices

Appendix A. Potential species identified by the Acacia Search project

(Extracted from Maslin and MacDonald 2003)

Species ranked 1 and 2 are considered the most prospective. They can be expected to display fast or moderately fast growth rates and produce high or moderately high volumes of wood biomass. They have potential to be cultivated over a reasonably wide geographic area, although in a number of cases this area is restricted to the temperate outer peripheral regions of the target zone.

Species ranked 3 and 4 are regarded as less prospective. While these species possess acceptable growth characteristics, they display certain attributes that tend to reduce their potential for crop development (most commonly these attributes are poor growth form, reduced wood biomass production, or relatively slow growth rates). Nevertheless, they should not be discounted at this early stage of the testing process.

Species ranking and Australian States of occurrence for the 35 prospective species are as follows:

Category 1	
A. saligna	(WA)
Category 1-2	
A. leucoclada ssp. *leucoclada*	(NSW)
A. linearifolia	(NSW)
A. retinodes 'typical' variant	(SA)
A. salicina	(NSW, NT, Qld, SA, Vic, ?WA)
Category 2	
A. decurrens	(ACT, NSW)
A. lasiocalyx	(WA)
A. mearnsii	(ACT, NSW, SA, Tas, Vic)
A. microbotrya	(WA)
A. pycnantha	(ACT, NSW, SA Vic)
A. retinodes 'swamp' variant	(SA, Vic)
Category 2-3	
A. dealbata ssp. *dealbata*	(NSW, Tas, Vic)
A. murrayana	(NSW, NT, Qld, SA, WA)
A. neriifolia	(NSW, Qld)
A. rivalis	(SA, ?NSW)
A. subfalcata	(WA)
Category 3	
A. acuminata	(WA)
A. baileyana	(NSW)
A. doratoxylon	(ACT, NSW, Vic)
A. filicifolia	(NSW, Qld)
A. hakeoides	(NSW, Qld, SA, Vic, WA)
A. implexa	(NSW, Qld, Tas, Vic)
A. melanoxylon	(ACT, NSW, Qld, SA, Tas, Vic)
A. parramattensis	(ACT, NSW)
A. retinodes 'Normanville' variant	(SA)
A. retinodes var. *uncifolia*	(SA, Tas)
A. rostellifera	(WA)
A. stenophylla	(NSW, NT, Qld, SA, Vic, WA)
A. victoriae	(NSW, NT, Qld, SA, Vic, WA)
A. wattsiana	(SA)
Category 3-4	
A. argyrophylla	(SA, ?Vic)
Category 4	
A. cyclops	(WA, SA)
A. dodonaeifolia	(SA)
A. euthycarpa	(SA, Vic)
A. affin. redolens	(WA)

Appendix B. FloraSearch workshop locations and participants

Adelaide (SA Region)

Primary Industry & Resources SA, Plant Research Centre, Urrbrae (24/10/02)

Andrew Allanson	Trees for Life, Pasadena
Mike Bennell	SA Water, Land & Biodiversity Conservation, Pasadena
Bob Boardman	Forestry SA (retired)
Neville Bonney	Greening Australia, SA, Pasadena
David Boomsma	Southern Tree Breeding Association, Mt. Gambier
Anne Brown	Greening Australia, SA, Jamestown
Ivan Clarke	Primary Industry & Resources SA, Mt. Barker
Jason Cooper	State Flora, SA Water, Land & Biodiversity Conservation, Murray Bridge
Tim Croft	SA Environment & Heritage, Adelaide
Mark Ellis	SA Water, Land & Biodiversity Conservation, Pasadena
Trevor Hobbs	SA Water, Land & Biodiversity Conservation, Pasadena
Steve Hughes	SA Research & Development Institute, Urrbrae
Bruce Munday	Facilitator, Mt. Torrens
Dean Nicolle	Flinders University, Bedford Park
Ian Nuberg	University of Adelaide, Urrbrae
Helen Lamont	Primary Industry & Resources SA, Cleve
Martin O'Leary	Adelaide Botanic Gardens, SA Environment & Heritage, Adelaide
Judy Pfeiffer	Murray Mallee Local Action Planning, Murray Bridge
Martin Ryder	CSIRO Land & Water, Urrbrae
Bruce Smith	Trees for Life, Pasadena
Des Stackpole	Vic. Natural Resources & Environment, Heidelberg
Mick Underdown	Forestry SA, Mt. Gambier

Bendigo (Vic Region)

Victorian Natural Resources & Environment, View Street Office, Bendigo (11/11/02)

Rod Bird	Pastoral & Veterinary Research Institute, Hamilton
Charles Hajek	Vic. Natural Resources & Environment, Horsham
Ian Higgins	Vic. Natural Resources & Environment, Bendigo

Trevor Hobbs	Facilitator, SA Water, Land & Biodiversity Conservation, Pasadena
David Millsom	Greening Australia, Victoria
Shaun Quayle	Vic. Natural Resources & Environment
Jim Robinson	Greening Australia, Victoria
Des Stackpole	Vic. Natural Resources & Environment, Heidelberg

Canberra (NSW region)

CSIRO Forestry & Forest Products, Black Mountain Laboratories, Black Mountain (17/12/02)

Mike Bennell	SA Water, Land & Biodiversity Conservation, Pasadena
Rod Clarke	NSW Forestry, Forbes
John Doran	CSIRO Forestry & Forest Products, Canberra
Brendan George	NSW Agriculture, Tamworth
Brett Honeysett	NSW Agriculture, Condobolin
Surrey Jacobs	Royal Botanic Gardens, Sydney
Nico Marcar	CSIRO Forestry & Forest Products, Canberra
Maurice McDonald	CSIRO Forestry & Forest Products, Canberra
Neil McMillan	NSW Land & Water Conservation, Condobolin
Peter Milthorpe	NSW Agriculture, Condobolin
Bruce Munday	Facilitator, Mt. Torrens SA
Jim Noble	CSIRO Sustainable Ecosystems, Canberra
Peter Ollerenshaw	Bywong Nursery, Canberra

Appendix C. Species nominated for further investigation during regional FloraSearch workshops

Species	Workshop Region
Acacia aneura	SA
Acacia argyrophylla	SA
Acacia baileyana	Vic
Acacia confluens	SA
Acacia cyclops	Vic
Acacia decurrens	NSW
Acacia iteaphylla	SA
Acacia ligulata	SA
Acacia mearnsii	Vic, NSW
Acacia murrayana	SA
Acacia oswaldii	Vic
Acacia pendula	Vic
Acacia pycnantha	SA, Vic
Acacia retinodes var. *retinodes (hill form)*	SA, Vic
Acacia retinodes var. *uncifolia*	SA
Acacia rivalis	SA
Acacia salicina	SA, Vic
Acacia stenophylla	Vic
Acacia victoriae ssp. *victoriae*	SA
Acrotriche depressa	SA
Alectryon oleifolius	SA
Allocasuarina luehmannii	SA
Allocasuarina verticillata	SA, Vic
Atriplex cinerea	Vic
Atriplex nummularia	SA, Vic
Atriplex vesicaria	SA, NSW
Brachyloma daphnoides	SA
Bursaria spinosa	NSW
Callitris glaucophylla	Vic, NSW
Callitris gracilis	SA
Casuarina cristata	NSW
Casuarina cunninghamiana ssp. *cunninghamiana*	NSW
Casuarina obesa	SA
Casuarina pauper	SA
Codonocarpus cotinifolius	SA, Vic
Correa glabra	SA
Dodonaea stenozyga	SA
Dodonaea viscosa	SA, Vic, NSW
Duboisia hopwoodii	SA
Enchylaena tomentosa	NSW
Eremocitrus glauca	Vic
Eremophila alternifolia	SA
Eremophila longifolia	SA
Eremophila scoparia	SA
Eucalyptus calycogona	SA
Eucalyptus camaldulensis	Vic, NSW
Eucalyptus cladocalyx	SA, Vic
Eucalyptus cneorifolia	SA
Eucalyptus dumosa	NSW
Eucalyptus froggattii	SA, Vic, NSW
Eucalyptus gracilis	SA
Eucalyptus intertexta	NSW
Eucalyptus leptophylla	NSW
Eucalyptus leucoxylon	SA, Vic
Eucalyptus macrorhyncha ssp. *macrorhyncha*	NSW
Eucalyptus melliodora	SA
Eucalyptus odorata	SA
Eucalyptus oleosa	SA
Eucalyptus petiolaris	SA
Eucalyptus polybractea	SA, Vic, NSW
Eucalyptus populnea ssp. *bimbil*	NSW
Eucalyptus porosa	SA
Eucalyptus socialis	SA, NSW
Eucalyptus viridis	SA, Vic
Eucalyptus viridis ssp. *wimmerensis*	Vic
Flindersia maculosa	NSW
Geijera linearifolia	SA

Species	Workshop Region
Geijera parviflora	NSW
Goodia lotifolia	Vic
Goodia medicaginea	Vic
Gyrostemon ramulosus	SA
Indigofera australis	Vic
Leptospermum coriaceum	SA
Logania recurva	SA
Maireana aphylla	NSW
Maireana brevifolia	SA
Maireana pyramidata	SA
Maireana rohrlachii	SA
Maireana sedifolia	SA
Maireana suaedifolia	SA
Melaleuca bracteata	NSW
Melaleuca dissitiflora	SA
Melaleuca pauperiflora	SA
Melaleuca uncinata	SA, Vic, NSW
Myoporum insulare	SA

Species	Workshop Region
Myoporum montanum	SA
Myoporum viscosum	Vic
Nitraria billardierei	SA, Vic, NSW
Owenia acidula	NSW
Prostanthera striatiflora	SA
Pultenaea largiflorens	SA
Rhagodia parabolica	NSW
Rhagodia spinescens	SA, NSW
Santalum acuminatum	Vic, NSW
Santalum spicatum	SA, Vic
Senna artemisioides	SA, Vic
Solanum simile	Vic
Templetonia egena	SA
Templetonia retusa	SA
Thryptomene calycina	SA
Thryptomene ericaea	SA
Viminaria juncea	Vic

Appendix D. Eucalypt taxa at Currency Creek Arboretum growing to six metres or more in five years

With 421 millimetre average annual rainfall in South Australia.

Taxon	Height (m)
Corymbia citriodora (syn. *C. variegata* ssp. *citriodora*)	6.4
Corymbia variegata	6.4
Eucalyptus alaticaulis	7.0
Eucalyptus amplifolia ssp. *amplifolia*	6.8
Eucalyptus angophroides	6.0
Eucalyptus argyphea	6.9
Eucalyptus aromaphloia	6.5
Eucalyptus astringens ssp. *redacta*	6.1
Eucalyptus banksii	8.0
Eucalyptus bicostata (syn. *E. globulus* ssp. *bicostata*)	7.3
Eucalyptus botryoides	6.0
Eucalyptus camaldulensis ssp. *simulata*	6.5
Eucalyptus camaldulensis var. *camaldulensis*	6.6
Eucalyptus camaldulensis var. *obtusa*	6.8
Eucalyptus camphora ssp. *humeana*	6.0
Eucalyptus canobolensis (syn. *E. rubida* ssp. *canobolensis*)	6.3
Eucalyptus cephalocarpa	6.3
Eucalyptus chloroclada	7.0
Eucalyptus cinerea	6.2
Eucalyptus cladocalyx	7.0
Eucalyptus dalrympleana ssp. *dalrympleana*	6.8
Eucalyptus dawsonii	6.3
Eucalyptus dunnii	6.3
Eucalyptus elliptica (syn. *E. mannifera* ssp. *elliptica*)	6.0
Eucalyptus fraxinoides	7.0
Eucalyptus georgei ssp. *fulgida*	6.0

Taxon	Height (m)
Eucalyptus gomphocephala	7.0
Eucalyptus goniocalyx ssp. *"saxicola" ms*	6.3
Eucalyptus grandis	6.4
Eucalyptus grisea	7.8
Eucalyptus interstans	6.0
Eucalyptus kitsoniana	6.2
Eucalyptus leucoxylon ssp. *bellarinensis*	6.4
Eucalyptus leucoxylon ssp. *pruinosa*	6.9
Eucalyptus longifolia	6.1
Eucalyptus mannifera (syn. *E. gullickii*, *E. maculosa*)	7.3
Eucalyptus megacarpa	6.0
Eucalyptus megacornuta	7.0
Eucalyptus nicholii	6.3
Eucalyptus nortonii	6.5
Eucalyptus notabilis	6.1
Eucalyptus occidentalis	6.4
Eucalyptus ovata var. *grandiflora*	6.5
Eucalyptus ovata var. *ovata*	7.5
Eucalyptus petiolaris (syn. *E. leucoxylon* ssp. *petiolaris*)	6.0
Eucalyptus punctata	7.0
Eucalyptus quadrangulata	6.3
Eucalyptus rubida ssp. *rubida*	6.8
Eucalyptus rudis ssp. *rudis*	6.5
Eucalyptus rudis ssp. *rudis* (syn. ssp. *cratyantha*)	6.5
Eucalyptus sabulosa (syn. *E. aromaphloia* ssp. *sabulosa*)	8.5
Eucalyptus sieberi	6.0
Eucalyptus smithii	6.3
Eucalyptus tereticornis ssp. *tereticornis*	7.0
Eucalyptus utilis (syn. *E. platypus* var. *heterophylla*)	6.2
Eucalyptus viminalis ssp. *cygnetensis*	6.2
Eucalyptus volcanica	6.3

Appendix E. List of prospective species for the FloraSearch study area

With observed annual average rainfall ranges (mm) in South Australia, Victoria and New South Wales.

[w & a] denotes species overlapping with WA Search and Acacia Search projects.

Species	Rainfall	
	Min	Max
Acacia acinacea	285	1018
Acacia adunca	629	785
Acacia anceps	239	527
Acacia aneura [w]	120	490
Acacia argyrophylla [a]	257	543
Acacia ausfeldii	387	799
Acacia baileyana [a]	386	1005
Acacia beckleri	222	436
Acacia brachybotrya	166	579
Acacia brachystachya	140	402
Acacia burkittii [w]	146	466
Acacia burrowii	478	730
Acacia buxifolia ssp. *buxifolia*	389	1041
Acacia caesiella	562	1041
Acacia calamifolia	190	794
Acacia cambagei	121	442
Acacia cana	176	383
Acacia caroleae	614	693
Acacia cheelii	613	1041
Acacia conferta	459	730
Acacia cultriformis	452	882
Acacia cupularis	268	738
Acacia cyclops [w]	237	641
Acacia dealbata [a]	331	1041
Acacia deanei	319	1041
Acacia decora	353	1041
Acacia decurrens [a]	398	1018
Acacia difformis	391	629
Acacia dodonaeifolia [a]	320	859

Species	Rainfall	
	Min	Max
Acacia doratoxylon [a]	329	882
Acacia euthycarpa [a]	285	534
Acacia excelsa	274	686
Acacia farnesiana	130	730
Acacia filicifolia [a]	531	681
Acacia genistifolia	420	1034
Acacia gillii	412	564
Acacia gunnii	431	1041
Acacia hakeoides [a]	238	882
Acacia harpophylla	370	806
Acacia havilandiorum	215	612
Acacia homalophylla	263	685
Acacia implexa [a]	364	1069
Acacia iteaphylla	184	829
Acacia jennerae [w]	127	288
Acacia leiophylla	375	789
Acacia leptoclada	531	743
Acacia leucoclada ssp. *leucoclada [a]*	549	820
Acacia ligulata [a]	109	738
Acacia linearifolia [a]	629	671
Acacia loderi	210	501
Acacia longifolia	282	1005
Acacia mearnsii [a]	320	882
Acacia melanoxylon [a]	318	1069
Acacia melvillei	266	390
Acacia microcarpa	253	564
Acacia mitchellii	409	769
Acacia mollifolia	459	732
Acacia montana	257	820
Acacia muelleriana	629	632
Acacia murrayana [w]	111	478
Acacia myrtifolia	283	1031
Acacia neriifolia [a]	614	1041
Acacia notabilis	197	573
Acacia oswaldii	113	882
Acacia oxycedrus	339	805

Species	Rainfall	
	Min	Max
Acacia paradoxa	283	1041
Acacia parramattensis [a]	650	650
Acacia pendula	343	882
Acacia penninervis	532	1041
Acacia podalyriifolia	638	896
Acacia pravifolia	267	730
Acacia pravissima	423	654
Acacia pycnantha [a]	255	1031
Acacia ramulosa	111	851
Acacia retinodes var. *retinodes (hill form) [a]*	285	1031
Acacia retinodes var. *retinodes (swamp form) [a]*	429	1031
Acacia retinodes var. *uncifolia [a]*	488	766
Acacia rigens	173	818
Acacia rivalis [a]	181	525
Acacia rubida	630	1041
Acacia salicina [a]	111	882
Acacia spectabilis	506	882
Acacia spinescens	151	1005
Acacia stenophylla [a]	113	643
Acacia stricta	618	805
Acacia tetragonophylla	116	686
Acacia trineura	300	523
Acacia triquetra	285	713
Acacia verniciflua	397	1005
Acacia verticillata	429	1031
Acacia victoriae ssp. *victoriae [w,a]*	110	882
Acacia wattsiana [a]	403	640
Adriana klotzschii	270	896
Adriana tomentosa var. *hookeri*	275	431
Alectryon diversifolius	649	730
Alectryon oleifolius [w]	132	882
Alectryon subdentatus	627	1041
Allocasuarina diminuta	515	732
Allocasuarina helmsii	173	343

Species	Rainfall	
	Min	Max
Allocasuarina littoralis	562	730
Allocasuarina luehmannii	232	730
Allocasuarina muelleriana	236	1018
Allocasuarina paludosa	346	875
Allocasuarina striata	315	1005
Allocasuarina verticillata	198	1031
Alphitonia excelsa	622	1041
Alstonia constricta	323	1041
Alyxia buxifolia	178	738
Angophora costata	625	1041
Angophora floribunda	560	1069
Angophora melanoxylon	353	633
Aotus subspinescens	173	1005
Apophyllum anomalum	280	730
Atalaya hemiglauca	128	730
Atriplex cinerea	244	794
Atriplex nummularia	114	501
Atriplex paludosa	237	637
Atriplex vesicaria	110	512
Babingtonia behrii	179	613
Banksia marginata	283	1031
Bertya cunninghamii	353	495
Bertya mitchellii	243	1041
Beyeria lechenaultii	198	940
Beyeria viscosa	323	1041
Beyeria viscosa	323	1041
Boronia anemonifolia	451	619
Boronia glabra	585	882
Brachychiton populneus	311	1041
Bursaria spinosa	198	1069
Callistemon brachyandrus	256	620
Callistemon citrinus	609	699
Callistemon macropunctatus	364	644
Callistemon rugulosus	283	940
Callistemon sieberi	399	1041
Callistemon viminalis	646	780

Species	Rainfall	
	Min	Max
Callitris canescens [w]	280	556
Callitris columellaris	377	699
Callitris endlicheri	352	1041
Callitris glaucophylla [w]	164	1041
Callitris gracilis	222	774
Callitris rhomboidea	344	1005
Callitris verrucosa	146	818
Calytrix alpestris	307	618
Calytrix glaberrima	404	865
Calytrix involucrata	197	588
Calytrix longiflora	288	511
Calytrix tetragona	146	1041
Canthium latifolium	161	660
Canthium oleifolium	210	882
Capparis mitchellii	148	882
Carissa ovata	418	806
Cassine australis var. *angustifolia*	515	1041
Cassinia aculeata	400	1041
Cassinia laevis	181	988
Cassinia longifolia	493	809
Cassinia quinquefaria	506	1069
Casuarina cristata	176	806
Casuarina cunninghamiana ssp. *cunninghamiana*	426	1041
Casuarina pauper	121	522
Chenopodium auricomum	117	675
Chenopodium gaudichaudianum	153	408
Chenopodium nitrariaceum	115	562
Codonocarpus cotinifolius [w]	146	382
Correa aemula	487	875
Correa alba var. *pannosa*	422	794
Correa glabra	318	1041
Correa pulchella	282	940
Correa reflexa	252	1041
Correa schlechtendalii	284	825
Crowea exalata	454	1041

Species	Rainfall	
	Min	Max
Cullen australasicum	110	1018
Daviesia asperula	298	846
Daviesia brevifolia	241	1005
Daviesia genistifolia	215	1069
Daviesia leptophylla	241	1031
Daviesia ulicifolia	146	1041
Dillwynia hispida	229	1031
Dodonaea filifolia	232	730
Dodonaea hexandra	257	843
Dodonaea humilis	306	738
Dodonaea viscosa	121	1041
Duboisia hopwoodii [w]	146	329
Enchylaena tomentosa	110	796
Eremophila bignoniiflora	113	622
Eremophila deserti [w]	146	882
Eremophila duttonii	134	434
Eremophila glabra	140	634
Eremophila longifolia [w]	110	882
Eremophila maculata	121	622
Eremophila mitchellii	273	882
Eremophila oppositifolia [w]	145	483
Eremophila santalina	247	573
Eremophila sturtii	145	633
Eucalyptus "anceps"	237	621
Eucalyptus albens	427	1041
Eucalyptus albopurpurea	443	738
Eucalyptus angulosa	261	738
Eucalyptus arenacea	326	805
Eucalyptus aromaphloia	404	603
Eucalyptus baxteri	283	1031
Eucalyptus behriana	257	576
Eucalyptus blakelyi	413	1041
Eucalyptus botryoides	577	608
Eucalyptus brachycalyx	210	497
Eucalyptus bridgesiana	592	1041
Eucalyptus calcareana	242	380

Species	Rainfall Min	Max
Eucalyptus calycogona	256	483
Eucalyptus camaldulensis [w]	130	1005
Eucalyptus ceratocorys	229	272
Eucalyptus chloroclada	427	806
Eucalyptus cladocalyx	338	846
Eucalyptus clarksoniana	518	730
Eucalyptus cneorifolia	439	796
Eucalyptus concinna	146	307
Eucalyptus conglobata	254	728
Eucalyptus conica	459	716
Eucalyptus coolabah	110	644
Eucalyptus cosmophylla	441	1018
Eucalyptus crebra	504	1041
Eucalyptus cyanophylla	241	329
Eucalyptus dealbata	422	1041
Eucalyptus diversifolia	262	940
Eucalyptus dives	530	699
Eucalyptus dumosa	216	738
Eucalyptus dwyeri	223	882
Eucalyptus fasciculosa	283	1018
Eucalyptus fibrosa	586	733
Eucalyptus flindersii	212	436
Eucalyptus flocktoniae	261	496
Eucalyptus gillii	150	375
Eucalyptus globulus	459	1031
Eucalyptus goniocalyx	375	1041
Eucalyptus gracilis	146	593
Eucalyptus incrassata [w]	239	818
Eucalyptus intertexta	151	567
Eucalyptus lansdowneana	293	672
Eucalyptus largiflorens	139	576
Eucalyptus leptophylla	146	696
Eucalyptus leucoxylon	277	1031
Eucalyptus macrorhyncha ssp. *macrorhyncha*	423	1041
Eucalyptus maculata	577	754

Species	Rainfall Min	Max
Eucalyptus melanophloia	371	1041
Eucalyptus melliodora	376	1069
Eucalyptus microcarpa	314	940
Eucalyptus moluccana	603	603
Eucalyptus morrisii	323	478
Eucalyptus nortonii	375	801
Eucalyptus obliqua	446	1060
Eucalyptus ochrophloia	244	287
Eucalyptus odorata	241	822
Eucalyptus oleosa	146	621
Eucalyptus ovata	487	910
Eucalyptus petiolaris	347	554
Eucalyptus phenax	278	460
Eucalyptus pileata	305	398
Eucalyptus pilligaensis	479	882
Eucalyptus polyanthemos	438	801
Eucalyptus polybractea [w]	382	576
Eucalyptus populnea ssp. *bimbil*	273	882
Eucalyptus porosa	227	896
Eucalyptus radiata	489	1034
Eucalyptus remota	533	865
Eucalyptus rossii	523	882
Eucalyptus rubida	576	1041
Eucalyptus rugosa	266	751
Eucalyptus siderophloia	567	567
Eucalyptus sideroxylon	392	882
Eucalyptus socialis	146	641
Eucalyptus sparsa	191	326
Eucalyptus striaticalyx	146	307
Eucalyptus terminalis	121	490
Eucalyptus tessellaris	398	670
Eucalyptus trachyphloia	622	882
Eucalyptus tricarpa	438	655
Eucalyptus trivalvis	198	323
Eucalyptus viminalis	391	1041
Eucalyptus viridis	241	738

Species	Rainfall	
	Min	Max
Eucalyptus viridis ssp. *wimmerensis*	302	508
Eucalyptus willisii ssp. *willisii*	642	780
Eucalyptus yalatensis	198	430
Eucalyptus youngiana	146	221
Eucalyptus yumbarrana	146	487
Eutaxia diffusa	283	834
Eutaxia microphylla	173	1005
Exocarpos aphyllus	148	969
Exocarpos sparteus	146	771
Exocarpos strictus	243	1041
Exocarpos syrticola	248	728
Flindersia maculosa	210	583
Geijera parviflora	228	882
Goodia lotifolia	522	705
Goodia medicaginea	241	882
Grevillea alpina	433	734
Grevillea juncifolia	121	390
Grevillea linearifolia	343	775
Grevillea nematophylla [w]	114	357
Grevillea pterosperma [w]	146	818
Grevillea robusta	453	820
Grevillea striata	121	639
Gyrostemon ramulosus [w]	146	382
Hakea decurrens	494	734
Hakea ednieana	151	375
Hakea eyreana	121	290
Hakea francisiana [w]	146	487
Hakea leucoptera	109	628
Hakea muelleriana	273	846
Hakea nodosa	451	805
Hakea repullulans	365	940
Hakea rostrata	388	1031
Hakea sericea	423	882
Hovea purpurea	375	548
Indigofera australis	198	1041
Indigofera brevidens	176	634

Species	Rainfall	
	Min	Max
Jacksonia scoparia	521	882
Kunzea ambigua	353	882
Kunzea ericoides	344	1041
Kunzea parvifolia	458	1041
Lasiopetalum baueri	239	896
Lasiopetalum discolor	277	768
Leionema microphyllum	415	434
Leptospermum continentale	283	1031
Leptospermum coriaceum	168	1005
Leptospermum divaricatum	419	882
Leptospermum laevigatum	330	1005
Leptospermum lanigerum	424	1031
Leptospermum myrsinoides	308	1031
Leptospermum obovatum	409	597
Leptospermum polygalifolium	440	1041
Leucopogon parviflorus	302	940
Lycium australe	146	739
Maireana aphylla	111	631
Maireana georgei	114	424
Maireana microphylla	269	882
Maireana planifolia	146	477
Maireana rohrlachii	175	563
Maireana tomentosa ssp. *urceolata*	161	407
Maytenus cunninghamii	445	1041
Melaleuca acuminata [w]	248	639
Melaleuca armillaris	233	1005
Melaleuca bracteata	230	1041
Melaleuca brevifolia	283	794
Melaleuca decussata	306	1005
Melaleuca densispicata	274	641
Melaleuca dissitiflora	181	308
Melaleuca eleutherostachya	173	487
Melaleuca erubescens	423	1041
Melaleuca gibbosa	307	865
Melaleuca glomerata	125	375

Species	Rainfall	
	Min	Max
Melaleuca halmaturorum ssp. *halmaturorum [w]*	275	728
Melaleuca lanceolata [w]	181	758
Melaleuca leiocarpa	202	243
Melaleuca parvistaminea	482	631
Melaleuca pauperiflora [w]	141	487
Melaleuca squarrosa	431	805
Melaleuca styphelioides	586	699
Melaleuca uncinata [w]	141	829
Micromyrtus hexamera	357	390
Micromyrtus sessilis	393	423
Myoporum brevipes	197	602
Myoporum insulare	242	829
Myoporum montanum	125	1041
Myoporum platycarpum [w]	146	824
Myoporum viscosum	296	940
Nitraria billardierei	110	728
Owenia acidula	130	730
Ozothamnus diosmifolius	507	1041
Ozothamnus ferrugineus	578	805
Phebalium bullatum	229	818
Phebalium glandulosum	330	882
Phebalium obcordatum	353	629
Phebalium squamulosum	384	882
Phebalium stenophyllum	404	882
Philotheca angustifolia	241	896
Philotheca brevifolia	371	505
Philotheca ciliata	458	625
Philotheca difformis	231	806
Philotheca myoporoides	384	705
Philotheca salsolifolia	458	732
Philotheca verrucosa	412	734
Phyllanthus saxosus	241	686
Phyllota pleurandroides	302	882
Pimelea microcephala	130	882
Pittosporum angustifolium [w]	176	1041

Species	Rainfall	
	Min	Max
Pittosporum phylliraeoides [w]	114	827
Pomaderris paniculosa	259	940
Pomaderris racemosa	310	607
Prostanthera behriana	329	896
Prostanthera lasianthos	427	1041
Prostanthera nivea	353	1041
Prostanthera ovalifolia	420	1041
Prostanthera rotundifolia	433	1041
Prostanthera saxicola	393	882
Prostanthera spinosa	375	846
Prostanthera striatiflora	134	483
Pultenaea daphnoides	310	1031
Rhagodia candolleana	197	940
Rhagodia crassifolia	161	738
Rhagodia parabolica	127	637
Rhagodia spinescens	114	675
Rhagodia ulicina	152	686
Santalum acuminatum [w]	124	1041
Santalum lanceolatum	114	1041
Santalum murrayanum [w]	236	851
Santalum spicatum	146	477
Sarcostemma viminale ssp. *australe*	124	1041
Scaevola crassifolia	265	738
Scaevola spinescens	116	633
Senna artemisioides	111	1041
Templetonia retusa [w]	199	701
Thomasia petalocalyx	283	969
Thryptomene calycina	380	525
Ventilago viminalis	309	882
Viminaria juncea [w]	347	969
Westringia cheelii	385	438
Westringia eremicola	290	1041
Zieria cytisoides	496	1041

Appendix F. Sampling Protocols

General Guidelines

Populations of each species to be tested are selected on a number of criteria:

- Live material from healthy plants occurring on landscapes and soil types that are targeted for broad-scale revegetation (e.g. not riparian zones or already salted landscapes).
- Trees of a young age present (5-15 years) where possible.
- Prioritise plantation material where possible, but must be of known provenance (not necessarily local, but provenance must be within study zone).
- Where plantation material is unavailable preferably chose populations that are naturally regenerating either from man-made or natural disturbance processes (e.g. roadside works, cessation of grazing, fire, etc.).
- For wild populations avoid small isolated residual populations in degraded environments.
- Where possible, target populations that occur closest to the 400mm rainfall isohyet, unless provenances of known interest occur elsewhere.
- Easy access (i.e. accessible land tenure, approval easy to obtain, and population accessible by vehicle).

At this stage we are only intending on collecting material from one source, later stages are likely to include samples from several populations and natural stands vs plantations.

It will not always feasible to select populations satisfying all these criteria. If another population of a previously sampled species is subsequently observed that better conforms to the above guidelines in a significant way (i.e. younger or more vigorous), that population is added to the data set.

Team of two required – both for safety, and for efficiency. One can do coring while the other collects voucher specimens, photographs voucher, labels collecting envelopes, commences measurements and recording.

Recording site data

All relevant information related to the collection site and trees sampled must be recorded at the time of collection. A data collection form provided. The following general site record details are suggested and specific recommendations for wood, leaf, fodder, gum, bark and seed collections are outlined under specific headings:

- Site Information.
- State.
- Site number (sequentially assigned).
- Latitude and longitude: Record the midpoint for the collection. Other coordinates such as the boundary limits can be recorded under comments. Use hand held GPS unit.
- Location: Provide sufficient detail for future collectors to return to the same site. Appropriate information will vary from site to site. Geographical features such as mountains, rivers, distance along roads in relation to features such as bridges, road junctions, etc. Recording the specific tree is not normally required but may be done for specific projects where selected trees are sampled over several years.
- Map: Map name and scale corresponding to the collection area.
- Collection team.
- Date.
- Landscape: Description of the environment in which the collection is made, i.e. sandhill, plain, ridge, etc.
- Aspect: Compass direction in which the slope of the collection is facing.
- Slope: Four options depending on the level of the slope.
- Soil texture of A Horizon: Based on a soil bolus prepared in the field ranging from clay to sand.
- Vegetation structure: Based on Specht (1970).
- List dominant species in order of dominance.
- Site photograph including general plant community.

Individual plant descriptions

- Genus and species (include subspecies, variety or form information if known) and observed frequency (e.g. abundant, rare, etc.).
- Field Collection No.: Each field worker records their collection whether they are sample, botanical or seed collection according to a sequential field number prefaced with the collector's initials. After the harvest is complete the fruit or sample material must be bagged and clearly labelled both inside and out. For labelling in the field each collector has their own sequential numbering system starting with 1 and prefixed by their initial. A separate number is issued to each tree collection. In the case of a bulk collection representing a population then a single field number is used to identify the collection. The individual tree number then becomes a permanent identifier throughout the system with the number linked to the sample/voucher/seed and documentation at all times. Enter the field numbers into a field record book.
- Voucher: Indicate if a botanic specimen taken. Botanical specimens are taken to vouch for the botanical identity of the collections or as herbarium specimens. Specimens must be labelled with the collector's field number. A single representative specimen of the species from each location (provenance) is thought to be sufficient unless there is considerable variation between trees. Identification confirmed by the relevant botanical gardens of each state.
- Photo No.(s): Indicate photographs taken with record of frame(s). Suggested a shot of:
  - Tree with scale.
  - Close up of leaf.
  - Close up of trunk.
- Wood Sample.
- Tree height in metres.
- Crown width.
- Plant form (e.g. tree, shrub, mallee).
- Tree age if possible.
- No. of stems:
  - for biomass only, or combined biomass/fodder species, the number of stems at 0.5 m.
  - for fodder only species the number of stems at 0.1m height.
- Trunk/Stem Circumferences for biomass only or combined biomass/fodder species:
  - circumferences using a cloth tape of all stems (≥ 2 cm diameter) at 0.5 m height.
  - for tree form species measure circumferences of all stems (≥ 2 cm diameter) at 1.3 m height.
  - for shrubby species a count of the number of stems (≥ 2 cm diameter) at 0.5 m height.
- Core/slice data.
- Core length (without bark) or N-S diameter of slice (without bark). If the core breaks (and they often do) note the number of pieces in the sample.
- Wet weight of core/slice.
- Bark thickness (mm) – N and S sides.

Sampling

Seed collection

- When undertaking a bulk collection of seed at least 10 individuals a minimum of 2-plant height apart should be collected from.
- Seed lot number: Enter from the project database on returning to the office. This is a unique number issued to each provenance collection.
- Bulk: Number of trees represented in the bulk seed mix for the provenance collection.
- Seed crop: Ranging from heavy to light relative to typical crops for that species.
- Crop timing: Whether the majority of the seed crop is at it early, peak or late stages of maturation through to dehiscence.
- Collect from crown and not low branches (higher likelihood of outcross seed).

- Do not collect from isolated trees.
- When severing branches, no more than one quarter of the crown should be removed. Under no circumstance will the tops be removed from trees.
- Trees should be a minimum distance apart of at least two tree heights.
- Necessary authorisations and permits should be obtained.
- Private landowners are to be contacted before commencement of any collections on freehold land.

Wood

Phase 1

Native species to test were selected on the grounds of:

- Height (3.5 metres or greater mature height)
- Form or estimated biomass (species with substantial amounts of wood favoured)
- Moderate to fast growing relative to other species in same region
- Species classified as endangered or rare excluded
- Species with specialised life strategies, i.e. parasitic given a low priority.
- Select one population for each species unless populations of specific interest are identified.

Phase 1 sampling requires collection of a slice or core from a minimum of three individuals of a species at one site and a 20 kg sample of wood for initial testing. The following method may be too demanding for some species in terms of numbers of individuals sampled and amount of material collected. If therefore these conditions cannot be met for any reason, use a default to a 1 kg wood sample plus slices or cores from three individuals. If this is not possible, cores/slices only is acceptable.

- Select six individuals within each population, preferably some distance apart (say 2 to 3 x tree height). It is expected that individuals of similar form and age are available. If a higher degree of variability occurs, sample a larger number of individuals (ten). Notes on the form of each individual and the reason for these decisions must be recorded on the data sheet.
- GPS location of each "site" recorded and individual trees tagged with cattle tags with number inserted. The accuracy of the hand held GPS units with the current signal distortion negates the value of recorded coordinates for each tree.
- Some discretion by the field team is required at this point with the need to depart from the standard where the conditions dictate.
- The standard procedure is to collect a long billet from each of the individuals to compile a total 20 kg fresh weight sample for that species at that site which is needed for Level 2 CSIRO processing. The bark will need to be removed from these specimens – a process which may be easiest while the plant is green and before the plant is felled. If a small population only is available and taking 20 kg would have an impact on the survival of the plants revert to a 1 kg sample to minimise damage. This size is sufficient for the early test stages.
- The upper cut should be at a height of 150 cm and the lower cut at 50 cm (billet length 100 cm). Keep billets at maximum length possible, as it is easier for CSIRO to process. Mark the specimen number and the North orientation of the sample in pencil. If sampling is needed from larger mature trees with a single trunk only remove samples from the lowest branches (Note this). Where long stem lengths are available cut additional sample billet from the next step up the stem.
- Cut a slice (approximately 2.5 cm wide) by chainsaw from the remaining stem (50 cm from ground level). Remove the bark noting the thickness on North and South sides of the stem, determine the wet weight of the bark sample and store in a labelled calico bag. Mark wood slice with the specimen number and North orientation of the sample in pencil. Measure the wet weight of the wood slice (without bark) and store in the calico bag.

- Measure the bark thickness at 0.5 m from ground level for both the North and South side of trunk/stem.
- In the lab determine volume by immersion, air-dry, re-weight to determine moisture content and dry wood density.
- Determine dry wood colour properties and ranges using Munsell chart.

There may be the need to depart from the above procedure in some cases. For larger diameter single stem trees where low branches are not reachable use a tree corer which attaches to petrol driven drill to take a 12 mm diameter core from woody plants (six individuals sampled is preferred but three is OK). Bits of 300 mm length are available.

- Cores are drilled horizontally at practical coring height. This is often low to the ground, as trees of the target age are generally smaller diameter than mature size, and drilling lower (through thicker part of the trunk) leaves a larger portion of the trunk intact, thus minimising the damage to the tree. Standard height of 0.5 m to be adopted. Coring one branch of trees with early multiple branching minimises risk of sampling being destructive to the entire tree.
- Cores are drilled right through the tree from one side to the other. The core is trimmed at both ends if necessary to remove bark and square up the ends.
- Fresh samples are immediately returned to the vehicle for measuring and weighing. The sample/core is weighed on an electronic balance (grams to one decimal place) to obtain wet weight, and its length (core) is measured. The sample/core is then stored in a calico bag. Information recorded on the bag is:
  - Site number
  - Species name
  - Collection Number
  - Number of pieces
- Basic density is calculated as the oven dry weight divided by the green volume – calculated simply from the green core length and diameter (12 mm) or with more accuracy using a water displacement method. For preliminary screening this level of accuracy is adequate.
- Where possible all stems of three individual plants should be cleared to a height of 10cm to enable a future assessment of a species' coppicing ability. Where the population is sensitive to this procedure (ecologically or culturally) fewer or no samples may be taken.

Upon return to the laboratory:

- Samples dried for 24 hours at 60 degrees Celsius (or until weight is stable – further drying after 24 hours is usually only 1% or so, which is probably small in terms of the other sources of error and variability).
- Colour of dry specimens is determined by reference to Munsell Soil Colour Chart. Usually two colours are recorded, to cover the range of colour in the wood, which can vary in a regular way along the core, (commonly heartwood is different to sapwood) or be mottled or striped.
- Dry cores are weighed (grams to one decimal places).
- Sample details and weights are recorded in computer file, and basic density and moisture content are calculated.
- Results of this phase to be assessed in consultation with CSIRO FFP.

Storage

- The bulk wood sample can be stored until assessment of the disks and cores is complete and a decision made on species to be tested in detail.

Phase 2

More accurate methods of both sampling and analysis are warranted for species that show sufficient promise. A strategy is needed that captures the variation between populations, between trees and within trees.

Species that appear prospective based on their basic density, colour and other attributes are selected for more extensive coring – to improve our data on density, to get a better understanding of density variation within the species, and to locate populations from which subsequent wood samples may be taken for further laboratory testing and sample product manufacture.

The target for these species is to collect cores from six trees from each of three different populations.

The sampling protocol is similar to Phase 1 (GPS location, voucher specimen taken from one tree, etc.) One tree in each population is selected for coring at three different heights

Phase 3

Involves collection of wood (150 kg) for laboratory testing for various uses (mostly paper, panel boards and bioenergy). Specifications to be decided in consultation with the laboratory that will be doing the tests. It is intended that wood will be collected from populations that have already been sampled, perhaps even from some of the same trees that were cored/sampled in Phase 1 and Phase 2.

Fodder

(Peter Milthorpe, NSW Department of Agriculture)

- Sample six plants, taking a range of leaf and twig material from different positions on the plants.
- Sample growth at bottom, side and top of plants, partition into stick, twigs and leaf. Twigs and leaf are usually separated after drying as both come away together in the initial partitioning process. Leaf only specimens are to be retained for testing
- Sub-sample (100-500 g) for analysis in lab. Record green and dry weights for moisture content. Foliage samples are stored in paper bags and encouraged to air dry on the field trip, and then oven dried at 60 degrees Celsius in the laboratory. Dry either in dehydrator or microwave (sometimes freeze dryer). Store samples in paper bags inside a plastic bag in deep freezer until analysis.
- Lab analysis.

  Forward sample to
  FeedTest – Agriculture Victoria
  Pastoral and Veterinary Institute
  Private Bag 105
  Reply Paid 60563
  Hamilton Victoria 3300
- Basic test
  - Crude Protein,
  - Estimated Metabolisable Energy
  - Digestibility (in vitro)
  - %dry Matter (in vivo).

Essential Oils (J, Brophy, University of NSW)

- Collect from natural stands, plantations or research trials. In collecting leaves from trees use a throwing rope with a weighted end to tear down leafy branches where needed, or pole secateurs
- Collect young mature leaves from six individual trees and bulk. Mix well and sub-sample 100-150 g. Place in calico or paper bags with the collection number added.
- Ideally, botanical voucher specimens would be collected from all sampled individuals but this will create a large amount of work in processing, curating and housing such a collection. Follow above suggestion of vouchering a single tree from the group
- Do a wet weight of the sample in the field to provide an option of a wet or dry weight expression of yield after analysis.
- Dispatch material to lab as soon as possible. Leaf weight and oil yield is usually calculated on a fresh weight or dry weight basis depending on the length of time the material takes to get to the laboratory.
- Where species have a wide geographic range, consider sampling over several widespread locations to determine if geographic chemotypes exist.

Tannins

Bark samples are collected from species likely to contain high tannin content. They are stored in cotton bags and receive the same drying treatment as the core and disk samples. Amount to be taken is small, < 50 g.

Gums

To be collected from Acacia species and a few other nominated species. These specimens need to be collected during summer as the gum is soluble and washes away with heavy rainfall. Material will often be naturally occurring but some minor deliberate wounding may be used to stimulate gum exudate. Gum is often not produced prolifically and small amounts will need to be collected from many individuals in the vicinity of the six individuals selected for sampling.

Only a small amount of material is needed for testing, <10 g, however collect 200-300 g in field if available.

Store in calico bags in a dry location labelled as for wood samples but nominate the sample type.

Appendix G. FloraSearch Wood Density Samples

Basic density statistics (Mean, Minimum, Maximum, No. of samples [*n*]) for FloraSearch wood samples.

Species	Mean	Min	Max	n
Acacia aneura	875	847	924	3
Acacia brachybotrya	851	815	870	3
Acacia deanei ssp. *deanei*	781	769	803	3
Acacia decora	793	746	835	3
Acacia euthycarpa	729	710	746	3
Acacia leucoclada ssp. *leucoclada*	627	594	675	3
Acacia notabilis	762	737	793	3
Acacia omalophylla	996	968	1038	3
Acacia pendula	900	860	930	3
Acacia penninervis	710	663	748	4
Acacia retinodes var. *retinodes (hill form)*	720	712	725	3
Acacia salicina	581	560	618	3
Acacia verniciflua	720	693	756	3
Acacia vestita	730	725	738	3
Allocasuarina luehmannii	738	694	765	3
Allocasuarina muelleriana	737	727	742	3
Allocasuarina verticillata	782	757	812	3
Alstonia constricta	529	517	542	3
Apophyllum anomalum	802	779	830	3
Atalaya hemiglauca	751	731	766	3
Brachychiton populneus	389	340	432	6
Callistemon rugulosus	840	824	853	3
Callistemon sieberi	702	678	732	3
Callitris endlicheri	577	555	612	3
Callitris glaucophylla	603	578	621	3
Callitris gracilis	529	495	548	3
Callitris verrucosa	657	642	673	3
Canthium oleifolium	780	742	804	3
Capparis mitchellii	695	618	742	3
Casuarina cristata	837	811	863	3

Species	Mean	Min	Max	n
Casuarina cunninghamiana ssp. *cunninghamiana*	491	484	500	3
Casuarina pauper	707	669	730	3
Dodonaea viscosa ssp. *mucronata*	824	772	871	3
Dodonaea viscosa ssp. *spatulata*	836	784	891	3
Eremophila bignoniiflora	813	786	859	3
Eremophila deserti	803	781	831	3
Eremophila longifolia	672	628	714	3
Eremophila mitchellii	838	768	910	3
Eucalyptus albens	850	832	866	3
Eucalyptus aromaphloia ssp. *sabulosa*	540	536	542	3
Eucalyptus baxteri	490	456	522	3
Eucalyptus blakelyi	543	530	555	3
Eucalyptus brachycalyx	810	772	852	3
Eucalyptus bridgesiana	539	521	572	3
Eucalyptus camaldulensis	502	492	509	3
Eucalyptus chloroclada	621	540	738	3
Eucalyptus cladocalyx	753	751	755	3
Eucalyptus cneorifolia	854	845	859	3
Eucalyptus conica	679	661	704	3
Eucalyptus cosmophylla	549	527	568	3
Eucalyptus fasciculosa	704	687	722	3
Eucalyptus fibrosa	801	748	830	3
Eucalyptus globulus ssp. *bicostata*	656	606	710	3
Eucalyptus goniocalyx	660	639	681	3
Eucalyptus gracilis	849	825	871	3
Eucalyptus incrassata	768	737	815	6
Eucalyptus leptophylla	779	731	813	3
Eucalyptus leucoxylon	773	771	775	3
Eucalyptus macrorhyncha ssp. *macrorhyncha*	668	627	710	3
Eucalyptus melanophloia	844	836	853	3
Eucalyptus melliodora	719	592	858	3

Species	Mean	Min	Max	n
Eucalyptus microcarpa	775	744	815	3
Eucalyptus nortonii	639	616	654	3
Eucalyptus odorata	777	760	790	3
Eucalyptus ovata	504	439	539	3
Eucalyptus petiolaris	664	628	689	3
Eucalyptus phenax	815	790	829	3
Eucalyptus pilligaensis	896	885	912	3
Eucalyptus polyanthemos	783	722	817	3
Eucalyptus porosa	641	579	683	3
Eucalyptus rubida	529	497	589	6
Eucalyptus sideroxylon	759	715	823	3
Eucalyptus socialis	765	761	770	3
Eucalyptus viminalis ssp. *cygnetensis*	532	520	555	3
Eucalyptus viridis ssp. *viridis*	837	814	865	3
Eucalyptus viridis ssp. *wimmerensis*	853	831	867	3
Flindersia maculosa	821	809	830	3

Species	Mean	Min	Max	n
Geijera parviflora	908	885	935	3
Grevillea striata	769	746	795	3
Leptospermum continentale	635	591	671	3
Leptospermum coriaceum	701	685	732	3
Leptospermum laevigatum	741	719	772	3
Melaleuca armillaris ssp. *armillaris*	576	517	609	3
Melaleuca halmaturorum ssp. *halmaturorum*	690	648	728	3
Melaleuca lanceolata	680	677	684	3
Melaleuca uncinata	650	649	652	3
Myoporum insulare	713	616	767	3
Myoporum platycarpum	685	670	693	3
Owenia acidula	801	790	822	3
Petalostylis labicheoides var. *labicheoides*	639	627	653	3
Ventilago viminalis	843	825	860	3

Appendix H. First and Subsequent Harvests Sensitivity Analyses

First Harvest Sensitivity Analysis - Export Pulpwood Only by stemwood productivity class [m³/ha/year]: ***Eucalyptus viminalis* ssp. *cygnetensis*.**

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
		Productivity class: p5				Productivity class: p10			
Baseline		6	12	$856	$71	4	9	$2,281	$253
Establishment & Cleanup	+50%	9	14	$364	$26	5	11	$2,211	$201
	-50%	4	9	$1,099	$122	3	9	$2,793	$310
Maintenance	+50%	7	12	$799	$67	4	9	$2,240	$249
	-50%	6	12	$912	$76	4	9	$2,323	$258
Harvest	+50%	8	14	$491	$35	6	12	$2,018	$168
	-50%	5	9	$1,032	$115	4	9	$3,169	$352
Distance or Transport	+500%	10	16	$293	$18	7	13	$1,676	$129
	+300%	8	14	$529	$38	6	12	$2,092	$174
	+100%	7	12	$714	$59	5	10	$2,256	$226
	+50%	7	12	$785	$65	5	10	$2,395	$240
	-50%	6	11	$853	$78	4	9	$2,418	$269
Delivered Price	+50%	4	9	$1,947	$216	3	9	$4,998	$555
	-50%	n.r.	20	-$832	-$42	n.r.	18	-$49	-$3
		Productivity class: p15				Productivity class: p20			
Baseline		4	9	$3,975	$442	3	9	$5,668	$630
Establishment & Cleanup	+50%	4	9	$3,463	$385	4	9	$5,157	$573
	-50%	3	9	$4,486	$498	3	9	$6,179	$687
Maintenance	+50%	4	9	$3,933	$437	3	9	$5,626	$625
	-50%	4	9	$4,016	$446	3	9	$5,709	$634

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
Harvest	+50%	5	11	$3,350	$305	4	11	$4,862	$442
	-50%	3	9	$5,306	$590	3	9	$7,443	$827
Distance or Transport	+500%	6	13	$3,152	$242	5	12	$4,280	$357
	+300%	5	11	$3,460	$315	4	11	$5,009	$455
	+100%	4	9	$3,566	$396	4	9	$5,123	$569
	+50%	4	9	$3,770	$419	3	9	$5,395	$599
	-50%	4	9	$4,179	$464	3	9	$5,940	$660
Delivered Price	+50%	3	9	$8,050	$894	2	9	$11,101	$1,233
	-50%	10	17	$650	$38	9	16	$1,282	$80
		Productivity class: p25				**Productivity class: p30**			
Baseline		3	9	$7,361	$818	3	9	$9,054	$1,006
Establishment & Cleanup	+50%	4	9	$6,850	$761	3	9	$8,543	$949
	-50%	3	9	$7,872	$875	3	9	$9,565	$1,063
Maintenance	+50%	3	9	$7,319	$813	3	9	$9,013	$1,001
	-50%	3	9	$7,402	$822	3	9	$9,095	$1,011
Harvest	+50%	4	11	$6,375	$580	4	10	$7,180	$718
	-50%	3	8	$8,516	$1,064	2	8	$10,432	$1,304
Distance or Transport	+500%	5	12	$5,657	$471	5	12	$7,035	$586
	+300%	4	10	$5,973	$597	4	10	$7,397	$740
	+100%	3	9	$6,680	$742	3	9	$8,237	$915
	+50%	3	9	$7,020	$780	3	9	$8,645	$961
	-50%	3	9	$7,701	$856	3	9	$9,462	$1,051
Delivered Price	+50%	2	9	$14,153	$1,573	2	8	$15,301	$1,913
	-50%	8	15	$1,833	$122	7	15	$2,472	$165

[$740/ha total establishment cost, $10/ha annual maintenance, $15/green t harvest cost, transport 50km @ $0.046/green t/km, delivered price $72.5/green t]

Subsequent Harvest Sensitivity Analysis - Export Pulpwood Only by stemwood productivity class [m³/ha/year]: *Eucalyptus viminalis* ssp. *cygnetensis*.

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
		Productivity class: p5 [7.5]				Productivity class: p10 [15]			
Baseline		2	9	$2,457	$273	2	9	$4,997	$555
Establishment & Cleanup	+50%	2	9	$2,457	$273	2	9	$4,997	$555
	-50%	2	9	$2,457	$273	2	9	$4,997	$555
Maintenance	+50%	2	9	$2,416	$268	2	9	$4,956	$551
	-50%	2	9	$2,498	$278	2	9	$5,038	$560
Harvest	+50%	3	9	$1,791	$199	3	9	$3,665	$407
	-50%	1	8	$2,802	$350	1	8	$5,676	$709
Distance or Transport	+500%	4	11	$1,799	$164	4	11	$3,701	$336
	+300%	3	9	$1,845	$205	3	9	$3,772	$419
	+100%	2	9	$2,253	$250	2	9	$4,588	$510
	+50%	2	9	$2,355	$262	2	9	$4,793	$533
	-50%	2	9	$2,559	$284	2	9	$5,201	$578
Delivered Price	+50%	1	8	$4,019	$502	1	8	$8,110	$1,014
	-50%	6	13	$714	$55	5	13	$1,551	$119
		Productivity class: p15 [22.5]				Productivity class: p20 [30]			
Baseline		2	9	$7,536	$837	2	9	$10,076	$1,120
Establishment & Cleanup	+50%	2	9	$7,536	$837	2	9	$10,076	$1,120
	-50%	2	9	$7,536	$837	2	9	$10,076	$1,120
Maintenance	+50%	2	9	$7,495	$833	2	9	$10,035	$1,115
	-50%	2	9	$7,578	$842	2	9	$10,117	$1,124
Harvest	+50%	3	9	$5,539	$615	3	9	$7,413	$824
	-50%	1	8	$8,549	$1,069	1	8	$11,423	$1,428

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
Distance or Transport	+500%	4	11	$5,604	$509	4	11	$7,506	$682
	+300%	3	9	$5,699	$633	3	9	$7,626	$847
	+100%	2	9	$6,924	$769	2	9	$9,259	$1,029
	+50%	2	9	$7,230	$803	2	9	$9,668	$1,074
	-50%	2	9	$7,843	$871	2	9	$10,484	$1,165
Delivered Price	+50%	1	8	$12,201	$1,525	1	8	$16,292	$2,037
	-50%	5	13	$2,388	$184	5	13	$3,225	$248
		Productivity class: p25 [37.5]				Productivity class: p30 [45]			
Baseline		2	9	$12,616	$1,402	2	9	$15,155	$1,684
Establishment & Cleanup	+50%	2	9	$12,616	$1,402	2	9	$15,155	$1,684
	-50%	2	9	$12,616	$1,402	2	9	$15,155	$1,684
Maintenance	+50%	2	9	$12,574	$1,397	2	9	$15,114	$1,679
	-50%	2	9	$12,657	$1,406	2	9	$15,196	$1,688
Harvest	+50%	3	9	$9,287	$1,032	3	9	$11,160	$1,240
	-50%	1	8	$14,297	$1,787	1	8	$17,171	$2,146
Distance or Transport	+500%	4	11	$9,408	$855	4	11	$11,310	$1,028
	+300%	3	9	$9,553	$1,061	3	9	$11,480	$1,276
	+100%	2	9	$11,595	$1,288	2	9	$13,930	$1,548
	+50%	2	9	$12,105	$1,345	2	9	$14,543	$1,616
	-50%	2	9	$13,126	$1,458	2	9	$15,768	$1,752
Delivered Price	+50%	1	8	$20,383	$2,548	1	8	$24,474	$3,059
	-50%	5	13	$4,062	$312	5	13	$4,899	$377

[$10/ha annual maintenance, $15/green t harvest cost, transport 50km @ $0.046/green t/km, delivered price $72.5/green t]

First Harvest Sensitivity Analysis - Australian Pulpwood Only by stemwood productivity class [m³/ha/year]: *Eucalyptus viminalis* ssp. *cygnetensis*.

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
		Productivity class: p5				Productivity class: p10			
Baseline		n.r.	18	-$348	-$19	8	14	$692	$49
Establishment & Cleanup	+50%	n.r.	20	-$1,104	-$55	13	16	$148	$9
	-50%	9	14	$279	$20	6	13	$1,204	$93
Maintenance	+50%	n.r.	17	-$411	-$24	8	14	$625	$45
	-50%	n.r.	18	-$260	-$14	8	14	$759	$54
Harvest	+50%	n.r.	20	-$842	-$42	n.r.	20	-$92	-$5
	-50%	9	13	$142	$11	5	10	$1,251	$125
Distance or Transport	+500%	n.r.	20	-$1,075	-$54	n.r.	20	-$558	-$28
	+300%	n.r.	20	-$807	-$40	n.r.	19	-$19	-$1
	+100%	n.r.	19	-$510	-$27	10	16	$492	$31
	+50%	n.r.	18	-$417	-$23	9	15	$598	$40
	-50%	n.r.	17	-$259	-$15	8	14	$834	$60
Delivered Price	+50%	7	12	$638	$53	5	10	$2,136	$214
	-50%	n.r.	20	-$1,503	-$75	n.r.	20	-$1,413	-$71
		Productivity class: p15				Productivity class: p20			
Baseline		7	13	$1,580	$122	6	13	$2,531	$195
Establishment & Cleanup	+50%	8	14	$1,104	$79	7	14	$2,110	$151
	-50%	5	12	$2,000	$167	5	12	$2,890	$241
Maintenance	+50%	7	13	$1,518	$117	6	13	$2,470	$190
	-50%	7	13	$1,642	$126	6	13	$2,593	$199
Harvest	+50%	12	19	$637	$34	10	18	$1,301	$72
	-50%	4	9	$2,214	$246	4	9	$3,321	$369
Distance or Transport	+500%	n.r.	20	-$41	-$2	16	20	$476	$24
	+300%	11	18	$709	$39	10	18	$1,446	$80
	+100%	8	15	$1,365	$91	7	14	$2,132	$152
	+50%	7	14	$1,483	$106	6	13	$2,246	$173
	-50%	6	13	$1,794	$138	5	12	$2,615	$218

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
Delivered Price	+50%	4	9	$3,412	$379	4	9	$4,918	$546
	-50%	n.r.	20	-$1,323	-$66	n.r.	20	-$1,234	-$62
		Productivity class: p25				**Productivity class: p30**			
Baseline		5	12	$3,222	$269	5	12	$4,113	$343
Establishment & Cleanup	+50%	6	13	$2,907	$224	6	13	$3,859	$297
	-50%	5	12	$3,781	$315	4	11	$4,288	$390
Maintenance	+50%	5	12	$3,165	$264	5	12	$4,056	$338
	-50%	5	12	$3,279	$273	5	12	$4,169	$347
Harvest	+50%	10	18	$2,001	$111	9	17	$2,553	$150
	-50%	3	9	$4,427	$492	3	9	$5,534	$615
Distance or Transport	+500%	14	20	$993	$50	13	20	$1,510	$76
	+300%	9	17	$2,068	$122	9	17	$2,773	$163
	+100%	6	14	$2,994	$214	6	14	$3,856	$275
	+50%	6	13	$3,127	$241	6	13	$4,007	$308
	-50%	5	12	$3,577	$298	5	11	$4,167	$379
Delivered Price	+50%	3	9	$6,424	$714	3	9	$7,930	$881
	-50%	n.r.	20	-$1,144	-$57	n.r.	20	-$1,055	-$53

[$740/ha total establishment cost, $10/ha annual maintenance, $15/green t harvest cost, transport 50km @ $0.046/green t/km, delivered price $45/green t]

Subsequent Harvest Sensitivity Analysis - Australian Pulpwood Only by stemwood productivity class [m³/ha/year]: *Eucalyptus viminalis* ssp. *cygnetensis*.

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
		Productivity class: p5 [7.5]				Productivity class: p10 [15]			
Baseline		4	11	$1,130	$103	4	11	$2,364	$215
Establishment & Cleanup	+50%	4	11	$1,130	$103	4	11	$2,364	$215
	-50%	4	11	$1,130	$103	4	11	$2,364	$215
Maintenance	+50%	4	11	$1,079	$98	4	11	$2,312	$210
	-50%	4	11	$1,182	$107	4	11	$2,415	$220
Harvest	+50%	7	16	$791	$49	7	16	$1,737	$109
	-50%	2	9	$1,577	$175	2	9	$3,237	$360
Distance or Transport	+500%	11	20	$580	$29	10	20	$1,356	$68
	+300%	7	16	$847	$53	7	16	$1,848	$115
	+100%	5	12	$1,010	$84	5	12	$2,133	$178
	+50%	4	11	$1,025	$93	4	11	$2,153	$196
	-50%	3	10	$1,131	$113	3	10	$2,354	$235
Delivered Price	+50%	2	9	$2,176	$242	2	9	$4,435	$493
	-50%	n.r.	20	-$61	-$3	19	20	$74	$4
		Productivity class: p15 [22.5]				Productivity class: p20 [30]			
Baseline		4	11	$3,597	$327	4	11	$4,831	$439
Establishment & Cleanup	+50%	4	11	$3,597	$327	4	11	$4,831	$439
	-50%	4	11	$3,597	$327	4	11	$4,831	$439
Maintenance	+50%	4	11	$3,546	$322	4	11	$4,779	$434
	-50%	4	11	$3,649	$332	4	11	$4,883	$444
Harvest	+50%	7	16	$2,683	$168	7	16	$3,628	$227
	-50%	2	9	$4,896	$544	2	9	$6,556	$728
Distance or Transport	+500%	10	20	$2,132	$107	10	20	$2,907	$145
	+300%	7	16	$2,849	$178	7	16	$3,850	$241
	+100%	4	12	$3,256	$271	4	12	$4,380	$365
	+50%	4	11	$3,281	$298	4	11	$4,409	$401
	-50%	3	10	$3,578	$358	3	10	$4,801	$480

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
Delivered Price	+50%	2	9	$6,693	$744	2	9	$8,952	$995
	-50%	18	20	$208	$10	17	20	$342	$17
		Productivity class: p25 [37.5]				**Productivity class: p30 [45]**			
Baseline		4	11	$6,064	$551	4	11	$7,298	$663
Establishment & Cleanup	+50%	4	11	$6,064	$551	4	11	$7,298	$663
	-50%	4	11	$6,064	$551	4	11	$7,298	$663
Maintenance	+50%	4	11	$6,013	$547	4	11	$7,246	$659
	-50%	4	11	$6,116	$556	4	11	$7,350	$668
Harvest	+50%	7	16	$4,574	$286	7	16	$5,520	$345
	-50%	2	9	$8,215	$913	2	9	$9,875	$1,097
Distance or Transport	+500%	10	20	$3,683	$184	10	20	$4,459	$223
	+300%	7	16	$4,851	$303	7	16	$5,851	$366
	+100%	4	12	$5,503	$459	4	12	$6,626	$552
	+50%	4	11	$5,537	$503	4	11	$6,665	$606
	-50%	3	10	$6,025	$602	3	10	$7,249	$725
Delivered Price	+50%	2	9	$11,210	$1,246	2	9	$13,469	$1,497
	-50%	17	20	$477	$24	17	20	$611	$31

[$10/ha annual maintenance, $15/green t harvest cost, transport 50km @ $0.046/green t/km, delivered price $45/green t]

First Harvest Sensitivity Analysis - Fibreboard/Particleboard Only by stemwood productivity class [m³/ha/year]: *Eucalyptus viminalis* ssp. *cygnetensis*.

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
		Productivity class: p5				Productivity class: p10			
Baseline		n.r.	20	-$1,137	-$57	n.r.	20	-$681	-$34
Establishment & Cleanup	+50%	n.r.	20	-$1,835	-$92	n.r.	20	-$1,380	-$69
	-50%	n.r.	20	-$438	-$22	18	20	$17	$1
Maintenance	+50%	n.r.	20	-$1,234	-$62	n.r.	20	-$779	-$39
	-50%	n.r.	20	-$1,039	-$52	n.r.	20	-$584	-$29
Harvest	+50%	n.r.	20	-$1,574	-$79	n.r.	20	-$1,555	-$78
	-50%	n.r.	19	-$661	-$35	10	15	$254	$17
Distance or Transport	+500%	n.r.	20	-$1,807	-$90	n.r.	20	-$2,021	-$101
	+300%	n.r.	20	-$1,539	-$77	n.r.	20	-$1,485	-$74
	+100%	n.r.	20	-$1,271	-$64	n.r.	20	-$949	-$47
	+50%	n.r.	20	-$1,204	-$60	n.r.	20	-$815	-$41
	-50%	n.r.	20	-$1,070	-$53	n.r.	20	-$547	-$27
Delivered Price	+50%	n.r.	18	-$348	-$19	8	14	$692	$49
	-50%	n.r.	20	-$1,868	-$93	n.r.	20	-$2,145	-$107
		Productivity class: p15				Productivity class: p20			
Baseline		n.r.	20	-$226	-$11	15	20	$229	$11
Establishment & Cleanup	+50%	n.r.	20	-$924	-$46	n.r.	20	-$469	-$23
	-50%	12	19	$453	$24	11	19	$893	$47
Maintenance	+50%	n.r.	20	-$323	-$16	16	20	$132	$7
	-50%	n.r.	20	-$128	-$6	15	20	$327	$16
Harvest	+50%	n.r.	20	-$1,537	-$77	n.r.	20	-$1,518	-$76
	-50%	7	13	$951	$73	6	12	$1,571	$131
Distance or Transport	+500%	n.r.	20	-$2,236	-$112	n.r.	20	-$2,450	-$123
	+300%	n.r.	20	-$1,432	-$72	n.r.	20	-$1,378	-$69
	+100%	n.r.	20	-$628	-$31	n.r.	20	-$306	-$15
	+50%	n.r.	20	-$427	-$21	n.r.	20	-$38	-$2
	-50%	n.r.	19	-$22	-$1	12	18	$460	$26

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
Delivered Price	+50%	7	13	$1,580	$122	6	13	$2,531	$195
	-50%	n.r.	20	-$2,421	-$121	n.r.	20	-$2,697	-$135
		Productivity class: p25				**Productivity class: p30**			
Baseline		13	19	$652	$34	12	19	$1,092	$57
Establishment & Cleanup	+50%	n.r.	20	-$14	-$1	15	20	$442	$22
	-50%	10	18	$1,266	$70	9	18	$1,687	$94
Maintenance	+50%	13	19	$560	$29	12	19	$999	$53
	-50%	12	19	$745	$39	11	19	$1,184	$62
Harvest	+50%	n.r.	20	-$1,500	-$75	n.r.	20	-$1,481	-$74
	-50%	5	12	$2,272	$189	5	11	$2,737	$249
Distance or Transport	+500%	n.r.	20	-$2,665	-$133	n.r.	20	-$2,879	-$144
	+300%	n.r.	20	-$1,325	-$66	n.r.	20	-$1,272	-$64
	+100%	20	20	$15	$1	17	20	$336	$17
	+50%	15	20	$350	$17	14	20	$738	$37
	-50%	11	18	$950	$53	10	18	$1,440	$80
Delivered Price	+50%	5	12	$3,222	$269	5	12	$4,113	$343
	-50%	n.r.	20	-$2,973	-$149	n.r.	20	-$3,249	-$162

[$740/ha total establishment cost, $10/ha annual maintenance, $15/green t harvest cost, transport 50km @ $0.046/green t/km, delivered price $30/green t]

Subsequent Harvest Sensitivity Analysis - Fibreboard/Particleboard Only by stemwood productivity class [m³/ha/year]: *Eucalyptus viminalis* ssp. *cygnetensis*.

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
		Productivity class: p5 [7.5]				Productivity class: p10 [15]			
Baseline		9	17	$433	$25	8	17	$1,031	$61
Establishment & Cleanup	+50%	9	17	$433	$25	8	17	$1,031	$61
	-50%	9	17	$433	$25	8	17	$1,031	$61
Maintenance	+50%	9	17	$351	$21	8	17	$949	$56
	-50%	8	17	$515	$30	8	17	$1,113	$65
Harvest	+50%	n.r.	20	-$167	-$8	n.r.	20	-$140	-$7
	-50%	3	9	$734	$82	3	9	$1,550	$172
Distance or Transport	+500%	n.r.	20	-$517	-$26	n.r.	20	-$839	-$42
	+300%	n.r.	20	-$115	-$6	n.r.	20	-$35	-$2
	+100%	12	20	$287	$14	11	20	$769	$38
	+50%	10	19	$372	$20	9	19	$929	$49
	-50%	7	16	$512	$32	7	16	$1,177	$74
Delivered Price	+50%	4	11	$1,130	$103	4	11	$2,364	$215
	-50%	n.r.	20	-$609	-$30	n.r.	20	-$1,024	-$51
		Productivity class: p15 [22.5]				Productivity class: p20 [30]			
Baseline		8	17	$1,629	$96	8	17	$2,226	$131
Establishment & Cleanup	+50%	8	17	$1,629	$96	8	17	$2,226	$131
	-50%	8	17	$1,629	$96	8	17	$2,226	$131
Maintenance	+50%	8	17	$1,546	$91	8	17	$2,144	$126
	-50%	8	17	$1,711	$101	8	17	$2,309	$136
Harvest	+50%	n.r.	20	-$112	-$6	n.r.	20	-$84	-$4
	-50%	3	9	$2,367	$263	3	9	$3,183	$354
Distance or Transport	+500%	n.r.	20	-$1,161	-$58	n.r.	20	-$1,482	-$74
	+300%	20	20	$45	$2	20	20	$126	$6
	+100%	11	20	$1,251	$63	11	20	$1,733	$87
	+50%	9	19	$1,486	$78	9	19	$2,043	$108
	-50%	7	16	$1,843	$115	7	16	$2,509	$157

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
Delivered Price	+50%	4	11	$3,597	$327	4	11	$4,831	$439
	-50%	n.r.	20	-$1,438	-$72	n.r.	20	-$1,852	-$93
		Productivity class: p25 [37.5]				**Productivity class: p30 [45]**			
Baseline		8	17	$2,824	$166	8	17	$3,422	$201
Establishment & Cleanup	+50%	8	17	$2,824	$166	8	17	$3,422	$201
	-50%	8	17	$2,824	$166	8	17	$3,422	$201
Maintenance	+50%	8	17	$2,742	$161	8	17	$3,340	$196
	-50%	8	17	$2,906	$171	8	17	$3,504	$206
Harvest	+50%	n.r.	20	-$56	-$3	n.r.	20	-$29	-$1
	-50%	3	9	$3,999	$444	3	9	$4,816	$535
Distance or Transport	+500%	n.r.	20	-$1,804	-$90	n.r.	20	-$2,126	-$106
	+300%	19	20	$206	$10	19	20	$286	$14
	+100%	11	20	$2,216	$111	10	20	$2,698	$135
	+50%	9	19	$2,600	$137	9	19	$3,157	$166
	-50%	7	16	$3,175	$198	7	16	$3,840	$240
Delivered Price	+50%	4	11	$6,064	$551	4	11	$7,298	$663
	-50%	n.r.	20	-$2,267	-$113	n.r.	20	-$2,681	-$134

[$10/ha annual maintenance, $15/green t harvest cost, transport 50km @ $0.046/green t/km, delivered price $30/green t]

First Harvest Sensitivity Analysis - Bioenergy Only by stemwood productivity class [m³/ha/year]: *Eucalyptus cladocalyx*.

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
		Productivity class: p5				Productivity class: p10			
Baseline		n.r.	16	-$792	-$49	7	9	$81	$9
Establishment & Cleanup	+50%	n.r.	20	-$1,707	-$85	n.r.	11	-$506	-$46
	-50%	n.r.	9	-$1	$0	3	7	$497	$71
Maintenance	+50%	n.r.	16	-$869	-$54	8	9	$40	$4
	-50%	n.r.	16	-$715	-$45	7	9	$123	$14
Harvest	+50%	n.r.	20	-$1,387	-$69	n.r.	20	-$1,183	-$59
	-50%	n.r.	9	-$127	-$14	4	8	$799	$100
Distance or Transport	+500%	n.r.	20	-$1,880	-$94	n.r.	20	-$2,168	-$108
	+300%	n.r.	20	-$1,531	-$77	n.r.	20	-$1,471	-$74
	+100%	n.r.	20	-$1,183	-$59	n.r.	10	-$299	-$30
	+50%	n.r.	19	-$1,040	-$55	n.r.	9	-$96	-$11
	-50%	n.r.	13	-$561	-$43	6	8	$234	$29
Delivered Price	+50%	6	8	$234	$29	3	7	$1,365	$195
	-50%	n.r.	20	-$1,767	-$88	n.r.	20	-$1,941	-$97
		Productivity class: p15				Productivity class: p20			
Baseline		4	8	$630	$79	3	7	$1,055	$151
Establishment & Cleanup	+50%	7	9	$163	$18	5	8	$699	$87
	-50%	3	6	$880	$147	2	6	$1,345	$224
Maintenance	+50%	4	8	$594	$74	3	7	$1,024	$146
	-50%	4	8	$666	$83	3	7	$1,086	$155
Harvest	+50%	n.r.	15	-$711	-$47	n.r.	10	-$299	-$30
	-50%	3	7	$1,547	$221	2	6	$2,089	$348
Distance or Transport	+500%	n.r.	20	-$2,456	-$123	n.r.	20	-$2,744	-$137
	+300%	n.r.	20	-$1,410	-$71	n.r.	20	-$1,350	-$67
	+100%	7	9	$143	$16	4	8	$520	$65
	+50%	5	8	$377	$47	4	8	$857	$107
	-50%	4	8	$883	$110	3	7	$1,365	$195

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
Delivered Price	+50%	2	6	$2,228	$371	2	5	$2,750	$550
	-50%	n.r.	20	-$2,115	-$106	n.r.	20	-$2,290	-$114
		Productivity class: p25				Productivity class: p30			
Baseline		3	7	$1,574	$225	3	6	$1,811	$302
Establishment & Cleanup	+50%	4	8	$1,263	$158	3	7	$1,613	$230
	-50%	2	5	$1,516	$303	2	5	$1,918	$384
Maintenance	+50%	3	7	$1,543	$220	3	6	$1,785	$298
	-50%	3	7	$1,605	$229	3	6	$1,837	$306
Harvest	+50%	n.r.	9	-$65	-$7	7	9	$143	$16
	-50%	2	6	$2,857	$476	2	5	$3,032	$606
Distance or Transport	+500%	n.r.	20	-$3,033	-$152	n.r.	20	-$3,321	-$166
	+300%	n.r.	20	-$1,289	-$64	n.r.	20	-$1,228	-$61
	+100%	4	8	$916	$114	3	7	$1,163	$166
	+50%	3	7	$1,187	$170	3	7	$1,628	$233
	-50%	3	6	$1,693	$282	2	6	$2,228	$371
Delivered Price	+50%	2	5	$3,673	$735	2	5	$4,597	$919
	-50%	n.r.	20	-$2,464	-$123	n.r.	20	-$2,638	-$132

[$740/ha total establishment cost, $10/ha annual maintenance, $10/green t harvest cost, transport 50km @ $0.046/green t/km, delivered price $20/green t]

Subsequent Harvest Sensitivity Analysis - Bioenergy Only by stemwood productivity class [m³/ha/year]: *Eucalyptus cladocalyx.*

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
		Productivity class: p5 [7.5]				Productivity class: p10 [15]			
Baseline		1	4	$458	$115	1	4	$947	$237
Establishment & Cleanup	+50%	1	4	$458	$115	1	4	$947	$237
	-50%	1	4	$458	$115	1	4	$947	$237
Maintenance	+50%	1	4	$443	$111	1	4	$932	$233
	-50%	1	4	$474	$118	1	4	$963	$241
Harvest	+50%	1	4	$141	$35	1	4	$312	$78
	-50%	1	4	$776	$194	1	4	$1,583	$396
Distance or Transport	+500%	n.r.	1	-$26	-$26	n.r.	1	-$42	-$42
	+300%	2	2	$11	$6	2	3	$53	$18
	+100%	1	4	$312	$78	1	4	$655	$164
	+50%	1	4	$385	$96	1	4	$801	$200
	-50%	1	4	$531	$133	1	4	$1,093	$273
Delivered Price	+50%	1	4	$1,093	$273	1	4	$2,218	$554
	-50%	n.r.	1	-$19	-$19	n.r.	1	-$29	-$29
		Productivity class: p15 [22.5]				Productivity class: p20 [30]			
Baseline		1	4	$1,436	$359	1	4	$1,926	$481
Establishment & Cleanup	+50%	1	4	$1,436	$359	1	4	$1,926	$481
	-50%	1	4	$1,436	$359	1	4	$1,926	$481
Maintenance	+50%	1	4	$1,421	$355	1	4	$1,910	$478
	-50%	1	4	$1,452	$363	1	4	$1,941	$485
Harvest	+50%	1	4	$484	$121	1	4	$655	$164
	-50%	1	4	$2,389	$597	1	4	$3,196	$799
Distance or Transport	+500%	n.r.	1	-$58	-$58	n.r.	1	-$74	-$74
	+300%	1	4	$121	$30	1	4	$172	$43
	+100%	1	4	$998	$250	1	4	$1,341	$335
	+50%	1	4	$1,217	$304	1	4	$1,633	$408
	-50%	1	4	$1,656	$414	1	4	$2,218	$554

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
Delivered Price	+50%	1	4	$3,342	$836	1	4	$4,467	$1,117
	-50%	n.r.	1	-$39	-$39	n.r.	1	-$49	-$49
		Productivity class: p25 [37.5]				**Productivity class: p30 [45]**			
Baseline		1	4	$2,415	$604	1	4	$2,904	$726
Establishment & Cleanup	+50%	1	4	$2,415	$604	1	4	$2,904	$726
	-50%	1	4	$2,415	$604	1	4	$2,904	$726
Maintenance	+50%	1	4	$2,399	$600	1	4	$2,888	$722
	-50%	1	4	$2,430	$608	1	4	$2,919	$730
Harvest	+50%	1	4	$827	$207	1	4	$998	$250
	-50%	1	4	$4,003	$1,001	1	4	$4,810	$1,202
Distance or Transport	+500%	n.r.	1	-$91	-$91	n.r.	1	-$107	-$107
	+300%	1	4	$223	$56	1	4	$274	$68
	+100%	1	4	$1,684	$421	1	4	$2,027	$507
	+50%	1	4	$2,049	$512	1	4	$2,466	$616
	-50%	1	4	$2,780	$695	1	4	$3,342	$836
Delivered Price	+50%	1	4	$5,591	$1,398	1	4	$6,715	$1,679
	-50%	n.r.	1	-$59	-$59	n.r.	1	-$68	-$68

[$10/ha annual maintenance, $10/green t harvest cost, transport 50km @ $0.046/green t/km, delivered price $20/green t]

First Harvest Sensitivity Analysis - Eucalyptus Oil Only, processed on-site, by stemwood productivity class [m³/ha/year]: *Eucalyptus porosa*.

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
		Productivity class: p5				Productivity class: p10			
Baseline		n.r.	20	-$2,457	-$123	n.r.	4	-$546	-$136
Establishment & Cleanup	+50%	n.r.	20	-$3,155	-$158	n.r.	20	-$4,020	-$201
	-50%	n.r.	4	-$288	-$72	n.r.	3	-$31	-$10
Maintenance	+50%	n.r.	20	-$2,554	-$128	n.r.	4	-$561	-$140
	-50%	n.r.	20	-$2,359	-$118	n.r.	4	-$530	-$133
Harvest	+50%	n.r.	20	-$3,224	-$161	n.r.	20	-$4,856	-$243
	-50%	n.r.	6	-$337	-$56	3	4	$311	$78
Distance or Transport	+500%	n.r.	20	-$2,460	-$123	n.r.	4	-$555	-$139
	+300%	n.r.	20	-$2,459	-$123	n.r.	4	-$552	-$138
	+100%	n.r.	20	-$2,457	-$123	n.r.	4	-$548	-$137
	+50%	n.r.	20	-$2,457	-$123	n.r.	4	-$547	-$137
	-50%	n.r.	20	-$2,457	-$123	n.r.	4	-$545	-$136
Delivered Price	+50%	n.r.	5	-$239	-$48	2	3	$378	$126
	-50%	n.r.	20	-$2,792	-$140	n.r.	20	-$3,992	-$200
		Productivity class: p15				Productivity class: p20			
Baseline		n.r.	3	-$248	-$83	n.r.	3	-$42	-$14
Establishment & Cleanup	+50%	n.r.	4	-$803	-$201	n.r.	3	-$465	-$155
	-50%	2	3	$175	$58	2	2	$279	$140
Maintenance	+50%	n.r.	3	-$258	-$86	n.r.	3	-$52	-$17
	-50%	n.r.	3	-$238	-$79	n.r.	3	-$32	-$11
Harvest	+50%	n.r.	20	-$6,488	-$324	n.r.	20	-$8,119	-$406
	-50%	2	3	$690	$230	2	3	$1,209	$403
Distance or Transport	+500%	n.r.	3	-$260	-$87	n.r.	3	-$57	-$19
	+300%	n.r.	3	-$255	-$85	n.r.	3	-$51	-$17
	+100%	n.r.	3	-$250	-$83	n.r.	3	-$45	-$15
	+50%	n.r.	3	-$249	-$83	n.r.	3	-$43	-$14
	-50%	n.r.	3	-$247	-$82	n.r.	3	-$40	-$13

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
Delivered Price	+50%	2	3	$1,000	$333	2	3	$1,623	$541
	-50%	n.r.	20	-$5,191	-$260	n.r.	20	-$6,391	-$320
		Productivity class: p25				**Productivity class: p30**			
Baseline		2	3	$164	$55	2	3	$370	$123
Establishment & Cleanup	+50%	n.r.	3	-$259	-$86	n.r.	3	-$52	-$17
	-50%	2	2	$454	$227	2	2	$629	$314
Maintenance	+50%	2	3	$154	$51	2	3	$360	$120
	-50%	2	3	$175	$58	2	3	$381	$127
Harvest	+50%	n.r.	2	-$857	-$428	n.r.	2	-$862	-$431
	-50%	2	3	$1,728	$576	2	3	$2,247	$749
Distance or Transport	+500%	2	3	$145	$48	2	3	$348	$116
	+300%	2	3	$153	$51	2	3	$357	$119
	+100%	2	3	$160	$53	2	3	$366	$122
	+50%	2	3	$162	$54	2	3	$368	$123
	-50%	2	3	$166	$55	2	3	$373	$124
Delivered Price	+50%	2	3	$2,245	$748	2	3	$2,867	$956
	-50%	n.r.	20	-$7,591	-$380	n.r.	20	-$8,791	-$440

[$740/ha total establishment cost, $10/ha annual maintenance, $25.5/green t harvest cost, transport 50km @ $0.046/t/km (oil component only), leaf for oil processed on-site, delivered price $2.5/kg oil]

Subsequent Harvest Sensitivity Analysis - Eucalyptus Oil Only, processed on-site, by stemwood productivity class [m³/ha/year]: *Eucalyptus porosa.*

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
		Productivity class: p5 [7.5]				Productivity class: p10 [15]			
Baseline		1	2	$252	$126	1	2	$514	$257
Establishment & Cleanup	+50%	1	2	$252	$126	1	2	$514	$257
	-50%	1	2	$252	$126	1	2	$514	$257
Maintenance	+50%	1	2	$247	$123	1	2	$509	$254
	-50%	1	2	$257	$128	1	2	$519	$259
Harvest	+50%	1	1	$8	$8	1	1	$26	$26
	-50%	1	2	$522	$261	1	2	$1,055	$527
Distance or Transport	+500%	1	2	$248	$124	1	2	$506	$253
	+300%	1	2	$250	$125	1	2	$509	$255
	+100%	1	2	$251	$126	1	2	$512	$256
	+50%	1	2	$251	$126	1	2	$513	$257
	-50%	1	2	$252	$126	1	2	$515	$257
Delivered Price	+50%	1	2	$654	$327	1	2	$1,317	$659
	-50%	n.r.	1	-$22	-$22	n.r.	1	-$35	-$35
		Productivity class: p15 [22.5]				Productivity class: p20 [30]			
Baseline		1	2	$776	$388	1	2	$1,038	$519
Establishment & Cleanup	+50%	1	2	$776	$388	1	2	$1,038	$519
	-50%	1	2	$776	$388	1	2	$1,038	$519
Maintenance	+50%	1	2	$771	$385	1	2	$1,033	$516
	-50%	1	2	$781	$391	1	2	$1,043	$522
Harvest	+50%	1	1	$43	$43	1	1	$61	$61
	-50%	1	2	$1,587	$794	1	2	$2,119	$1,060
Distance or Transport	+500%	1	2	$765	$382	1	2	$1,023	$512
	+300%	1	2	$769	$385	1	2	$1,029	$515
	+100%	1	2	$774	$387	1	2	$1,035	$518
	+50%	1	2	$775	$387	1	2	$1,037	$518
	-50%	1	2	$777	$389	1	2	$1,039	$520

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
Delivered Price	+50%	1	2	$1,981	$991	1	2	$2,645	$1,323
	-50%	n.r.	1	-$48	-$48	n.r.	1	-$61	-$61
		Productivity class: p25 [37.5]				**Productivity class: p30 [45]**			
Baseline		1	2	$1,300	$650	1	2	$1,562	$781
Establishment & Cleanup	+50%	1	2	$1,300	$650	1	2	$1,562	$781
	-50%	1	2	$1,300	$650	1	2	$1,562	$781
Maintenance	+50%	1	2	$1,295	$647	1	2	$1,557	$778
	-50%	1	2	$1,305	$653	1	2	$1,567	$784
Harvest	+50%	1	1	$79	$79	1	1	$96	$96
	-50%	1	2	$2,652	$1,326	1	2	$3,184	$1,592
Distance or Transport	+500%	1	2	$1,282	$641	1	2	$1,540	$770
	+300%	1	2	$1,289	$644	1	2	$1,549	$774
	+100%	1	2	$1,296	$648	1	2	$1,558	$779
	+50%	1	2	$1,298	$649	1	2	$1,560	$780
	-50%	1	2	$1,302	$651	1	2	$1,564	$782
Delivered Price	+50%	1	2	$3,309	$1,654	1	2	$3,973	$1,986
	-50%	n.r.	1	-$74	-$74	n.r.	1	-$87	-$87

[$10/ha annual maintenance, $25.5/green t harvest cost, transport 50km @ $0.046/t/km (oil component only), leaf for oil processed on-site, delivered price $2.5/kg oil]

First Harvest Sensitivity Analysis - In situ Farm Fodder Only, by stemwood productivity class [m³/ha/year]: *Atriplex nummularia.*

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
		Productivity class: p5				Productivity class: p10			
Baseline		n.r.	8	-$487	-$61	4	5	$243	$49
Establishment & Cleanup	+50%	n.r.	20	-$2,294	-$115	n.r.	7	-$276	-$39
	-50%	4	5	$101	$20	2	4	$646	$161
Maintenance	+50%	n.r.	8	-$523	-$65	4	5	$223	$45
	-50%	n.r.	8	-$451	-$56	4	5	$264	$53
Harvest	+50%	n.r.	8	-$487	-$61	4	5	$243	$49
	-50%	n.r.	8	-$487	-$61	4	5	$243	$49
Distance or Transport	+500%	n.r.	8	-$487	-$61	4	5	$243	$49
	+300%	n.r.	8	-$487	-$61	4	5	$243	$49
	+100%	n.r.	8	-$487	-$61	4	5	$243	$49
	+50%	n.r.	8	-$487	-$61	4	5	$243	$49
	-50%	n.r.	8	-$487	-$61	4	5	$243	$49
Delivered Price	+50%	n.r.	6	-$69	-$11	3	4	$733	$183
	-50%	n.r.	20	-$1,646	-$82	n.r.	8	-$487	-$61
		Productivity class: p15				Productivity class: p20			
Baseline		3	4	$733	$183	2	4	$1,322	$331
Establishment & Cleanup	+50%	4	5	$386	$77	3	5	$1,046	$209
	-50%	2	4	$1,235	$309	2	3	$1,403	$468
Maintenance	+50%	3	4	$717	$179	2	4	$1,307	$327
	-50%	3	4	$748	$187	2	4	$1,338	$334
Harvest	+50%	3	4	$733	$183	2	4	$1,322	$331
	-50%	3	4	$733	$183	2	4	$1,322	$331
Distance or Transport	+500%	3	4	$733	$183	2	4	$1,322	$331
	+300%	3	4	$733	$183	2	4	$1,322	$331
	+100%	3	4	$733	$183	2	4	$1,322	$331
	+50%	3	4	$733	$183	2	4	$1,322	$331
	-50%	3	4	$733	$183	2	4	$1,322	$331

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
Delivered Price	+50%	2	4	$1,617	$404	2	4	$2,500	$625
	-50%	n.r.	6	-$69	-$11	4	5	$243	$49
		Productivity class: p25				**Productivity class: p30**			
Baseline		2	4	$1,911	$478	2	4	$2,500	$625
Establishment & Cleanup	+50%	2	4	$1,409	$352	2	4	$1,999	$500
	-50%	2	3	$1,880	$627	2	3	$2,357	$786
Maintenance	+50%	2	4	$1,896	$474	2	4	$2,485	$621
	-50%	2	4	$1,927	$482	2	4	$2,516	$629
Harvest	+50%	2	4	$1,911	$478	2	4	$2,500	$625
	-50%	2	4	$1,911	$478	2	4	$2,500	$625
Distance or Transport	+500%	2	4	$1,911	$478	2	4	$2,500	$625
	+300%	2	4	$1,911	$478	2	4	$2,500	$625
	+100%	2	4	$1,911	$478	2	4	$2,500	$625
	+50%	2	4	$1,911	$478	2	4	$2,500	$625
	-50%	2	4	$1,911	$478	2	4	$2,500	$625
Delivered Price	+50%	2	3	$2,587	$862	2	3	$3,303	$1,101
	-50%	3	5	$574	$115	3	4	$733	$183

[$850/ha total establishment cost, $10/ha annual maintenance, $0/green t harvest cost, transport 0km @ $0.046/green t/km, leaf to farm fodder value $40/green t]

Subsequent Harvest Sensitivity Analysis - In situ Farm Fodder Only, by stemwood productivity class [m³/ha/year]: *Atriplex nummularia.*

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
		Productivity class: p5 [7.5]				Productivity class: p10 [15]			
Baseline		1	3	$695	$232	1	3	$1,411	$470
Establishment & Cleanup	+50%	1	3	$695	$232	1	3	$1,411	$470
	-50%	1	3	$695	$232	1	3	$1,411	$470
Maintenance	+50%	1	3	$685	$228	1	3	$1,401	$467
	-50%	1	3	$706	$235	1	3	$1,421	$474
Harvest	+50%	1	3	$695	$232	1	3	$1,411	$470
	-50%	1	3	$695	$232	1	3	$1,411	$470
Distance or Transport	+500%	1	3	$695	$232	1	3	$1,411	$470
	+300%	1	3	$695	$232	1	3	$1,411	$470
	+100%	1	3	$695	$232	1	3	$1,411	$470
	+50%	1	3	$695	$232	1	3	$1,411	$470
	-50%	1	3	$695	$232	1	3	$1,411	$470
Delivered Price	+50%	1	3	$1,053	$351	1	3	$2,127	$709
	-50%	1	3	$337	$112	1	3	$695	$232
		Productivity class: p15 [22.5]				Productivity class: p20 [30]			
Baseline		1	3	$2,127	$709	1	3	$2,843	$948
Establishment & Cleanup	+50%	1	3	$2,127	$709	1	3	$2,843	$948
	-50%	1	3	$2,127	$709	1	3	$2,843	$948
Maintenance	+50%	1	3	$2,117	$706	1	3	$2,833	$944
	-50%	1	3	$2,137	$712	1	3	$2,853	$951
Harvest	+50%	1	3	$2,127	$709	1	3	$2,843	$948
	-50%	1	3	$2,127	$709	1	3	$2,843	$948
Distance or Transport	+500%	1	3	$2,127	$709	1	3	$2,843	$948
	+300%	1	3	$2,127	$709	1	3	$2,843	$948
	+100%	1	3	$2,127	$709	1	3	$2,843	$948
	+50%	1	3	$2,127	$709	1	3	$2,843	$948
	-50%	1	3	$2,127	$709	1	3	$2,843	$948

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
Delivered Price	+50%	1	3	$3,201	$1,067	1	3	$4,275	$1,425
	-50%	1	3	$1,053	$351	1	3	$1,411	$470
		Productivity class: p25 [37.5]				**Productivity class: p30 [45]**			
Baseline		1	3	$3,559	$1,186	1	3	$4,275	$1,425
Establishment & Cleanup	+50%	1	3	$3,559	$1,186	1	3	$4,275	$1,425
	-50%	1	3	$3,559	$1,186	1	3	$4,275	$1,425
Maintenance	+50%	1	3	$3,548	$1,183	1	3	$4,264	$1,421
	-50%	1	3	$3,569	$1,190	1	3	$4,285	$1,428
Harvest	+50%	1	3	$3,559	$1,186	1	3	$4,275	$1,425
	-50%	1	3	$3,559	$1,186	1	3	$4,275	$1,425
Distance or Transport	+500%	1	3	$3,559	$1,186	1	3	$4,275	$1,425
	+300%	1	3	$3,559	$1,186	1	3	$4,275	$1,425
	+100%	1	3	$3,559	$1,186	1	3	$4,275	$1,425
	+50%	1	3	$3,559	$1,186	1	3	$4,275	$1,425
	-50%	1	3	$3,559	$1,186	1	3	$4,275	$1,425
Delivered Price	+50%	1	3	$5,349	$1,783	1	3	$6,422	$2,141
	-50%	1	3	$1,769	$590	1	3	$2,127	$709

[$10/ha annual maintenance, $0/green t harvest cost, transport 0km @ $0.046/green t/km, leaf to farm fodder value $40/green t]

First Harvest Sensitivity Analysis - Off-farm Fodder Only, by stemwood productivity class [m³/ha/year]: *Atriplex nummularia.*

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
		Productivity class: p5				Productivity class: p10			
Baseline		n.r.	20	-$1,837	-$92	n.r.	6	-$269	-$45
Establishment & Cleanup	+50%	n.r.	20	-$2,640	-$132	n.r.	8	-$1,000	-$125
	-50%	n.r.	6	-$160	-$27	3	4	$260	$65
Maintenance	+50%	n.r.	20	-$1,935	-$97	n.r.	6	-$295	-$49
	-50%	n.r.	20	-$1,740	-$87	n.r.	6	-$243	-$41
Harvest	+50%	n.r.	20	-$1,955	-$98	n.r.	6	-$458	-$76
	-50%	n.r.	20	-$1,719	-$86	n.r.	6	-$80	-$13
Distance or Transport	+500%	n.r.	20	-$2,381	-$119	n.r.	20	-$2,963	-$148
	+300%	n.r.	20	-$2,164	-$108	n.r.	20	-$2,527	-$126
	+100%	n.r.	20	-$1,946	-$97	n.r.	6	-$443	-$74
	+50%	n.r.	20	-$1,892	-$95	n.r.	6	-$356	-$59
	-50%	n.r.	20	-$1,783	-$89	n.r.	6	-$182	-$30
Delivered Price	+50%	n.r.	7	-$392	-$56	3	4	$347	$87
	-50%	n.r.	20	-$1,991	-$100	n.r.	20	-$2,182	-$109
		Productivity class: p15				Productivity class: p20			
Baseline		3	4	$154	$39	3	4	$550	$138
Establishment & Cleanup	+50%	n.r.	6	-$378	-$63	4	5	$95	$19
	-50%	2	3	$503	$168	2	3	$839	$280
Maintenance	+50%	3	4	$139	$35	3	4	$535	$134
	-50%	3	4	$170	$42	3	4	$566	$141
Harvest	+50%	n.r.	5	-$53	-$11	3	4	$286	$72
	-50%	3	4	$352	$88	2	4	$815	$204
Distance or Transport	+500%	n.r.	20	-$3,544	-$177	n.r.	4	-$665	-$166
	+300%	n.r.	5	-$483	-$97	n.r.	4	-$179	-$45
	+100%	n.r.	5	-$34	-$7	3	4	$307	$77
	+50%	4	4	$63	$16	3	4	$429	$107
	-50%	3	4	$245	$61	2	4	$672	$168

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
Delivered Price	+50%	2	4	$1,038	$259	2	3	$1,308	$436
	-50%	n.r.	20	-$2,374	-$119	n.r.	20	-$2,565	-$128
		Productivity class: p25				**Productivity class: p30**			
Baseline		2	4	$947	$237	2	3	$1,027	$342
Establishment & Cleanup	+50%	3	4	$445	$111	3	4	$841	$210
	-50%	2	3	$1,176	$392	2	3	$1,512	$504
Maintenance	+50%	2	4	$931	$233	2	3	$1,016	$339
	-50%	2	4	$962	$241	2	3	$1,037	$346
Harvest	+50%	2	4	$616	$154	2	3	$737	$246
	-50%	2	4	$1,277	$319	2	3	$1,316	$439
Distance or Transport	+500%	n.r.	3	-$419	-$140	n.r.	3	-$304	-$101
	+300%	3	4	$35	$9	3	3	$228	$76
	+100%	2	4	$643	$161	2	3	$761	$254
	+50%	2	4	$795	$199	2	3	$894	$298
	-50%	2	4	$1,099	$275	2	3	$1,160	$387
Delivered Price	+50%	2	3	$1,883	$628	2	3	$2,458	$819
	-50%	n.r.	5	-$615	-$123	n.r.	5	-$522	-$104

[$850/ha total establishment cost, $10/ha annual maintenance, $5/green t harvest cost, transport 50km @ $0.046/green t/km, leaf and fine twig to feedlot/processed fodder value $40/green t]

Subsequent Harvest Sensitivity Analysis - Off-farm Fodder Only, by stemwood productivity class [m³/ha/year]: *Atriplex nummularia.*

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
		Productivity class: p5 [7.5]				Productivity class: p10 [15]			
Baseline		1	2	$333	$167	1	2	$677	$339
Establishment & Cleanup	+50%	1	2	$333	$167	1	2	$677	$339
	-50%	1	2	$333	$167	1	2	$677	$339
Maintenance	+50%	1	2	$328	$164	1	2	$672	$336
	-50%	1	2	$339	$169	1	2	$682	$341
Harvest	+50%	1	2	$292	$146	1	2	$594	$297
	-50%	1	2	$375	$188	1	2	$760	$380
Distance or Transport	+500%	1	2	$142	$71	1	2	$294	$147
	+300%	1	2	$218	$109	1	2	$447	$224
	+100%	1	2	$295	$148	1	2	$600	$300
	+50%	1	2	$314	$157	1	2	$639	$319
	-50%	1	2	$353	$176	1	2	$715	$358
Delivered Price	+50%	1	2	$566	$283	1	2	$1,143	$571
	-50%	1	2	$101	$50	1	2	$212	$106
		Productivity class: p15 [22.5]				Productivity class: p20 [30]			
Baseline		1	2	$1,021	$510	1	2	$1,365	$682
Establishment & Cleanup	+50%	1	2	$1,021	$510	1	2	$1,365	$682
	-50%	1	2	$1,021	$510	1	2	$1,365	$682
Maintenance	+50%	1	2	$1,016	$508	1	2	$1,359	$680
	-50%	1	2	$1,026	$513	1	2	$1,370	$685
Harvest	+50%	1	2	$896	$448	1	2	$1,198	$599
	-50%	1	2	$1,146	$573	1	2	$1,531	$766
Distance or Transport	+500%	1	2	$446	$223	1	2	$598	$299
	+300%	1	2	$676	$338	1	2	$904	$452
	+100%	1	2	$906	$453	1	2	$1,211	$606
	+50%	1	2	$963	$482	1	2	$1,288	$644
	-50%	1	2	$1,078	$539	1	2	$1,441	$721

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
Delivered Price	+50%	1	2	$1,719	$859	1	2	$2,295	$1,148
	-50%	1	2	$323	$161	1	2	$434	$217
		Productivity class: p25 [37.5]				**Productivity class: p30 [45]**			
Baseline		1	2	$1,708	$854	1	2	$2,052	$1,026
Establishment & Cleanup	+50%	1	2	$1,708	$854	1	2	$2,052	$1,026
	-50%	1	2	$1,708	$854	1	2	$2,052	$1,026
Maintenance	+50%	1	2	$1,703	$852	1	2	$2,047	$1,023
	-50%	1	2	$1,713	$857	1	2	$2,057	$1,029
Harvest	+50%	1	2	$1,500	$750	1	2	$1,802	$901
	-50%	1	2	$1,917	$958	1	2	$2,302	$1,151
Distance or Transport	+500%	1	2	$750	$375	1	2	$902	$451
	+300%	1	2	$1,133	$567	1	2	$1,362	$681
	+100%	1	2	$1,517	$758	1	2	$1,822	$911
	+50%	1	2	$1,612	$806	1	2	$1,937	$968
	-50%	1	2	$1,804	$902	1	2	$2,167	$1,084
Delivered Price	+50%	1	2	$2,872	$1,436	1	2	$3,448	$1,724
	-50%	1	2	$545	$272	1	2	$656	$328

[$10/ha annual maintenance, $5/green t harvest cost, transport 50km @ $0.046/green t/km, leaf and fine twig to feedlot/processed fodder value $40/green t]

First Harvest Sensitivity Analysis - Australian Pulpwood and Bioenergy, by stemwood productivity class [m³/ha/year]: *Eucalyptus viminalis* ssp. *cygnetensis*.

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
		Productivity class: p5				Productivity class: p10			
Baseline		n.r.	15	-$327	-$22	6	10	$565	$56
Establishment & Cleanup	+50%	n.r.	19	-$1,141	-$60	10	13	$113	$9
	-50%	7	10	$236	$24	4	9	$1,008	$112
Maintenance	+50%	n.r.	15	-$399	-$27	6	10	$518	$52
	-50%	n.r.	15	-$255	-$17	6	10	$611	$61
Harvest	+50%	n.r.	20	-$1,089	-$54	n.r.	20	-$587	-$29
	-50%	7	9	$288	$32	4	8	$1,506	$188
Distance or Transport	+500%	n.r.	20	-$1,177	-$59	n.r.	20	-$761	-$38
	+300%	n.r.	20	-$909	-$45	n.r.	16	-$145	-$9
	+100%	n.r.	17	-$523	-$31	8	12	$376	$31
	+50%	n.r.	16	-$423	-$26	7	11	$478	$43
	-50%	n.r.	14	-$235	-$17	6	10	$704	$70
Delivered Price	+50%	5	9	$756	$84	3	8	$2,357	$295
	-50%	n.r.	20	-$1,699	-$85	n.r.	20	-$1,806	-$90
		Productivity class: p15				Productivity class: p20			
Baseline		5	9	$1,298	$144	4	9	$2,098	$233
Establishment & Cleanup	+50%	6	10	$894	$89	5	9	$1,587	$176
	-50%	3	9	$1,809	$201	3	9	$2,609	$290
Maintenance	+50%	5	9	$1,256	$140	4	9	$2,057	$229
	-50%	5	9	$1,339	$149	4	9	$2,140	$238
Harvest	+50%	n.r.	18	-$66	-$4	12	17	$391	$23
	-50%	3	8	$2,791	$349	2	8	$4,076	$509
Distance or Transport	+500%	n.r.	20	-$346	-$17	17	20	$70	$3
	+300%	9	15	$466	$31	7	14	$1,017	$73
	+100%	6	10	$1,004	$100	5	9	$1,554	$173
	+50%	5	9	$1,093	$121	4	9	$1,826	$203
	-50%	4	9	$1,502	$167	4	9	$2,371	$263

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
Delivered Price	+50%	3	8	$4,068	$508	2	8	$5,778	$722
	-50%	n.r.	20	-$1,913	-$96	n.r.	20	-$2,020	-$101
		Productivity class: p25				Productivity class: p30			
Baseline		4	9	$2,899	$322	3	9	$3,700	$411
Establishment & Cleanup	+50%	4	9	$2,388	$265	4	9	$3,189	$354
	-50%	3	8	$3,039	$380	2	8	$3,761	$470
Maintenance	+50%	4	9	$2,858	$318	3	9	$3,659	$407
	-50%	3	9	$2,940	$327	3	9	$3,741	$416
Harvest	+50%	10	17	$852	$50	9	16	$1,239	$77
	-50%	2	8	$5,361	$670	2	7	$5,819	$831
Distance or Transport	+500%	13	19	$469	$25	11	18	$826	$46
	+300%	7	13	$1,496	$115	6	13	$2,050	$158
	+100%	4	9	$2,218	$246	4	9	$2,883	$320
	+50%	4	9	$2,559	$284	4	9	$3,291	$366
	-50%	3	9	$3,239	$360	3	8	$3,654	$457
Delivered Price	+50%	2	8	$7,488	$936	2	8	$9,199	$1,150
	-50%	n.r.	20	-$2,126	-$106	n.r.	20	-$2,233	-$112

[$740/ha total establishment cost, $10/ha annual maintenance, $20/green t harvest cost, transport 50km @ $0.046/green t/km, pulpwood chips delivered price $45/green t, biomass for electricity generation delivered price $20/green t]

Subsequent Harvest Sensitivity Analysis - Australian Pulpwood and Bioenergy, by stemwood productivity class [m³/ha/year]: *Eucalyptus viminalis* ssp. *cygnetensis*.

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
		Productivity class: p5 [7.5]				Productivity class: p10 [15]			
Baseline		2	8	$1,010	$126	1	8	$2,092	$262
Establishment & Cleanup	+50%	2	8	$1,010	$126	1	8	$2,092	$262
	-50%	2	8	$1,010	$126	1	8	$2,092	$262
Maintenance	+50%	2	8	$974	$122	1	8	$2,056	$257
	-50%	1	8	$1,046	$131	1	8	$2,128	$266
Harvest	+50%	6	14	$454	$32	6	14	$1,041	$74
	-50%	1	6	$1,418	$236	1	6	$2,887	$481
Distance or Transport	+500%	8	16	$369	$23	7	16	$892	$56
	+300%	4	10	$566	$57	3	10	$1,226	$123
	+100%	2	8	$816	$102	2	8	$1,703	$213
	+50%	2	8	$913	$114	2	8	$1,898	$237
	-50%	1	8	$1,107	$138	1	8	$2,287	$286
Delivered Price	+50%	1	7	$2,205	$315	1	7	$4,471	$639
	-50%	n.r.	20	-$355	-$18	n.r.	20	-$516	-$26
		Productivity class: p15 [22.5]				Productivity class: p20 [30]			
Baseline		1	8	$3,174	$397	1	8	$4,257	$532
Establishment & Cleanup	+50%	1	8	$3,174	$397	1	8	$4,257	$532
	-50%	1	8	$3,174	$397	1	8	$4,257	$532
Maintenance	+50%	1	8	$3,138	$392	1	8	$4,220	$528
	-50%	1	8	$3,210	$401	1	8	$4,293	$537
Harvest	+50%	6	14	$1,629	$116	6	14	$2,216	$158
	-50%	1	6	$4,357	$726	1	6	$5,826	$971
Distance or Transport	+500%	7	16	$1,416	$88	7	16	$1,939	$121
	+300%	3	10	$1,885	$188	3	10	$2,544	$254
	+100%	2	8	$2,591	$324	2	8	$3,479	$435
	+50%	1	8	$2,883	$360	1	8	$3,868	$483
	-50%	1	8	$3,466	$433	1	8	$4,645	$581

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
Delivered Price	+50%	1	7	$6,738	$963	1	7	$9,004	$1,286
	-50%	n.r.	20	-$676	-$34	n.r.	20	-$836	-$42
		Productivity class: p25 [37.5]				**Productivity class: p30 [45]**			
Baseline		1	8	$5,339	$667	1	8	$6,421	$803
Establishment & Cleanup	+50%	1	8	$5,339	$667	1	8	$6,421	$803
	-50%	1	8	$5,339	$667	1	8	$6,421	$803
Maintenance	+50%	1	8	$5,303	$663	1	8	$6,385	$798
	-50%	1	8	$5,375	$672	1	8	$6,457	$807
Harvest	+50%	6	14	$2,804	$200	6	14	$3,391	$242
	-50%	1	6	$7,295	$1,216	1	6	$8,765	$1,461
Distance or Transport	+500%	7	16	$2,462	$154	7	16	$2,986	$187
	+300%	3	10	$3,203	$320	3	10	$3,862	$386
	+100%	2	8	$4,367	$546	2	8	$5,255	$657
	+50%	1	8	$4,853	$607	1	8	$5,838	$730
	-50%	1	8	$5,825	$728	1	8	$7,004	$876
Delivered Price	+50%	1	7	$11,271	$1,610	1	7	$13,537	$1,934
	-50%	n.r.	20	-$997	-$50	n.r.	20	-$1,157	-$58

[$10/ha annual maintenance, $20/green t harvest cost, transport 50km @ $0.046/green t/km, pulpwood chips delivered price $45/green t, biomass for electricity generation delivered price $20/green t]

First Harvest Sensitivity Analysis - Fibreboard/Particleboard and Bioenergy, by stemwood productivity class [m³/ha/year]: *Eucalyptus viminalis* ssp. *cygnetensis*.

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
		Productivity class: p5				Productivity class: p10			
Baseline		n.r.	20	-$1,238	-$62	n.r.	20	-$885	-$44
Establishment & Cleanup	+50%	n.r.	20	-$1,937	-$97	n.r.	20	-$1,583	-$79
	-50%	n.r.	20	-$540	-$27	n.r.	14	-$88	-$6
Maintenance	+50%	n.r.	20	-$1,336	-$67	n.r.	20	-$982	-$49
	-50%	n.r.	20	-$1,141	-$57	n.r.	20	-$787	-$39
Harvest	+50%	n.r.	20	-$1,821	-$91	n.r.	20	-$2,050	-$102
	-50%	n.r.	13	-$348	-$27	5	9	$556	$62
Distance or Transport	+500%	n.r.	20	-$1,908	-$95	n.r.	20	-$2,225	-$111
	+300%	n.r.	20	-$1,640	-$82	n.r.	20	-$1,689	-$84
	+100%	n.r.	20	-$1,372	-$69	n.r.	20	-$1,153	-$58
	+50%	n.r.	20	-$1,305	-$65	n.r.	20	-$1,019	-$51
	-50%	n.r.	20	-$1,171	-$59	n.r.	17	-$625	-$37
Delivered Price	+50%	n.r.	11	-$91	-$8	4	9	$931	$103
	-50%	n.r.	20	-$2,065	-$103	n.r.	20	-$2,537	-$127
		Productivity class: p15				Productivity class: p20			
Baseline		n.r.	16	-$395	-$25	n.r.	14	-$42	-$3
Establishment & Cleanup	+50%	n.r.	20	-$1,229	-$61	n.r.	17	-$722	-$42
	-50%	8	12	$207	$17	6	11	$463	$42
Maintenance	+50%	n.r.	16	-$473	-$30	n.r.	14	-$109	-$8
	-50%	n.r.	16	-$318	-$20	13	14	$25	$2
Harvest	+50%	n.r.	20	-$2,279	-$114	n.r.	20	-$2,507	-$125
	-50%	4	8	$1,259	$157	3	8	$2,033	$254
Distance or Transport	+500%	n.r.	20	-$2,541	-$127	n.r.	20	-$2,857	-$143
	+300%	n.r.	20	-$1,737	-$87	n.r.	20	-$1,785	-$89
	+100%	n.r.	20	-$933	-$47	n.r.	20	-$713	-$36
	+50%	n.r.	19	-$694	-$37	n.r.	17	-$358	-$21
	-50%	n.r.	14	-$147	-$11	8	12	$225	$19

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
Delivered Price	+50%	3	8	$1,770	$221	3	8	$2,714	$339
	-50%	n.r.	20	-$3,010	-$151	n.r.	20	-$3,483	-$174
		Productivity class: p25				Productivity class: p30			
Baseline		9	13	$261	$20	7	12	$528	$44
Establishment & Cleanup	+50%	n.r.	16	-$347	-$22	14	14	$4	$0
	-50%	5	10	$675	$68	5	10	$934	$93
Maintenance	+50%	9	13	$199	$15	7	12	$471	$39
	-50%	8	13	$323	$25	7	12	$584	$49
Harvest	+50%	n.r.	20	-$2,736	-$137	n.r.	20	-$2,965	-$148
	-50%	3	8	$2,808	$351	2	7	$3,151	$450
Distance or Transport	+500%	n.r.	20	-$3,173	-$159	n.r.	20	-$3,489	-$174
	+300%	n.r.	20	-$1,833	-$92	n.r.	20	-$1,881	-$94
	+100%	n.r.	19	-$467	-$25	n.r.	18	-$237	-$13
	+50%	n.r.	16	-$74	-$5	11	15	$186	$12
	-50%	7	11	$549	$50	6	10	$824	$82
Delivered Price	+50%	2	8	$3,659	$457	2	7	$4,040	$577
	-50%	n.r.	20	-$3,956	-$198	n.r.	20	-$4,428	-$221

[$740/ha total establishment cost, $10/ha annual maintenance, $20/green t harvest cost, transport 50km @ $0.046/green t/km, MDF chips delivered price $30/green t, biomass for electricity generation delivered price $20/green t]

Subsequent Harvest Sensitivity Analysis - Fibreboard/Particleboard and Bioenergy, by stemwood productivity class [m³/ha/year]: *Eucalyptus viminalis* ssp. *cygnetensis*.

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
		Productivity class: p5 [7.5]				Productivity class: p10 [15]			
Baseline		2	9	$275	$31	2	9	$633	$70
Establishment & Cleanup	+50%	2	9	$275	$31	2	9	$633	$70
	-50%	2	9	$275	$31	2	9	$633	$70
Maintenance	+50%	3	9	$234	$26	2	9	$592	$66
	-50%	2	9	$317	$35	2	9	$675	$75
Harvest	+50%	n.r.	20	-$538	-$27	n.r.	20	-$882	-$44
	-50%	1	5	$718	$144	1	5	$1,477	$295
Distance or Transport	+500%	n.r.	20	-$669	-$33	n.r.	20	-$1,144	-$57
	+300%	n.r.	20	-$267	-$13	n.r.	20	-$340	-$17
	+100%	6	13	$123	$9	6	13	$370	$28
	+50%	4	9	$173	$19	3	9	$429	$48
	-50%	2	8	$341	$43	2	8	$755	$94
Delivered Price	+50%	1	6	$1,045	$174	1	6	$2,141	$357
	-50%	n.r.	20	-$904	-$45	n.r.	20	-$1,613	-$81
		Productivity class: p15 [22.5]				Productivity class: p20 [30]			
Baseline		2	9	$991	$110	2	9	$1,349	$150
Establishment & Cleanup	+50%	2	9	$991	$110	2	9	$1,349	$150
	-50%	2	9	$991	$110	2	9	$1,349	$150
Maintenance	+50%	2	9	$950	$106	2	9	$1,308	$145
	-50%	2	9	$1,033	$115	2	9	$1,391	$155
Harvest	+50%	n.r.	20	-$1,225	-$61	n.r.	20	-$1,568	-$78
	-50%	1	5	$2,237	$447	1	5	$2,996	$599
Distance or Transport	+500%	n.r.	20	-$1,618	-$81	n.r.	20	-$2,092	-$105
	+300%	n.r.	20	-$412	-$21	n.r.	20	-$484	-$24
	+100%	5	13	$617	$47	5	13	$864	$66
	+50%	3	9	$685	$76	3	9	$941	$105
	-50%	2	8	$1,168	$146	1	8	$1,582	$198

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
Delivered Price	+50%	1	6	$3,237	$540	1	6	$4,334	$722
	-50%	n.r.	20	-$2,322	-$116	n.r.	20	-$3,031	-$152
		Productivity class: p25 [37.5]				**Productivity class: p30 [45]**			
Baseline		2	9	$1,707	$190	2	9	$2,065	$229
Establishment & Cleanup	+50%	2	9	$1,707	$190	2	9	$2,065	$229
	-50%	2	9	$1,707	$190	2	9	$2,065	$229
Maintenance	+50%	2	9	$1,666	$185	2	9	$2,024	$225
	-50%	2	9	$1,748	$194	2	9	$2,106	$234
Harvest	+50%	n.r.	20	-$1,911	-$96	n.r.	20	-$2,254	-$113
	-50%	1	5	$3,755	$751	1	5	$4,515	$903
Distance or Transport	+500%	n.r.	20	-$2,567	-$128	n.r.	20	-$3,041	-$152
	+300%	n.r.	20	-$557	-$28	n.r.	20	-$629	-$31
	+100%	5	13	$1,111	$85	5	13	$1,358	$104
	+50%	3	9	$1,197	$133	3	9	$1,453	$161
	-50%	1	8	$1,995	$249	1	8	$2,408	$301
Delivered Price	+50%	1	6	$5,430	$905	1	6	$6,527	$1,088
	-50%	n.r.	20	-$3,740	-$187	n.r.	20	-$4,449	-$222

[$10/ha annual maintenance, $20/green t harvest cost, transport 50km @ $0.046/green t/km, MDF chips delivered price $30/green t, biomass for electricity generation delivered price $20/green t]

Phase Crop Harvest Sensitivity Analysis - Australian Pulpwood, On-farm Fodder and Bioenergy, by stemwood productivity class [m³/ha/year]: *Acacia retinodes* var. *retinodes*.

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
		Productivity class: p5				Productivity class: p10			
Baseline		n.r.	10	-$6	-$1	4	8	$987	$123
Establishment & Cleanup	+50%	n.r.	14	-$672	-$48	6	9	$582	$65
	-50%	4	8	$457	$57	3	7	$1,302	$186
Maintenance	+50%	n.r.	9	-$47	-$5	4	8	$951	$119
	-50%	9	10	$40	$4	4	8	$1,023	$128
Harvest	+50%	n.r.	17	-$699	-$41	8	10	$140	$14
	-50%	5	9	$482	$54	3	8	$1,915	$239
Distance or Transport	+500%	n.r.	16	-$709	-$44	8	9	$113	$13
	+300%	n.r.	13	-$377	-$29	5	9	$505	$56
	+100%	n.r.	10	-$108	-$11	4	8	$804	$101
	+50%	n.r.	10	-$57	-$6	4	8	$896	$112
	-50%	8	9	$43	$5	4	8	$1,079	$135
Delivered Price	+50%	4	8	$984	$123	2	7	$2,680	$383
	-50%	n.r.	20	-$1,510	-$76	n.r.	20	-$1,428	-$71
		Productivity class: p15				Productivity class: p20			
Baseline		3	8	$2,012	$252	3	7	$2,666	$381
Establishment & Cleanup	+50%	4	8	$1,517	$190	3	8	$2,542	$318
	-50%	2	7	$2,224	$318	2	6	$2,703	$451
Maintenance	+50%	3	8	$1,976	$247	3	7	$2,635	$376
	-50%	3	8	$2,049	$256	3	7	$2,697	$385
Harvest	+50%	5	9	$730	$81	4	9	$1,341	$149
	-50%	2	7	$3,025	$432	2	6	$3,769	$628
Distance or Transport	+500%	5	9	$722	$80	4	8	$1,207	$151
	+300%	4	8	$1,188	$149	3	8	$1,939	$242
	+100%	3	8	$1,738	$217	3	8	$2,672	$334
	+50%	3	8	$1,875	$234	3	7	$2,501	$357
	-50%	3	8	$2,150	$269	3	7	$2,831	$404

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
Delivered Price	+50%	2	6	$3,897	$649	2	6	$5,523	$921
	-50%	n.r.	20	-$1,347	-$67	n.r.	20	-$1,265	-$63
		Productivity class: p25				**Productivity class: p30**			
Baseline		2	7	$3,588	$513	2	7	$4,511	$644
Establishment & Cleanup	+50%	3	8	$3,568	$446	3	7	$4,030	$576
	-50%	2	6	$3,508	$585	2	6	$4,313	$719
Maintenance	+50%	2	7	$3,558	$508	2	7	$4,480	$640
	-50%	2	7	$3,619	$517	2	7	$4,542	$649
Harvest	+50%	4	8	$1,743	$218	3	8	$2,304	$288
	-50%	2	6	$4,956	$826	2	6	$6,144	$1,024
Distance or Transport	+500%	3	8	$1,774	$222	3	8	$2,342	$293
	+300%	3	8	$2,690	$336	2	7	$3,026	$432
	+100%	2	7	$3,176	$454	2	7	$4,016	$574
	+50%	2	7	$3,382	$483	2	7	$4,263	$609
	-50%	2	7	$3,795	$542	2	7	$4,758	$680
Delivered Price	+50%	2	6	$7,150	$1,192	2	6	$8,776	$1,463
	-50%	n.r.	20	-$1,183	-$59	n.r.	20	-$1,101	-$55

[$740/ha total establishment & cleanup cost, $10/ha annual maintenance, $18/green t harvest cost, transport 50km @ $0.046/green t/km, pulpwood chips delivered price $45/green t, leaf to farm fodder value $40/green t, biomass for electricity generation delivered price $20/green t]

Phase Crop Harvest Sensitivity Analysis - Australian Pulpwood, Off-farm Fodder and Bioenergy, by stemwood productivity class [m³/ha/year]: *Acacia retinodes* var. *retinodes*.

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
		Productivity class: p5				Productivity class: p10			
Baseline		n.r.	11	-$151	-$14	5	9	$823	$91
Establishment & Cleanup	+50%	n.r.	16	-$910	-$57	7	9	$312	$35
	-50%	5	9	$370	$41	3	8	$1,223	$153
Maintenance	+50%	n.r.	11	-$202	-$18	5	9	$782	$87
	-50%	n.r.	11	-$99	-$9	4	9	$864	$96
Harvest	+50%	n.r.	20	-$1,013	-$51	n.r.	15	-$261	-$17
	-50%	6	9	$401	$45	3	8	$1,758	$220
Distance or Transport	+500%	n.r.	20	-$1,093	-$55	n.r.	17	-$481	-$28
	+300%	n.r.	17	-$711	-$42	8	11	$115	$10
	+100%	n.r.	13	-$317	-$24	5	9	$574	$64
	+50%	n.r.	12	-$231	-$19	5	9	$699	$78
	-50%	n.r.	11	-$86	-$8	4	8	$845	$106
Delivered Price	+50%	4	8	$854	$107	3	7	$2,437	$348
	-50%	n.r.	20	-$1,631	-$82	n.r.	20	-$1,669	-$83
		Productivity class: p15				Productivity class: p20			
Baseline		3	8	$1,622	$203	3	8	$2,517	$315
Establishment & Cleanup	+50%	5	9	$1,276	$142	4	8	$2,022	$253
	-50%	2	7	$1,860	$266	2	7	$2,661	$380
Maintenance	+50%	3	8	$1,586	$198	3	8	$2,481	$310
	-50%	3	8	$1,658	$207	3	8	$2,553	$319
Harvest	+50%	8	12	$272	$23	6	10	$662	$66
	-50%	2	7	$2,803	$400	2	6	$3,496	$583
Distance or Transport	+500%	12	14	$38	$3	8	12	$435	$36
	+300%	5	9	$666	$74	4	9	$1,256	$140
	+100%	4	8	$1,266	$158	3	8	$2,043	$255
	+50%	4	8	$1,444	$181	3	8	$2,280	$285
	-50%	3	8	$1,800	$225	3	8	$2,754	$344

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
Delivered Price	+50%	2	7	$4,168	$595	2	6	$5,080	$847
	-50%	n.r.	20	-$1,707	-$85	n.r.	20	-$1,746	-$87
		Productivity class: p25				**Productivity class: p30**			
Baseline		3	8	$3,413	$427	2	7	$3,782	$540
Establishment & Cleanup	+50%	3	8	$2,917	$365	3	8	$3,812	$477
	-50%	2	7	$3,461	$494	2	7	$4,262	$609
Maintenance	+50%	3	8	$3,376	$422	2	7	$3,751	$536
	-50%	3	8	$3,449	$431	2	7	$3,813	$545
Harvest	+50%	5	9	$1,007	$112	5	9	$1,429	$159
	-50%	2	6	$4,615	$769	2	6	$5,735	$956
Distance or Transport	+500%	6	11	$784	$71	6	11	$1,178	$107
	+300%	4	9	$1,847	$205	3	8	$2,173	$272
	+100%	3	8	$2,820	$352	3	8	$3,596	$450
	+50%	3	8	$3,116	$390	2	8	$3,952	$494
	-50%	2	7	$3,254	$465	2	7	$4,109	$587
Delivered Price	+50%	2	6	$6,596	$1,099	2	6	$8,112	$1,352
	-50%	n.r.	20	-$1,784	-$89	n.r.	20	-$1,823	-$91

[$740/ha total establishment & cleanup cost, $10/ha annual maintenance, $20/green t harvest cost, transport 50km @ $0.046/green t/km, pulpwood chips delivered price $45/green t, leaf to feedlot delivered price $40/green t, biomass for electricity generation delivered price $20/green t]

First Harvest Sensitivity Analysis - Eucalyptus Oil and Bioenergy, by stemwood productivity class [m³/ha/year]: *Eucalyptus porosa.*

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
		Productivity class: p5				Productivity class: p10			
Baseline		n.r.	6	-$166	-$28	3	4	$534	$133
Establishment & Cleanup	+50%	n.r.	8	-$759	-$95	4	5	$181	$36
	-50%	3	4	$251	$63	2	3	$748	$249
Maintenance	+50%	n.r.	6	-$192	-$32	3	4	$518	$130
	-50%	n.r.	6	-$140	-$23	3	4	$549	$137
Harvest	+50%	n.r.	20	-$2,195	-$110	n.r.	4	-$323	-$81
	-50%	3	5	$372	$74	2	4	$1,391	$348
Distance or Transport	+500%	n.r.	20	-$2,099	-$105	n.r.	4	-$177	-$44
	+300%	n.r.	7	-$550	-$79	3	4	$107	$27
	+100%	n.r.	6	-$269	-$45	3	4	$392	$98
	+50%	n.r.	6	-$217	-$36	3	4	$463	$116
	-50%	n.r.	6	-$114	-$19	3	4	$605	$151
Delivered Price	+50%	3	5	$810	$162	2	4	$2,181	$545
	-50%	n.r.	20	-$2,344	-$117	n.r.	20	-$3,096	-$155
		Productivity class: p15				Productivity class: p20			
Baseline		2	4	$1,253	$313	2	3	$1,518	$506
Establishment & Cleanup	+50%	3	4	$816	$204	2	4	$1,536	$384
	-50%	2	3	$1,345	$448	2	3	$1,941	$647
Maintenance	+50%	2	4	$1,238	$309	2	3	$1,507	$502
	-50%	2	4	$1,269	$317	2	3	$1,528	$509
Harvest	+50%	n.r.	3	-$16	-$5	2	3	$267	$89
	-50%	2	4	$2,539	$635	2	3	$2,768	$923
Distance or Transport	+500%	3	3	$150	$50	2	3	$489	$163
	+300%	2	4	$613	$153	2	3	$901	$300
	+100%	2	4	$1,040	$260	2	3	$1,312	$437
	+50%	2	4	$1,146	$287	2	3	$1,415	$472
	-50%	2	4	$1,360	$340	2	3	$1,621	$540

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
Delivered Price	+50%	2	3	$2,831	$944	2	3	$4,063	$1,354
	-50%	n.r.	20	-$3,848	-$192	n.r.	20	-$4,600	-$230
		Productivity class: p25				**Productivity class: p30**			
Baseline		2	3	$2,114	$705	2	3	$2,710	$903
Establishment & Cleanup	+50%	2	4	$2,255	$564	2	3	$2,287	$762
	-50%	2	3	$2,537	$846	1	3	$3,133	$1,044
Maintenance	+50%	2	3	$2,103	$701	2	3	$2,699	$900
	-50%	2	3	$2,124	$708	2	3	$2,720	$907
Harvest	+50%	2	3	$550	$183	2	3	$834	$278
	-50%	2	3	$3,677	$1,226	2	3	$4,586	$1,529
Distance or Transport	+500%	2	3	$828	$276	2	3	$1,167	$389
	+300%	2	3	$1,342	$447	2	3	$1,784	$595
	+100%	2	3	$1,857	$619	2	3	$2,401	$800
	+50%	2	3	$1,985	$662	2	3	$2,555	$852
	-50%	2	3	$2,242	$747	2	3	$2,864	$955
Delivered Price	+50%	2	3	$5,296	$1,765	1	3	$6,528	$2,176
	-50%	n.r.	20	-$5,352	-$268	n.r.	20	-$6,104	-$305

[$740/ha total establishment cost, $10/ha annual maintenance, $25.5/green t harvest cost, transport 50km @ $0.046/green t/km, leaf for oil processed on-site, oil delivered price $2.5/kg, residual biomass for electricity generation delivered price $20/green t]

Subsequent Harvest Sensitivity Analysis - Eucalyptus Oil and Bioenergy, by stemwood productivity class [m³/ha/year]: *Eucalyptus porosa.*

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
		Productivity class: p5 [7.5]				Productivity class: p10 [15]			
Baseline		1	2	$584	$292	1	2	$1,179	$590
Establishment & Cleanup	+50%	1	2	$584	$292	1	2	$1,179	$590
	-50%	1	2	$584	$292	1	2	$1,179	$590
Maintenance	+50%	1	2	$579	$290	1	2	$1,174	$587
	-50%	1	2	$590	$295	1	3	$1,778	$593
Harvest	+50%	1	2	$314	$157	1	2	$638	$319
	-50%	1	3	$1,342	$447	1	3	$2,706	$902
Distance or Transport	+500%	1	2	$365	$182	1	2	$739	$370
	+300%	1	2	$453	$226	1	2	$915	$458
	+100%	1	2	$540	$270	1	2	$1,091	$546
	+50%	1	2	$562	$281	1	2	$1,135	$568
	-50%	1	3	$912	$304	1	3	$1,845	$615
Delivered Price	+50%	1	3	$1,828	$609	1	3	$3,677	$1,226
	-50%	1	1	$0	$0	1	1	$10	$10
		Productivity class: p15 [22.5]				Productivity class: p20 [30]			
Baseline		1	3	$2,662	$887	1	3	$3,556	$1,185
Establishment & Cleanup	+50%	1	3	$2,662	$887	1	3	$3,556	$1,185
	-50%	1	3	$2,662	$887	1	3	$3,556	$1,185
Maintenance	+50%	1	2	$1,769	$884	1	3	$3,545	$1,182
	-50%	1	3	$2,672	$891	1	3	$3,566	$1,189
Harvest	+50%	1	2	$963	$481	1	2	$1,287	$644
	-50%	1	3	$4,069	$1,356	1	3	$5,432	$1,811
Distance or Transport	+500%	1	2	$1,114	$557	1	2	$1,489	$745
	+300%	1	2	$1,378	$689	1	2	$1,841	$921
	+100%	1	2	$1,642	$821	1	2	$2,193	$1,096
	+50%	1	2	$1,708	$854	1	2	$2,281	$1,140
	-50%	1	3	$2,777	$926	1	3	$3,710	$1,237

Variable		Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)	Break-even (years)	Max Return (years)	NPV (/ha)	AER (/ha)
Delivered Price	+50%	1	3	$5,526	$1,842	1	3	$7,374	$2,458
	-50%	1	1	$20	$20	1	1	$30	$30
		Productivity class: p25 [37.5]				**Productivity class: p30 [45]**			
Baseline		1	3	$4,450	$1,483	1	3	$5,344	$1,781
stablishment & Cleanup	+50%	1	3	$4,450	$1,483	1	3	$5,344	$1,781
	-50%	1	3	$4,450	$1,483	1	3	$5,344	$1,781
Maintenance	+50%	1	3	$4,439	$1,480	1	3	$5,334	$1,778
	-50%	1	3	$4,460	$1,487	1	3	$5,354	$1,785
Harvest	+50%	1	2	$1,612	$806	1	2	$1,936	$968
	-50%	1	3	$6,795	$2,265	1	3	$8,158	$2,719
Distance or Transport	+500%	1	2	$1,864	$932	1	2	$2,239	$1,120
	+300%	1	2	$2,304	$1,152	1	2	$2,767	$1,383
	+100%	1	2	$2,744	$1,372	1	2	$3,294	$1,647
	+50%	1	2	$2,853	$1,427	1	2	$3,426	$1,713
	-50%	1	3	$4,643	$1,548	1	3	$5,575	$1,858
Delivered Price	+50%	1	3	$9,223	$3,074	1	3	$11,072	$3,691
	-50%	1	1	$40	$40	1	1	$50	$50

[$10/ha annual maintenance, $25.5/green t harvest cost, transport 50km @ $0.046/green t/km, leaf for oil processed on-site, oil delivered price $2.5/kg, residual biomass for electricity generation delivered price $20/green t]

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