An Australian Government Initiative

Joint Venture Agroforestry Program

Rural Industries Research & Development Corporation

Forest & Wood Products Australia

Land & Water Australia

Potential agroforestry species and regional industries for lower rainfall southern Australia

FLORASEARCH 2

FUTURE FARM INDUSTRIES CRC

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FUTURE FARM INDUSTRIES CRC

A report for the RIRDC / L&WA / FWPA / MDBC
Joint Venture Agroforestry Program
Future Farm Industries CRC

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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, which was initiated in 2002, was developed to focus on the development of commercially viable woody crops for southern Australian agricultural regions. The project focuses on selecting and developing new crop species to supply feedstock for large-scale markets including wood products, renewable energy and fodder. New developments in prospective industry sectors are reviewed, prospective species are targeted for ongoing development, and the results from modelling of industry potential are provided that support the ongoing relevance and importance of this project.

This project was funded by the Joint Venture Agroforestry Program (JVAP), which is supported by three R&D corporations – Rural Industries Research and Development Corporation (RIRDC), Land & Water Australia (L&WA), and Forest and Wood Products Research and Development Corporation (FWPRDC[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]: SA Department of Water, Land and Biodiversity Conservation; WA Department of Environment and Conservation; Ensis/CSIRO Forestry and Forest Products; NSW Department of Primary Industries; and Victorian Department of Primary Industries.

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 input and helpful advice of project collaborators and interested supporters of the FloraSearch project is gratefully appreciated. This includes Rosemary Lott, Mike Ewing, Kevin Goss, Graeme Olsen, Don Cooper, Richard Mazanec, Brendan George, Malem McLeod, George Freischmidt, John Doran, Des Stackpole, Isla Grundy, Peter Milthorpe, Peter Jessop, Peter Butler, Andrew Fisher, Joe Landsberg and Julian Morison. The high quality of field surveys, trial site management, databases, administrative support would not have been possible without the support of Merv Tucker, Peter Georgaras, Gary Brennan, Julie Dean, Ligita Bligzna and a cast of many casual and contract field assistants.

Finally we would like to recognise and thank the warm-hearted and giving nature of numerous farmers and landholders across southern Australia for access to their cherished woodlots and revegetation efforts – even when we were armed with chainsaws and lance-like measuring poles.

Abbreviations

ABARE	Australian Bureau of Agricultural and Resource Economics
AER	Annual Equivalent Return
bdt	Bone Dry Tonne
CP	Crude Protein
CRC PBMDS	Cooperative Research Centre for Plant-based Management of Dryland Salinity
dbh	Diameter at Breast Height
dm	Dry Matter
ECe	Electrical Conductivity
FWPA	Forest & Wood Products Australia
FTWG	Field Trials of Woody Germplasm
GJ	Gigajoule
GWh	Gigawatt hour
IWP	Integrated Wood Processing
JVAP	Joint Venture Agroforestry Program
L&WA	Land & Water Australia
MAI	Mean Annual Increment
MDBC	Murray-Darling Basin Commission
MDF	Medium Density Fibreboard
ME	Metabolisable Energy
MJ	Megajoule
MW	Megawatt
NPV	Net Present Value
PJ	Petajoule
RIPA	Regional Industry Potential Analysis
RIRDC	Rural Industries Research and Development Corporation
SARDI	South Australian Research and Development Institute

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Executive summary

What the report is about

This report identifies Australian agroforestry and fodder shrub species with the greatest potential for development as broad scale commercial woody biomass crops in the lower rainfall regions of southern Australia. It also highlights the range of potential markets and 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 greatest potential for new agroforestry expansion or 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 southern Australia. It aims to influence decision makers at all levels involved in developing sustainable and productive agroforestry within Australian low rainfall farming systems.

Background

The overarching goal of FloraSearch is the development of commercially viable, broad scale woody perennial crops for low to medium rainfall agricultural areas of southern Australia. These crops need to be suited to integration with existing annual cropping and grazing systems providing a range of natural resource benefits (including improved dryland and stream salinity and improved resilience of agricultural systems in response to climatic variability) and forming the foundation of new, large-scale rural industries. The general rationale and methodology for this undertaking is described in Bennell *et al.* (2008) but since then there have been major developments in project structure, emerging issues in dealing with climate variability and technological developments in some product areas.

The FloraSearch project is about to enter its sixth year with two nodes of activity in Adelaide and Perth, with collaborating scientists in Victoria and NSW. The successful development of a unified approach has been greatly supported by the Cooperative Research Centre for Plant-based Management of Dryland Salinity (CRC PBMDS)[3] that has facilitated the networking. This report describes the first outputs of the project following the linking of the preceding WA Search Project and the eastern Australian focused FloraSearch Phase 1 project.

Aims and Objectives

The key objectives of FloraSearch Phase 2 are:

- Completion of a systematic survey of the native woody perennial flora of southern Australia's winter rainfall wheat-sheep zones, including selection and testing of species suitable for products identified in the FloraSearch Phase 1 and WA Search projects. This will capture eastern and western node information of prospective native species in a common database of attributes (based on existing information, including performance and product potential)
- Assessment of the agronomic suitability of development species for cultivation in the wheat-sheep belt including adaptability and productive potential

[3] 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.

- Production of a short list of species with merit for further evaluation as commercial crops (development species) or the subject of domestication in the next phase including plant improvement (focus species)
- Development and refinement of spatial analysis tools, to evaluate opportunities at the regional scale for new large-scale industries based on products from woody perennial production systems
- Contribution to the establishment of field trials to test the performance of development species, in conjunction with a related CRC PBMDS project.

Methods Used

Products and Markets

Potential products and markets identified by our earlier work have been reviewed and re-prioritised based on new information on trends of expected market volumes and prices. This information has been extracted from the literature, online historical and current industry market data for both national and international markets, and through discussions with current biomass industry collaborators.

Mindful that potential biomass markets are not static, we have been scanning commodity markets, environmental drivers, industry and political trends, and technological advances for emerging markets and industries that could potentially utilise large volumes of industrial feedstocks from short-cycle woody crop systems or create market values for environmental services such as carbon sequestration in the lower rainfall regions of southern Australia.

Species Evaluation

Species evaluation, product testing and performance information on native woody perennial plants from the FloraSearch Phase 1 research for eastern Australia has been merged with data from the Western Australian Search project. The combined database now covers potential agroforestry species for the wheat-sheep zone of all of southern Australia. Many of the species identified with the highest potential for development have been subject to additional regional suitability and productivity assessments from the collation of existing field trials data, new plantation surveys and evaluations of new field trials established by FloraSearch in partnership with the CRC-funded "Field Trials of Woody Germplasm" project. Concurrently, several new plantations and provenances of high priority species have been subject to additional laboratory testing of wood density, pulp yields, paper-making qualities and nutritional values for livestock fodder.

Results from these additional surveys, product testing and analysis have been used to prioritise the species and provenances with the greatest potential for development. Additional literature searches and evaluations have been conducted for the most highly ranked species to better understand their taxonomy and crop potential. This process has identified a short-list of species nominated for further evaluations, plant breeding, germplasm development and domestication.

Regional Industry Potential Analysis

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. This geographic information system-based economic modelling provides an opportunity to evaluate the potential perennial crop industries described in the report. This work was first described in the FloraSearch Phase 1 report (Bennell *et al.* 2008) and was based on early estimates of productivity and foundation analyses. This work has progressed and is becoming a sophisticated tool able to support the systematic regional evaluation of perennial crop options. It incorporates improved species knowledge including productivity estimates, product development and updated costs and returns, refinement in the modelling process and now includes the WA region.

Results / Key Findings

Products and Markets

Wood products (pulp and paper, fibreboard and particle board) remain as a high priority industry with continued high level policy comment on the huge net import of wood fibre products into Australian in the order of $2 billion annually, major new infrastructure developments (pulp mills) proposed for the southeast of SA and western Victoria, and concerns by some sectors of the forest products industry about future short fall in feedstock availability.

Australian and world energy consumption is continuing to increase. In Australia, electricity generation is predominantly based on black and brown coal deposits and opportunities exist for greater use of woody biomass to generate electricity either as a coal replacement (or blend) in existing solid fuel plants or as a co-product in a Narrogin style integrated wood processing facility. World oil prices have escalated from around US$25 per barrel in 2001 to over US$60 per barrel in 2006. The Australian Biofuels Taskforce has recently reported to the Prime Minister on status, potential and issues of biofuels development and adoption in Australia. This report states a target of 350ML of biofuels by 2010 and focuses on the viability of ethanol and biodiesel in the current policy and market environment. They recommend that the potential of lignocellulosic feedstocks for ethanol production be thoroughly assessed before any major commitment is made to other ethanol feedstocks and production opportunities. In North America and Europe the technology for production of ethanol from woody biomass is developing rapidly.

The metallurgical industry faces increasing pressure to reduce emissions of greenhouse gases from production of metals. The substitution of fossil carbon by renewable carbon from biomass has the potential to radically reduce the net carbon emissions from metallurgical processes. The high reactivity and low sulphur content of charcoal makes it an attractive metallurgical reductant. This opens up large potential markets for wood carbons as reductants.

Oldman Saltbush and the exotic Tagasaste or Lucerne Tree (*Chamaecytisus* spp.) have been widely used as a southern Australian fodder shrub crop for the last decade. The nutritional value of Oldman Saltbush on saline affected landscapes is reported to be diminished due to presence of high salt loads in the foliage on these sites (Lefroy 2002). However, the salt load in the foliage is much less significant on non-saline affected sites. Further, Oldman Saltbush provides a highly valued green feed resource during summer and autumn, when other typically annual fodder species are desiccated and are less nutritious. The green feed value of Oldman Saltbush crops during this time is at a level similar to that of lucerne pastures.

Climate change is emerging as a significant issue for federal and state governments and this has increased the relevance and opportunities for the research goals of FloraSearch. Carbon sequestration can now be considered as a product in its own right. The opportunities for renewable energy from biomass are expanding. There is also a growing realisation that agricultural production systems of the future need to account for the risk of increased climate variability. Robust and productive perennial plant species can make an important contribution to the resilience of future farming systems.

Species Evaluation

Recent surveys and product testing have revealed several significant advances in product yields and industrial suitability for some germplasm collections. Examples of this include the mallees *Eucalyptus polybractea* and *Eucalyptus horistes* where laboratory analysis has enabled selection of breeding populations with double the oil content of the average from random selection. Recent evaluation of *Eucalyptus cladocalyx* has discovered variants with lower wood densities that allow this species (with demonstrated high pulp yields) to be considered for paper making when previously the wood was too dense to be used in conventional pulp mills. Selections of *Eucalyptus globulus* spp. *bicostata* from low rainfall regions

(<400 mm annual rainfall) provide germplasm that can be utilised by the existing Tasmanian blue gum plantation industries in lower rainfall regions where current industry selections fail.

Concurrent with the testing program there has been a significant effort on improving the knowledge of the productive potential of the development species. The first year measurements at FloraSearch trial sites in SA, NSW, Victoria and WA are providing data on ease of establishment, levels of survival and growth rates. These are valuable in assessing the suitability of species to a range of site conditions, survival, growth rate and product yields under plantation environments. Many FloraSearch selections have not been used in revegetation activity before, and even failures (such as the difficulties in propagating and growing *Codonocarpus cotinifolius* – an otherwise ideal pulpwood and fibreboard species) provide important research data. Equally, a relatively unknown species such as *Viminaria juncea* is proving to have an exceptional growth rate in its early years. Side-by-side with the species evaluation process has been the development of improved methodologies to rapidly assess the productivity of woody crops. Most notable are the development of solid relationships (allometric equations) between plant height and stem area to determine stemwood and biomass accumulation rates.

The current highest priority species (or "Focus Species") include the fodder shrub Oldman Saltbush (*Atriplex nummularia*) for southern Australia, and Orange Wattle (*Acacia saligna*) for Western Australia, The next highest priority (or "Development Species") include: (alphabetically) *Acacia decurrens; Acacia lasiocalyx; Acacia mearnsii; Acacia retinodes* var. *retinodes; Anthocercis littorea; Casuarina obesa*; *Codonocarpus cotinifolius; Eucalyptus cladocalyx; Eucalyptus globulus* spp. *bicostata; Eucalyptus horistes; Eucalyptus loxophleba* ssp. *lissophloia; Eucalyptus occidentalis; Eucalyptus ovata; Eucalyptus polybractea; Eucalyptus rudis; Eucalyptus viminalis* ssp. *cygnetensis* and *Viminaria juncea.*

Regional Industry Potential Analysis

The Regional Industry Potential Analysis (RIPA) now covers the entire wheat-sheep zone of southern Australia. Spatial and economic information on industrial infrastructure, production costs and delivered feedstock values has been updated for this report and new analyses conducted for high priority biomass industry type. Analyses demonstrate expected landholder annual equivalent returns for the first 20 years of a range of short-cycle woody biomass in this lower rainfall region. The industry types presented here include pulpwood, fibreboards, electricity generation, eucalyptus oil, integrated wood processing, carbon sequestration and fodder shrub systems for livestock production.

The current analyses presented in this report show that many FloraSearch industries may be profitable in many locations across southern Australia. The potential profitability and sustainability of perennial woody crops can provide landholders with important options for long term diversification.

Recommendations

The evaluation of species will continue at a reduced level and be focused on evaluating provenance variability in growth rates, site suitability, product yields and matching development species to emerging industry types with greatest potential. The assessment of fodder value of selected woody species will continue and be expanded in conjunction with project work on grazing systems based on woody perennials in the Enrich project. We are also liaising on a project to evaluate charcoal use in metal smelting. The evaluation of feedstock value for lignocellulosic ethanol production may be considered.

Economic evaluation and spatial analysis of farm and industry economics will be refined as new data becomes available, such as improved industry and market knowledge flowing from related projects and improved understanding of the effects of biophysical factors on woody crop productivity, especially water movement and capture. Estimated farm returns from new industries will be compared to current land use options. This component of FloraSearch will have strong links with, and draw on results from, the CRC's New Industry and Marketing project. Utilising the economic and spatial tools described above we intend to undertake a case study of pilot industry development option(s) in conjunction with an industry partner.

Research into the domestication of selected focus and development species will be a central area of work. This includes germplasm collection and establishment of plant improvement trials for focus species. Multiple provenances will be collected for development species and included in the trials to collect field performance data. Future species development evaluation will also include weed and genetic pollution risks assessed in collaboration with related CRC programs and projects. Agronomic experimentation will be used to determine optimum plantation designs and management regimes.

1. Introduction

The overarching goal of FloraSearch is the development of commercially viable, broad scale woody perennial crops for low to medium rainfall agricultural areas of southern Australia. These crops need to be suited to integration with existing annual cropping and grazing systems providing a range of natural resource benefits (including improved dryland and stream salinity and improved resilience of agricultural systems in response to climatic variability) and forming the foundation of new, large-scale rural industries. The general rational and methodology for this undertaking is well described in the FloraSearch Phase 1 report (Bennell *et al.* 2008) but there have been major developments in project structure, emerging issues in dealing with climate variability and evolution in some product areas.

This report provides an update and expansion of earlier FloraSearch work as the project evolves from an initial context and screening phase (Phase 1) to a more targeted and development phase (Phase 2). This report should be read in conjunction with reports from the earlier FloraSearch (Bennell *et al.* 2008), WA Search (Olsen *et al.* 2004) and Acacia Search (Maslin and MacDonald 2004). These reports detail the process of selecting "best bet" species and industries for the current focus of FloraSearch research, species selection and prioritisation and regional industry potential analysis.

Within FloraSearch Phase 2 the earlier work of the Western Australian Search project has been amalgamated with the FloraSearch Phase 1 work conducted in southeastern Australia. The southeastern and southwestern nodes now contribute to the single FloraSearch project covering the entire wheat-sheep zone of southern Australia (see Figure 1).

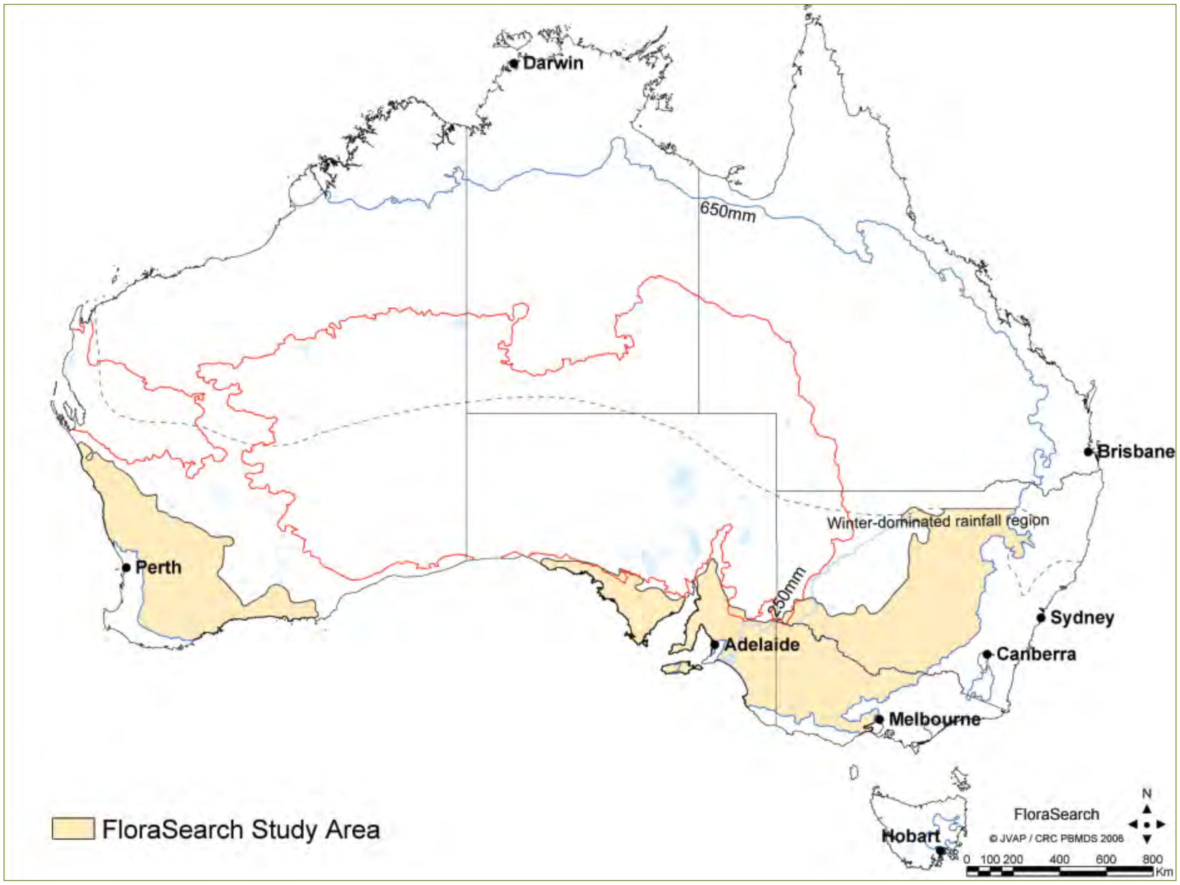
This report focuses on the following key components:

- An update of prospective FloraSearch industries and markets, reflecting emerging opportunities and new information on previously reported industries
- Completion of the initial screening process outlined in the FloraSearch (Phase 1) report, their product testing results and early evaluations of species/provenance variations in plant physical properties and product yields
- Continued evaluations of high priority species identified in the first phase of FloraSearch's research program to identify provenances with better growth potential and higher product yields
- Profiles of priority "Development" species researched further and discussions on the process of advancing the highest priority "Focus" species

- The assimilation of productivity data for "Development" and "Focus" species to enable more accurate estimates of plant growth and product yield, and to outline FloraSearch's involvement in evaluating prospective species using field trials across southern Australia
- A refinement of the Regional Industry Potential Analysis (RIPA) to encompass the southern Australian wheat-sheep zone, more detailed spatial predictions of woody crop yields, potential industries and farm economics.

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

Bounded by the low rainfall limit of cropping, summer dominated rainfall areas, and the 650 mm annual rainfall isohyet.



2. Product and market directions

The FloraSearch Phase 1 report (Bennell *et al.* 2008) and the WA Search report (Olsen *et al.* 2004) identified the most prospective industry types for the wheat-sheep zone of southern Australia. In the last few years there have been numerous changes in international and local markets for biomass products, energy demands and policies relating to primary production and the environment. These changes and trends influence the priority and value of the high priority or "best bet" industries identified in 2004 and identify emerging industries that may be serviced by woody crop production in the mid-low rainfall areas of Australia. The following sections provide updated information on previously identified high priority industries, and likely biomass related markets emerging from a world environment of higher fossil fuel costs, climate change, environmental awareness and advances in technology.

High Priority Industry Types

Wood Fibre Industries

The Australian Bureau of Agricultural and Resource Economics (ABARE) regularly produce summary statistics on the nature, volume and value of Australian wood production, imports and exports (ABARE 2004, 2005a). Australian forest industries consume around 20 million cubic metres of broad-leaved and coniferous logs every year to produce lumber, paper products and panel products for Australian and export markets (see Table 1 and Figure 2). Approximately 71% of this consumption is based on softwood coniferous forests (mainly Pinus spp.) with the remainder based on hardwood Eucalyptus species. Additionally, the export of pulpwood chips consumes around 5.6 million tonnes of chips, mainly from hardwood Eucalyptus species (see Table 2 and Table 3).

Focusing on the paper and paperboards, fibreboards and particleboards (part of the wood-based panel products sector) and woodchip components of that data, we can provide an indication of the scale and value of those market sectors within the current Australian forestry industry. These markets provide opportunities for new industry development in low rainfall zones to supplement or expand capacity in existing industries and markets. The paper and paperboard manufacturing industries consume the largest share by value (62%) of wood fibre supply in Australia, followed by woodchip exports (19%) and secondary paper manufactures (e.g. boxes, etc., 12%). The Australian consumption and export of paper products, pulp and woodchips was worth over $4506M/year in 2004-2005. The total value of imports and exports of wood fibre panel products in 2004-2005 was $467M/year, and is dominated by medium density fibreboards (81% by value), primarily from export markets.

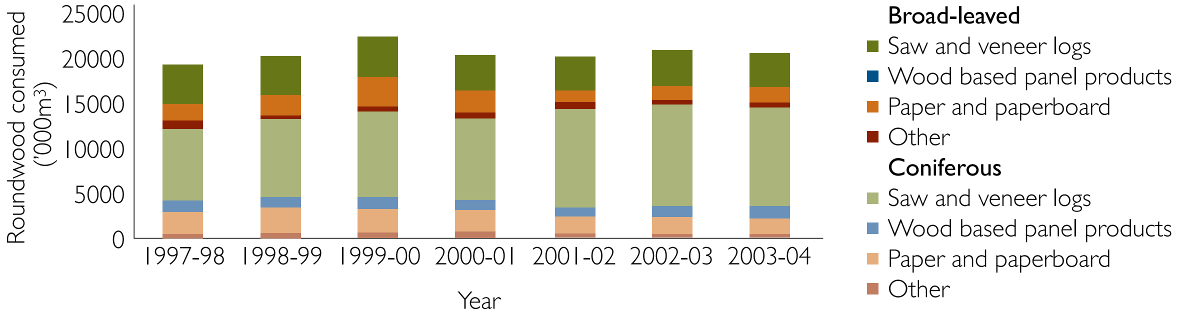
The volume of Australian consumption of total paper and paperboards has increased by over 21% in the last 5 years, 4% for fibre-based wood panels, 146% for recovered paper, 11% for pulp and 12% for woodchips (see Table 4). These trends are also reflected in Australian consumption and exports of paper and paperboard products, fibre-based panel boards and woodchips (see Figure 3, Figure 4 and Figure 5). Australia imports ($2876M/year) a greater value of manufactured wood fibre products (paper and panel fibre/particleboards) than it exports ($1838M/year) – a deficit that may be reduced by the encouragement of Australian manufacturing and lowering the cost of producing and harvesting Australian wood fibres.

Table 1. Volume of roundwood consumed by Australian forest industries in recent years.

Roundwood consumed ['000 m³]	1997-98	1998-99	1999-00	2000-01	2001-02	2002-03	2003-04
Broad-leaved							
Saw and veneer logs	3840	4015	4079	3562	3402	3623	3567
Wood based panel products	69	48	50	4	51	23	54
Paper and paperboard	2083	2407	3230	2568	1493	1595	1758
Other	130	111	383	388	421	440	407
Total	**6122**	**6580**	**7742**	**6522**	**5367**	**5681**	**5785**
Coniferous							
Saw and veneer logs	8258	8556	9425	8917	10793	10917	10739
Wood based panel products	1255	1039	1214	1026	953	1209	1012
Paper and paperboard	2412	2841	2623	2570	1881	1879	1951
Other	414	484	478	531	419	419	344
Total	**12338**	**12919**	**13740**	**13043**	**14046**	**14424**	**14046**
Broad-leaved and coniferous							
Saw and veneer logs	12098	12570	13504	12478	14195	14540	14306
Wood based panel products	1323	1087	1264	1029	1005	1233	1066
Paper and paperboard	4495	5248	5853	5138	3374	3474	3708
Other	544	595	861	919	840	859	750
Total	**18553**	**19549**	**21488**	**19565**	**19414**	**19433**	**19831**

Sources: ABARE 2004, 2005a

Figure 2. Volume of roundwood consumed by Australian forest industries in recent years.



Sources: ABARE 2004, 2005a

Table 2. Quantity and value of wood fibre imports in Australia in the last five years.

Imports Quantity	Unit	2000-01	2001-02	2002-03	2003-04	2004-05
Wood based panels						
Particleboard	'000 m^3	43.9	70.0	93.0	60.5	65.2
Hardboard	'000 m^3	8.2	7.3	8.0	12.8	21.7
Medium density fibreboard	'000 m^3	88.3	81.4	77.3	47.2	27.7
Softboard and other fibreboards	'000 m^3	33.5	19.9	21.9	15.2	17.0
Total	**'000 m^3**	**173.9**	**178.6**	**200.2**	**135.7**	**131.6**
Paper and paperboard						
Newsprint	kt	283.9	224.3	273.3	303.5	314.0
Printing and writing	kt	760.3	822.2	970.6	1099.1	1186.5
Household and sanitary	kt	54.8	55.9	66.7	84.6	77.9
Packaging and industrial	kt	310.8	212.9	144.1	153.7	175.2
Total	**kt**	**1409.8**	**1315.3**	**1454.7**	**1641.0**	**1753.6**
Recovered paper	kt	41.2	31.0	35.2	22.1	55.8
Pulp	kt	303.4	314.5	359.0	376.6	350.3
Woodchips	kt	3.1	0.3	0.4	0.5	0.8
Imports Value	**Unit**	**2000-01**	**2001-02**	**2002-03**	**2003-04**	**2004-05**
Wood based panels						
Particleboard	$m	13.8	18.7	21.5	17.2	24.4
Hardboard	$m	5.5	7.1	6.0	10.7	18.8
Medium density fibreboard	$m	34.7	31.7	29.4	22.9	15.0
Softboard and other fibreboards	$m	9.7	8.3	11.8	7.1	8.4
Total	**$m**	**63.7**	**65.8**	**68.7**	**57.9**	**66.6**
Paper and paperboard						
Newsprint	$m	277.5	219.8	243.9	261.0	260.7
Printing and writing	$m	1181.7	1261.9	1446.1	1422.5	1442.7
Household and sanitary	$m	94.7	102.5	117.9	137.9	127.9
Packaging and industrial	$m	534.1	407.0	303.2	280.8	306.6
Total	**$m**	**2088.0**	**1991.3**	**2111.2**	**2102.1**	**2137.9**
Paper manufactures (secondary)	$m	377.5	372.4	409.9	375.3	442.0
Recovered paper	$m	8.8	4.6	8.0	4.7	2.3
Pulp	$m	316.6	221.3	253.7	235.1	225.1
Woodchips	$m	1.4	1.2	1.5	1.4	2.0

Sources: ABARE 2004, 2005a

Table 3. Quantity and value of wood fibre exports in Australia in the last five years.

Exports Quantity	Unit	2000-01	2001-02	2002-03	2003-04	2004-05
Wood based panels						
Particleboard	'000 m³	97.9	100.0	54.5	31.8	13.5
Hardboard	'000 m³	12.8	11.0	7.7	11.5	7.8
Medium density fibreboard	'000 m³	389.1	402.6	405.4	357.4	364.6
Softboard and other fibreboards	'000 m³	10.4	14.1	26.5	17.5	14.5
Total	**'000 m³**	**510.2**	**527.7**	**494.1**	**418.2**	**400.4**
Paper and paperboard						
Newsprint	kt	2.4	1.6	2.5	0.3	1.6
Printing and writing	kt	100.3	236.3	199.9	158.7	174.7
Household and sanitary	kt	20.2	23.7	51.2	35.2	36.6
Packaging and industrial	kt	405.7	411.5	483.2	596.5	567.7
Total	kt	529.4	673.0	736.9	790.7	780.6
Recovered paper	kt	246.1	301.5	296.6	343.2	649.8
Pulp	kt	17.8	9.1	3.0	1.2	4.7
Woodchips	kt	5004.1	4720.7	5437.1	5263.9	5598.3
Exports Value	**Unit**	**2000-01**	**2001-02**	**2002-03**	**2003-04**	**2004-05**
Wood based panels						
Particleboard	$m	26.5	26.7	17.4	11.3	6.4
Hardboard	$m	10.6	6.0	4.0	5.8	4.5
Medium density fibreboard	$m	150.6	162.4	145.6	112.4	118.9
Softboard and other fibreboards	$m	6.7	10.2	9.9	9.3	11.4
Total	**$m**	**194.4**	**205.3**	**176.9**	**138.8**	**141.2**
Paper and paperboard						
Newsprint	$m	2.6	1.3	0.9	0.2	0.7
Printing and writing	$m	145.6	284.9	213.2	170.1	182.3
Household and sanitary	$m	80.4	94.8	97.2	117.0	102.2
Packaging and industrial	$m	300.1	315.4	314.4	342.3	336.5
Total	**$m**	**528.8**	**698.7**	**625.7**	**629.6**	**621.7**
Paper manufactures (secondary)	$m	83.8	101.6	156.8	136.1	116.1
Recovered paper	$m	39.7	55.5	49.6	52.6	96.6
Pulp	$m	4.6	2.8	2.1	1.4	4.4
Woodchips	$m	743.8	712.0	808.0	794.4	858.2

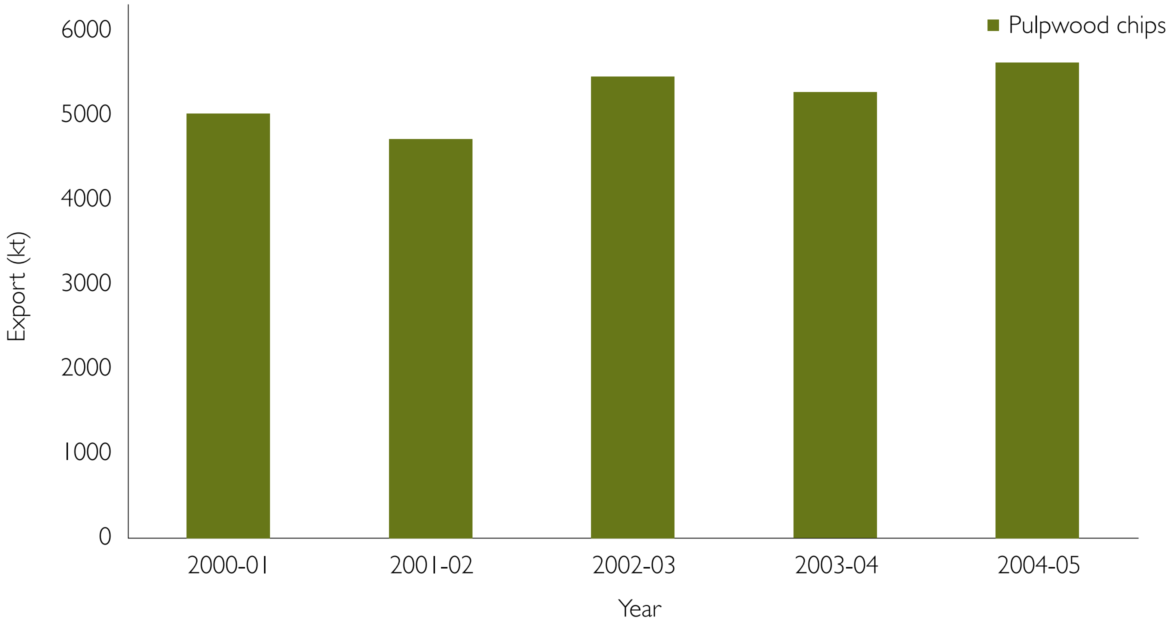
Sources: ABARE 2004, 2005a

Table 4. Volumes of production and imports of wood fibre products in Australia in the last five years.

Production and Import	Unit	2000-01	2001-02	2002-03	2003-04	2004-05
Wood based panels						
Particleboard	'000 m^3	947.9	1035.0	1118.0	1108.5	1008.2
Hardboard	'000 m^3	8.2	7.3	8.0	12.8	21.7
Medium density fibreboard	'000 m^3	800.3	813.4	863.3	842.2	821.7
Softboard and other fibreboards	'000 m^3	33.5	19.9	21.9	15.2	17.0
Total	**'000 m^3**	**1789.9**	**1875.6**	**2011.2**	**1978.7**	**1868.6**
Paper and paperboard						
Newsprint	kt	748.9	619.3	685.3	725.5	737.0
Printing and writing	kt	1314.3	1446.2	1534.6	1684.1	1790.5
Household and sanitary	kt	258.8	253.9	260.7	284.6	273.9
Packaging and industrial	kt	1759.8	1891.9	2036.1	2109.7	2155.2
Total	**kt**	**4081.8**	**4212.3**	**4515.7**	**4805.0**	**4956.6**
Recovered paper	kt	287.3	332.5	331.8	365.3	705.6
Pulp	kt	321.2	323.6	362.0	377.8	355.0
Woodchips	kt	5007.2	4721.0	5437.5	5264.4	5599.1

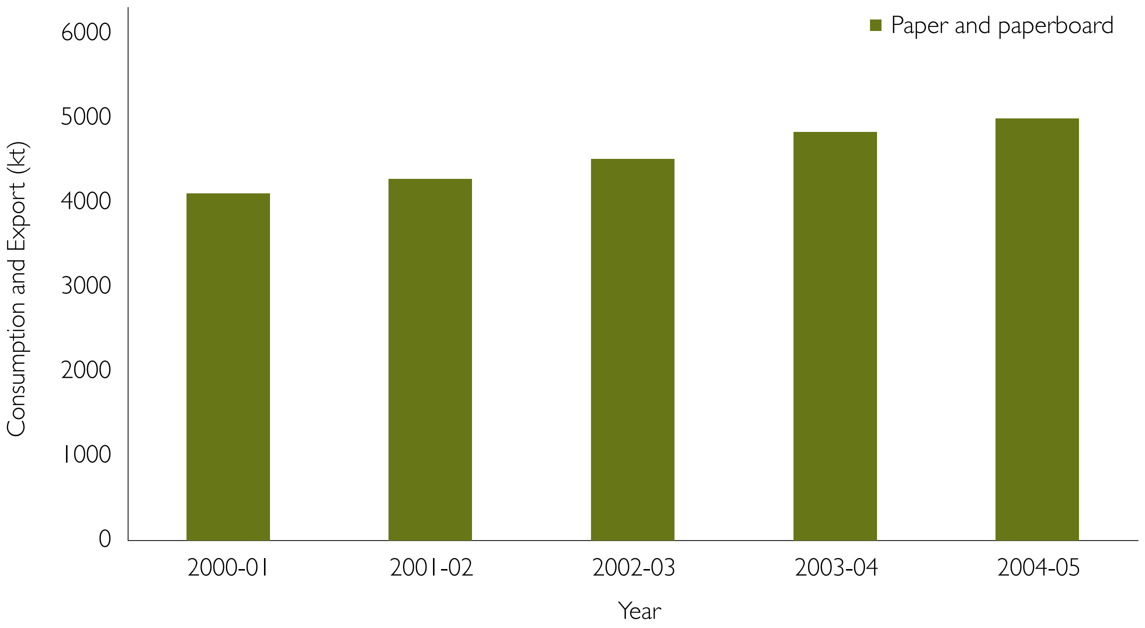
Sources: ABARE 2004, 2005a

Figure 3. Mass of pulpwood chips exported from Australia in recent years.



Sources: ABARE 2004, 2005a

Figure 4. Mass of paper and paperboard consumed within, and exported from, Australia.



Sources: ABARE 2004, 2005a

Delivered price

Export woodchips

Export hardwood (broad-leaved) pulpwood chip prices are measured in terms of Australian dollars per bone dry tonne ($/bdt). Recently these prices have increased by 11-57% from $93-146/bdt in 2001-02 to $162/bdt in 2005-06 (ABARE 2004, Neilson and Flynn 2006, Gunns 2006) with current exports having greater proportions of plantation woodchips. Standards are high within this sector and purchasers demand woodchips virtually free of bark and other contaminants. With a moisture content of approximately 45% by weight the 2006 freshwood chip value equates to approximate $90/green tonne for dryland plantation Eucalypts and Acacias.

Australian pulpwood

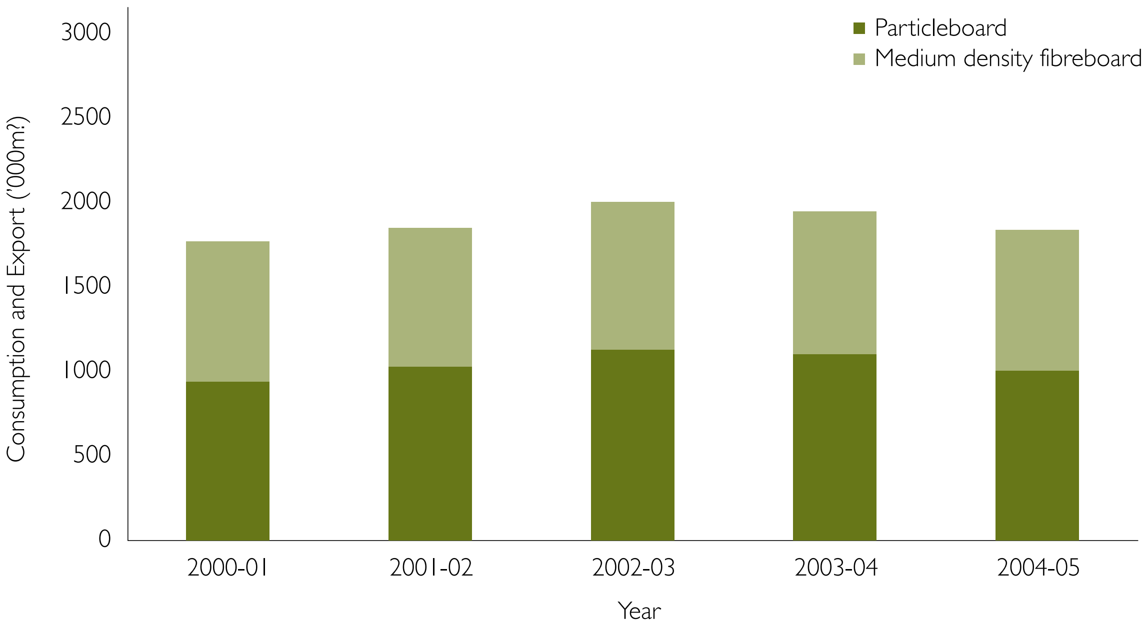
Australia pulpwood chips are typically valued per freshwood weight of approximately $80/green tonne for hardwood species and $50/green tonne for softwood species (George Freischmidt, pers. comm.). Feedstocks need to meet high quality standards, with low bark contaminants, to attract the best prices. A feedstock that has already been chipped in-field with significant contaminants removed prior to delivery is likely to have an average value at closer to $85/green tonne at the mill gate.

Medium density fibreboard

The FloraSearch 1 report did not discriminate between the value of wood fibre feedstocks intended for fibreboard and particleboard mills, however, more recent information from George Freischmidt (Ensis/CSIRO Forestry and Forests Products) suggests a greater difference in the mill gate price of these feedstocks.

The current mill gate price of logs used for medium density fibreboard (MDF) production in southeastern Australia is approximately $60/green tonne (range $50-70; George Freischmidt, pers. comm. 2006). These MDF log prices are dependent on logs with low

Figure 5. Volume of particleboards and medium density fibreboards consumed within, and exported from, Australia.



Source: ABARE 2004, 2005a

contaminants, especially bark detritus. A feedstock that has already been chipped and cleaned in-field is likely to have an average value at closer to $65/green tonne at the mill gate.

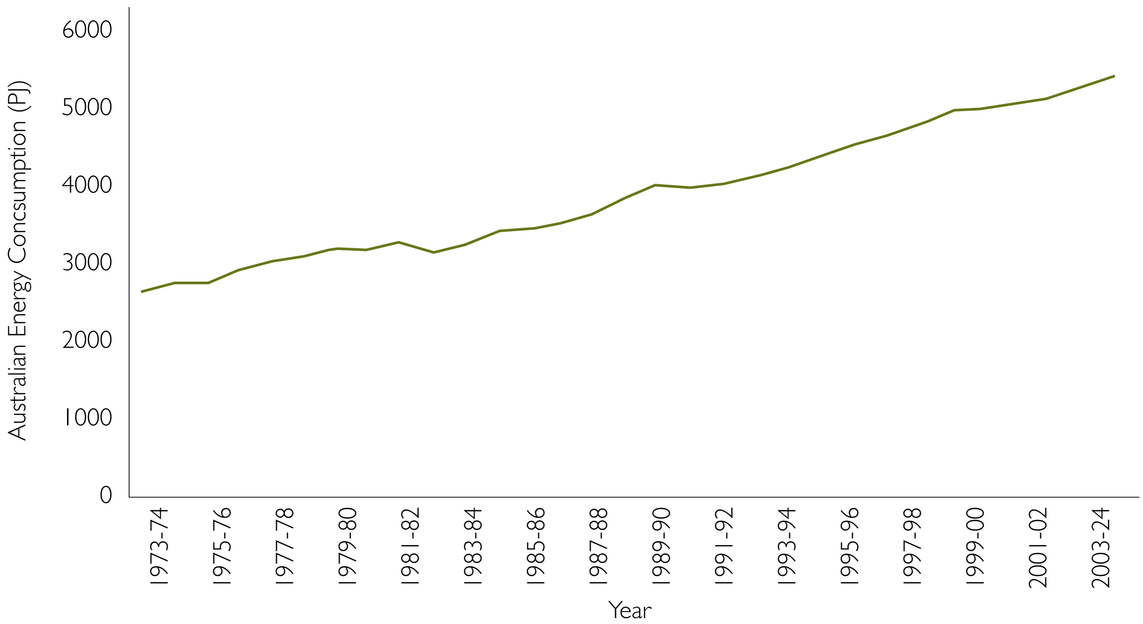
Particleboard

Logs and other raw wood sources for particleboard production in southeastern Australia are currently valued at approximately $40/green tonne at the mill gate (range $30-50; George Freischmidt, pers. comm.). Particleboard production can utilise poorer quality source material than paper and other fibreboard industries and are able to utilise sawdust, filler-like materials (e.g. regrind) and other coarser source materials. Particleboard mills often utilise wastewood streams from nearby or adjoining sawmills (such as the Benalla Particleboard Mill) which may result in poorer prices paid for alternate feedstock sources. A pre-chipped feedstock may attract a slightly higher premium of around $43/green tonne.

Bioenergy (electricity generation)

Australia currently consumes around 5500 Petajoules (1 PJ = 10^{15} joules) of energy ever year across its industrial, mining, agricultural, commercial and residential sectors (see Figure 6). Approximately 900PJ of energy is used to generate electricity (see Table 5). In Australia, electricity generation is predominantly based on black and brown coal deposits with current ABARE (2005b) forecasts expecting this heavy reliance on coal resources to continue. Our major coal resources, used to generate electricity, are widely variable in their inherent energy values largely due to their variable moisture and carbon contents (see Table 6 and Table 7). The value of thermal coals for both domestic and export markets have increased by at least 12% in recent years (see Table 8, ABARE 2005b).

Figure 6. Total energy consumption across all energy sectors in Australia since 1973-74.



Source: ABARE 2005b

Table 5. Current and projected electricity generation by fuel type in Australia.

Electricity generation, by fuel	2004-05 [PJ]	2009-10 [PJ]	2014-15 [PJ]	2019-20 [PJ]	2029-30 [PJ]
Thermal					
Black coal	469	513	578	640	757
Brown coal	187	199	211	226	256
Oil	11	11	12	13	15
Gas	128	157	184	221	321
Total thermal	**796**	**880**	**985**	**1101**	**1349**
Renewables					
Hydro	58	61	61	62	65
Wind	5.5	13.5	20.9	21.7	28.4
Biomass	3.3	5.4	7.4	11.2	23.1
Biogas	2.1	4.7	5.2	5.8	7.7
Total renewables	**69**	**85**	**94**	**101**	**124**

Source: ABARE 2005b

Table 6. Energy content of major solid fuels in Australia.

Type by Location	GJ/t		GJ/t
Black coal		**Black Coal (cont)**	
New South Wales		Western Australia	
Exports		Steaming coal	19.7
- coking coal	29.0	Tasmania	
- steaming coal	27.0	Steaming coal	22.8
Electricity generation	23.4		
Steelworks	30.0	**Brown Coal / Lignite**	
Washed steaming coal	27.0	Victorian brown coal	9.8
Unwashed steaming coal	23.9	South Australia	15.2
Queensland		Brown coal briquettes	22.1
Exports			
Coking coal	30.0	**Other**	
Steaming coal	27.0	Coke	27.0
Electricity generation	23.4	Wood (dry)	16.2
Other	23.0	Bagasse	9.6

Source: ABARE 2005b

Table 7. The calorific value and carbon content of major southern Australian coal resources.

Coal Type and Location	Gross Calorific Value #1 [GJ/dry t]	Carbon Content #1 [%dry weight]	Moisture Content #2 [%fresh weight]	Gross Calorific Value [GJ/fresh weight t]
Black Coal (Collie WA)	25.1	69.5	26.0	20.0
Black Coal (Hunter Valley NSW)	25.6	63.2	3.3	24.7
Black Coal (Liddle NSW)	20.7	50.6	3.3	20.0
Black Coal (Mt Piper NSW)	27.5	67.3	3.2	26.6
Brown Coal (Gippsland Vic)	26.4	67.5	60.6	10.4
Brown Coal (Leigh Creek SA)	21.2	54.3	31.0	15.1

Sources: #1 CSIRO Biofuels Database 2006; #2 DEH 2005.

Table 8. Recent historical, and predicted, volumes and values of Australia thermal coal exports.

Recent Years	**Unit**	**2000-01**	**2001-02**	**2002-03**	**2003-04**	**2004-05**
Volume	Mt	88.0	92.0	99.9	106.7	106.4
Value	A$m	4677	5722	4661	4481	6337
Unit value	A$/t	53.14	62.16	46.66	42.00	59.55
ABARE Forecast	**Unit**	**2005-06**	**2006-07**	**2007-08**	**2008-09**	**2009-10**
Volume	Mt	109.0	124.7	128.5	130.5	131.7
Value	A$m	6860	6954	6472	6038	5609
Unit value	A$t	62.90	56.40	50.40	46.30	42.60

Source: ABARE 2005b

Results from detailed destructive sampling of *Eucalyptus* (mainly mallees) and *Acacia* species in the wheat-sheep zone of South Australia provides us with information on biomass fractions and fresh weight water content of hardwood species (Hobbs and Bennell 2005, see Appendix A). The average moisture content of whole ten year old plants is 39% (range 34-44%), with no significant difference between Eucalypt and Acacia species. The average dry biomass ratio by weight of Stemwood: Twigs: Leaf and Fine Twigs was found to be 38:31:31.

The average gross calorific value of fresh weight biomass from Australian hardwood species is greater than some coal deposits used to generate electricity in Australia (see Table 9 and Table 7). Many current coal powered generation plants can readily accept 5% plant biomass blended with coal with no requirement for engineering modifications. Higher proportions of plant biomass are likely to require only minimal engineering changes in generation facilities.

Delivered price

Based on values of export thermal coal prices and relative calorific value of *Eucalyptus* and *Acacia* species compared with export grade Australian coal deposits, a likely delivered price of whole plant woody biomass for electricity generation would be $28/fresh weight tonne.

Eucalyptus Oil

The increased cost of petrochemical-based solvents and adhesives resulting from sustained higher world oil prices, and the declining use of more carcinogenic adhesive and preservatives (e.g. formaldehyde) in composite wood manufacturing has resulted in an improved market potential and price for many biomass extractives in local and international sectors (see Figure 7). ABARE (2004, 2005b; see Table 10) reports on the high import and export value of wood and biomass extractives, the stable demand for essential oils and the demonstrated trend of increasing value of lacquers, gums and resins in Australian exports and imports.

The reported world market consumes around 3000 tonnes/year of eucalyptus oil (mainly cineole), which is mainly produced in China, Portugal and India (OMC 2006). However, Australian production is ~7% (200 tonnes) of the world's production and is primarily destined for specialty fragrance markets. It appears there is currently a high demand for oil volumes and production levels appear to be increasing. Good growing conditions in China in 2005 has put forecasts of Chinese *Eucalyptus globulus* oil production in 2006 at 4500 tonnes with an expectation of prices remaining stable (FDL 2006). The cineole component of eucalyptus oil is well recognised for its degreasing and solvent

Table 9. The calorific value and carbon content of selected Australian hardwood species.

Species	Gross Calorific Value [#1] [GJ/dry t]	Carbon Content [#1] [%dry weight]	Moisture Content [#2] [%fresh weight]	Gross Calorific Value [GJ/fresh weight t]
Acacia saligna	19.1	49.4	*39.0*	11.5
Atriplex nummularia	16.8	42.3	39.0	9.2
Corymbia maculata	19.1	48.7	39.0	11.4
Eucalyptus camaldulensis	19.4	49.5	39.0	11.8
Eucalyptus cladocalyx	19.0	49.0	*39.0*	11.4
Eucalyptus cneorifolia	19.9	49.9	39.0	12.3
Eucalyptus globulus	19.2	49.1	39.0	11.6
Eucalyptus grandis	18.8	48.8	39.0	11.2
Eucalyptus horistes	20.0	49.0	39.0	12.4
Eucalyptus occidentalis	19.0	49.3	39.0	11.4
Eucalyptus sideroxylon	19.9	50.9	39.0	12.3
Eucalyptus polybractea	19.7	48.7	39.0	12.1
Melaleuca uncifolia	20.9	52.0	39.0	13.3
Average Eucalypt/Acacia	19.4	49.3	39.0	11.8

Sources: [#1]CSIRO Biofuels Database 2006; [#2]Average moisture content of whole native plants (*estimated for species*) Hobbs & Bennell 2005.

Table 10. The value of extractives and other miscellaneous forest products.

Miscellaneous forest products	Unit	2000-01	2001-02	2002-03	2003-04	2004-05
Imports						
Lac, gums and resins	$'000	6289	7998	8307	7288	10087
Essential oils	$'000	10839	10437	12750	11391	11066
Rosins and wood tar	$'000	251	151	97	87	34
Fuel wood	$'000	65	75	79	40	69
Wood charcoal	$'000	354	276	287	590	806
Exports						
Lac, gums, resins etc	$'000	1901	2348	1148	1918	9750
Eucalypt oils	$'000	1981	2175	1783	2965	2003
Rosins and wood tar	$'000	638	533	398	73	12
Fuelwood	$'000	1853	23	20	2003	32
Wood charcoal	$'000	1342	2068	2070	2655	3412

Source: ABARE 2005b

properties. Large potential markets exist for this purpose after the implementation of measures to eliminate the use of the petrochemical-based Trichloroethane, an ozone depleting chemical, during the 1990s. Other essential oils extracted from *Eucalyptus* leaves are very highly prized for their medicinal, anti-fouling and other properties which would attract premium prices in niche markets. Recent reports (GHC 2006) have priced this year's *Eucalyptus globulus* oil at US$4.40/kg (A$7.52/kg using US dollar exchange rate of 0.5850, RBA 29/03/2006), Eucalyptol (cineole 99.5%) at US$6.50/kg (A$11.11/kg) and Brazilian *Eucalyptus citriodora* oil at US$7.50/kg (A$12.82/kg).

Delivered price

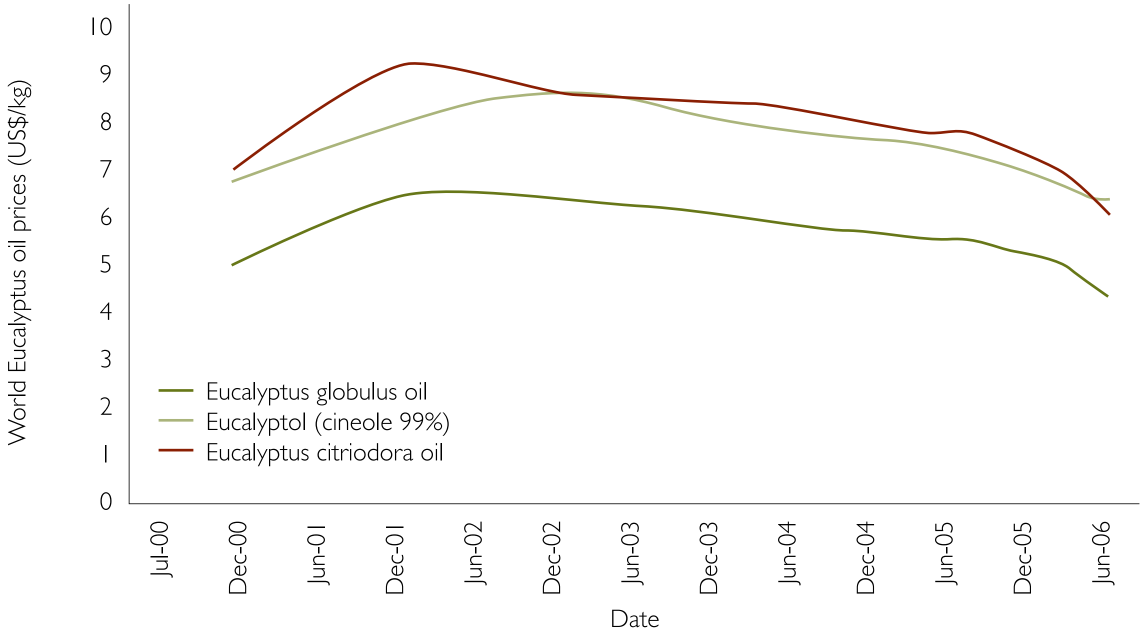
The price of eucalyptus oil produced from Western Australia mallee species currently ranges between $7/kg to $12/kg for specialty and pharmaceutical use (OMC 2006). Industrial grade and volumes of oil are expected to only attract a price of about $3/kg. Current best selections of mallee Eucalypt species have cineole contents of over 8% per dry tonne of leaves, which equates to about 4% of leaf fresh weight.

Using in-field processing with mobile distillers and a bulk oil price of $3/kg values the leaf fraction at $80/freshweight tonne, and at an oil price of price of $7.52/kg the gum leaves are worth $210/freshweight tonne.

Integrated Wood Processing Plant (oil/charcoal/bioenergy)

The development of an integrated wood processing (IWP) demonstration plant at Narrogin in WA has been reported in depth by Western Power (2006) and Enecon (2001). Most of the engineering of the IWP plant was completed in 2005 and planned to be tested during 2006. The concept is based on utilising in-field chipping harvest technologies to deliver 20,000 tonnes of chipped mallee (*Eucalyptus* spp.) wood, twigs and leaves to the plant per annum for processing to produce 7.5 GWh/year of electricity, 690 tonnes/year of activated carbon, and 210 tonnes/year of eucalyptus oil. The IWP plant will incorporate a fluidised bed carbonising plant, steam distillation plant, thermal gasifier spent leaf combustor plant and a 1 MW

Figure 7. Trends in world market prices of eucalyptus oils in recent years.



Source: FDL 2006

steam turbine power generation plant. Additional benefits will be derived from greenhouse gas abatement from renewable energy generation, rootmass fixation and standing woody crop biomass.

Delivered price

Initial projections valued the delivered feedstock at $30 per green tonne (Enecon 2001). However, given inflation costs since 2001, the increased markets and value of energy resources (> +12% price/tonne for steaming coal), wood charcoal (+149% gross value, see Table 10) and Eucalypt oils (+2% gross value) a higher delivered feedstock value of around $36 per green tonne or more could be expected.

Fodder Industries

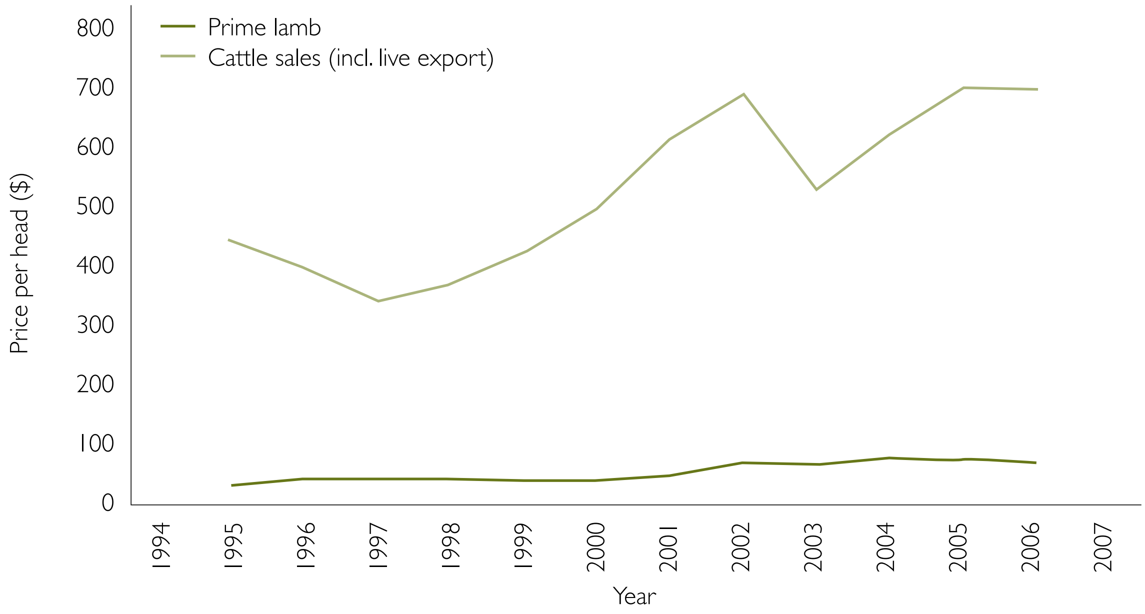
There are several broad segments in the Australian fodder industry, including on-farm meat production, on-farm wool production, feedlot production of meat and livestock feed manufactures. All these segments require a primary resource of livestock fodder, which is presently based on predominantly annual crops of pasture and cereals. However, some herbaceous perennial plant species (predominantly lucerne) are widely utilised, and highly valued, for their provision of green feed or nutritious hay for dry season fodder in the paddock or as a feedlot resource.

On-farm meat and wool

Gross value of Australian farm production for livestock slaughterings and production was approximately $17.8 billion in 2004-05 (MLA 2006), based on herds of 102.7 million sheep and lambs, and 27.7 million cattle and calves. The Australian red meat market has strengthened in recent years. The strong demand has generally driven up livestock and meat prices (Figure 8 and Figure 9).

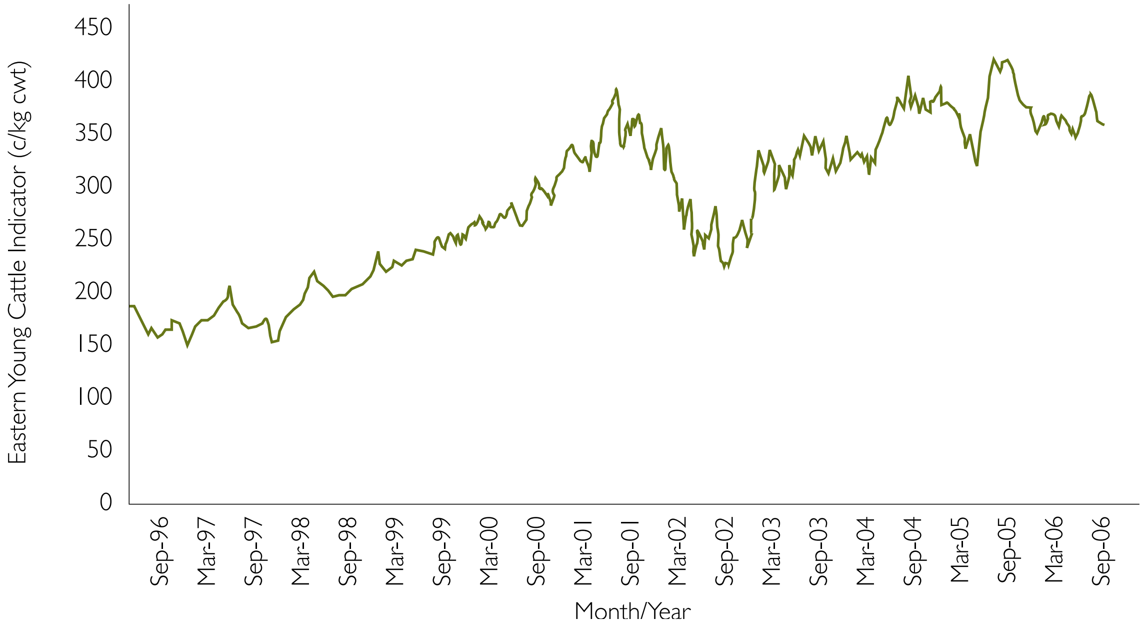
The number of sheep currently shorn for wool in Australia (106 million head in 2004-2005; AWI 2006) has decreased by around 32% since 2000-01 (140 million head). Australian Wool Innovation forecast the 2005-06 shearings would be approximately 106 million head producing around 456 million kilograms of greasy wool. An offset to the lower production values in

Figure 8. The average sale value per head of prime lambs and cattle in Australia in recent years.



Source: ABARE 2006c

Figure 9. The Eastern Young Cattle Indicator prices for the last ten years.



Source: MLA 2006

recent years has been the increasing proportion of production of higher value low micron fine wools.

Australian Feedlots and Stockfeed Manufacturers

The Australian Lot Feeders' Association reported (ALFA 2007) that the turn-off of lotfed cattle for 2006 was a record 2.63 million head. The feedlot holding of cattle in December 2007 was around 909,000 head (Table 11 and Figure 10), at 87% of total current capacity (1.1 million head).

The stockfeed manufacturing industry utilises a wide range of agricultural resources, including cereal grains, legume grains, oil seeds, protein meals, cereal milling co-products, hays and other fibre sources, to produce a variety of meals, fibres, supplementary pellets, ration and finishing pellets. Australia's annual consumption of manufactured stockfeed has doubled since 2003 (4.95 million tonnes) to about 10 million tonnes in 2005 (SFMCA 2006). The greatest consumption by volume of manufactured stockfeed is in the dairy (27.2%), poultry (27.1%), feedlot beef (24.6%) and pig (16.4%) industries. The demand and prices of these products is closely tied to local and export livestock markets.

Perennial shrub fodder sources

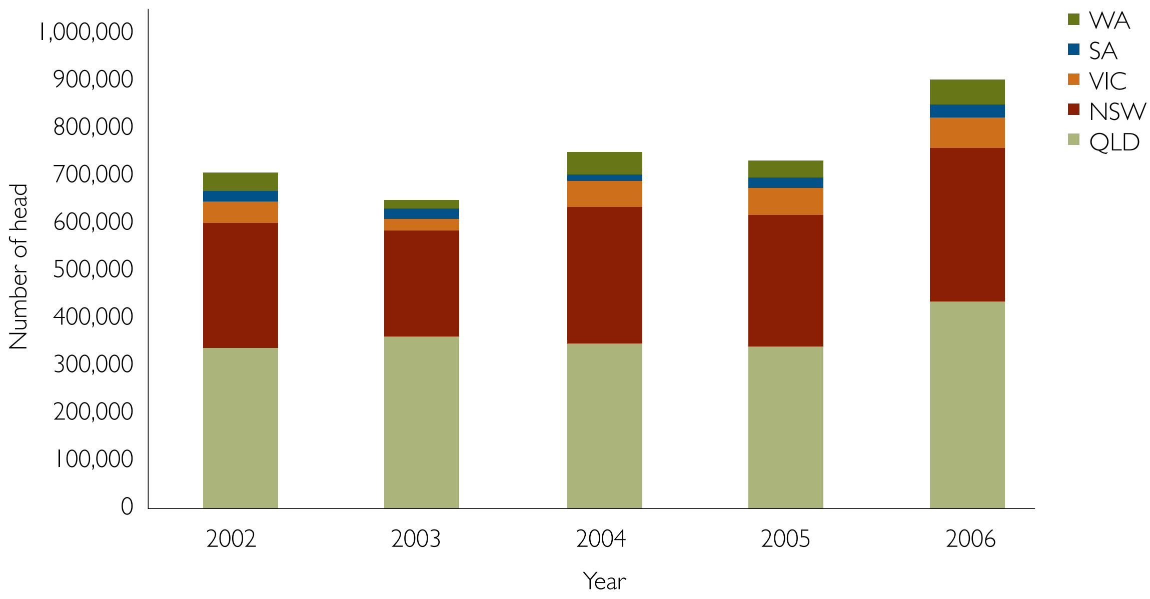
Lucerne is highly nutritious and widely used for forage in southern Australian livestock industries. It is a relatively adaptable species suited to a variety of climates and soil types in Australia. Even with extensive breeding and selection programs lasting many years it still fails to perform as a dryland crop in some areas, especially in lower rainfall regions (<500 mm) and on soils that are shallow, acidic, high in exchangeable aluminium or sodium salt, or with hostile subsoils. Many livestock palatable Australian chenopods (e.g. saltbushes, bluebushes) are more suited to drier and harsher environments, so are many Australian Acacias, other Fabaceous genera, and other palatable native species. Many species from this group have a long history of use as livestock fodder plants in relatively natural Australian rangelands. Over the years a few species have been planted specifically for use as fodder crops.

Table 11. The number of head, and percentage of total, of livestock held in feedlots for the December period over the last five years by state.

State	NSW		Vic		Qld		SA		WA		Total
Year	Head	%	Head	%	Head	%	Head	%	Head	%	Head
2002	259084	36.7%	50849	7.2%	343604	48.6%	16703	2.4%	36237	5.1%	706477
2003	219672	33.7%	34004	5.2%	365522	56.1%	12379	1.9%	20517	3.1%	652094
2004	281724	37.4%	61759	8.2%	353030	46.9%	11592	1.5%	44200	5.9%	752305
2005	274824	37.4%	61150	8.3%	346257	47.2%	16654	2.3%	35473	4.8%	734358
2006	319067	35.1%	64468	7.1%	440704	48.5%	27161	3.0%	54420	6.0%	908820

Source ALFA 2007

Figure 10. The number of head of livestock held in feedlots for the December period over the last five years by state.



Source: ALFA 2007

The most widely used and valued of these is the easily propagated, fast growing, readily managed and grazing tolerant Oldman Saltbush (*Atriplex nummularia*). Early Australian selections programs commenced around 50 years ago, with some small advances in nutritional status in the time. Over the last decade some further selections and clonal reproduction by private industry has been used to make more nutritious and better forms of Oldman Saltbush (e.g. "Eyre's Green" cv Topline Nursery – crude protein (CP) of 14.4% dry matter, digestibility of 34% of dry matter, metabolisable energy (ME) 5.1 MJ/kg dry matter). Interest also exists in several other Atriplex species (e.g. *A. amnicola, A. cinerea, A. vescicaria*). *Acacia* species, although often palatable to livestock and with some species tolerant to grazing pressure, are generally lower in their nutritional value and harder to digest. Some populations of *Acacia saligna* from Western Australia have proven to be more nutritious (CP 14.4%, digestibility 34%, ME 5.1 MJ/kg), hardy and easier to establish than most other *Acacia* species, although their taller form requires a greater degree of crop management. Oldman Saltbush and *Acacia saligna* will be discussed at greater length in the "Development and Focus Species" section of this report.

Oldman Saltbush and the exotic Tagasaste or Lucerne Tree (*Chamaecytisus* spp.) have been widely used as a southern Australian fodder shrub crop the last decade. Early research on Oldman Saltbush on saline affected landscapes have painted a poor picture of its nutritional status (Lefroy 2002) largely due to high salt loads in the foliage from these environments. However, the salt load in the foliage is much less significant on non-saline affected sites. Further, Oldman Saltbush provides a valuable green feed resource during summer and autumn, when other typically annual fodder species are desiccated. This seasonally increases the value of the saltbush fodder crop to a level similar to that of lucerne pastures or hay.

Delivered price

Lucerne hay has an average CP of 20 % of dry matter and ME of 9 MJ/kg dry matter and clover hay has CP 12% and ME 9 MJ/ kg. Other highly valued fodder resources include cereal barley (CP 10%, ME 12) and peas (CP 24 %, ME 13) (FeedTest Agriculture Victoria). As Oldman Saltbush's dry weight nutritional value (CP 20-25%, ME 11-12, digestibility 76-80%) often exceeds that of the highly valued lucerne, the fodder value of saltbush is on par to that of lucerne. Current average prices of hay for sale from the Australian Fodder Industry Association (March 2006, for SA, Victoria and NSW, moisture content ~10%) shows lucerne hay is valued at $211/t (range $154-242/t), pure clover hay $177/t ($170-180/t), clover/rye pasture hay $153/t ($120-160/t) and oat hay $146/t ($135-150/t).

The value of fodder and hay is seasonally sensitive and may increase by 50% in price over the course of a year (even higher during drought events). In 2005 lucerne hay in NSW reached values of $350-400/t (AFIA 2006). Allowing for moisture contents of the different products, and the slight diminishing nutritional value due to salt content in some Oldman Saltbush (*Atriplex nummularia*) stands (say -10%) and seasonal variations in demand, saltbush leaves and fine twigs are worth between $45/green tonne (winter-spring) when other fodder is readily available and $65/green tonne (summer-autumn) when competing directly with other equally high quality hay products. In modest drought conditions (like 2005 in NSW) saltbush fodder value could reach $123/green tonne. Due to its lower nutritional value the fodder value of Orange Wattle (*Acacia saligna*) leaves is approximately 50% that of Oldman Saltbush.

Emerging Industry Types

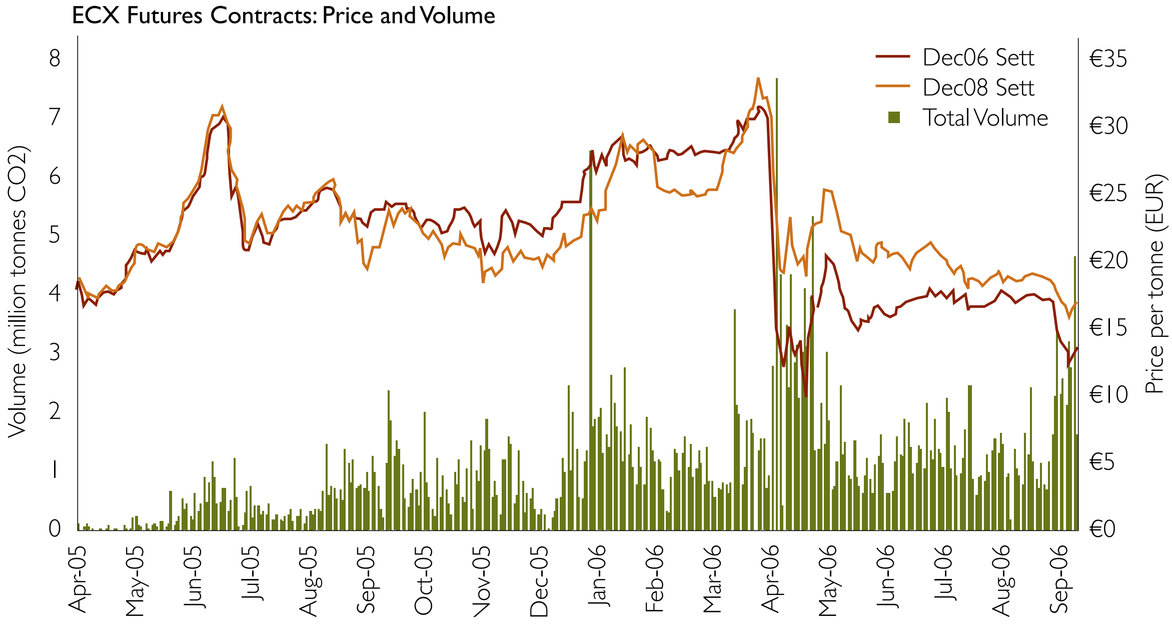
Since the writing of the FloraSearch Phase 1 and WA Search reports some new industry prospects have emerged, most notably these include carbon trading, mineral processing industry interest in the use of carbon from renewable biomass sources, ethanol production from woody biomass, and other extractives.

Carbon Sequestration

The potential for carbon trading has become a significant factor in evaluating the economics of long-term perennial vegetation as permanent sinks but there is also increasing interest in the carbon stores held in harvested perennial crop systems such as classical forestry and other shorter rotation agroforestry crops. European carbon dioxide trading has been active since early 2005 and has since traded well over 400 million tonnes of carbon dioxide (ICE 2006, Figure 11). In Australia, the carbon trading market has yet to fully take off, but NSW has mandated carbon emissions controls and other state governments and private corporations are already gearing up for carbon trading.

The current European price suggests that carbon sequestration alone may be economically viable for revegetation in some landscapes and regions. Additionally, commercial woody crops may also include the average standing biomass of these crops as a carbon sequestration value, or even the long

Figure 11. The ECX settlement price (line) by year and volumes (bars) traded in recent times.



Source: ICE 2006

term carbon stored in the roots and accumulated soil carbon of these crops, as a contributor to the economic value of these perennial farming systems.

Delivered price

International trade currently values a tonne of carbon dioxide at €12.85/tonne (European Climate Exchange average trade-weighted price 29/09/2006; http://www.ecxeurope.com) and with an exchange rate of A$1= €0.5891 (on 29/09/2006, RBA 2006) puts carbon dioxide tradeable value at around A$21.81/t. Near future average prices for 2007 and 2008 are expected to be €13.30/t and €16.15/t respectively. From our destructive samples the average ratio between fresh weight whole plant biomass and carbon dioxide equivalent is 1:0.891. Using this ratio and European September 2006 trade prices equates to a value of A$19.43 per fresh weight tonne of above ground biomass.

Industrial Carbon (carbonised wood and charcoal)

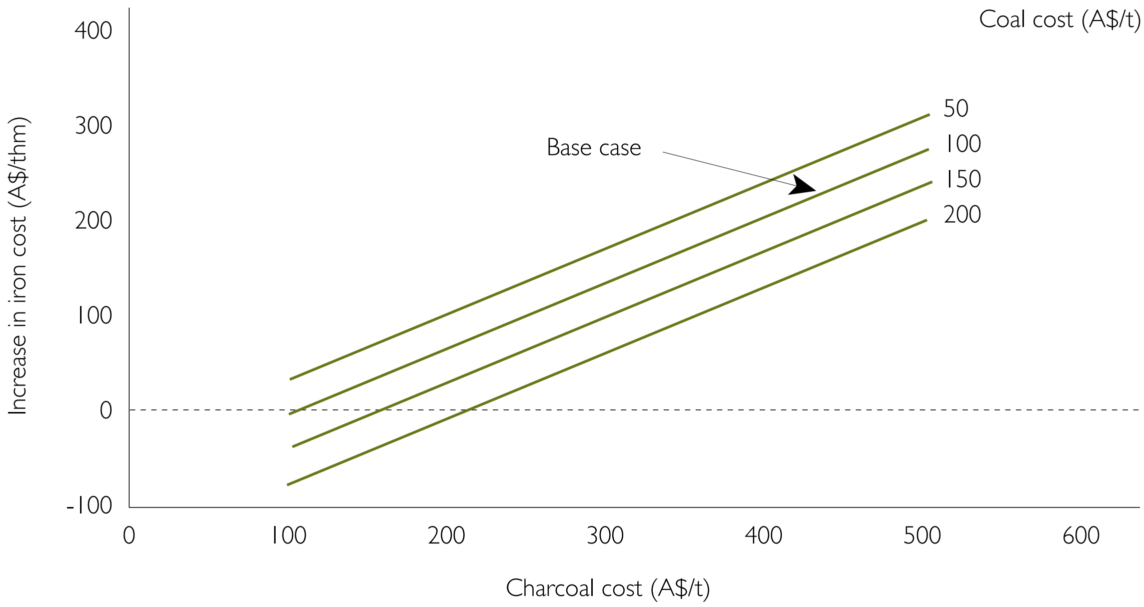
The refining of metal oxides requires carbon as a reducing agent. Coke, a derivative of coal, is currently the major source of carbon used for metal refining. The steel industry in Australia consumes around 5.2 million tonnes of black coal for this purpose (ACA 2006). Australian export of metallurgical coal is significant, at around 125 million tonnes per year. This rate has been increasing in recent years, although it is likely that export volumes will stabilise in future years (Table 12). The interest in the use of renewable sources of carbon for mineral processing is increasing. In Australia some mining companies have been exploring the potential of renewable carbon for metal refining. Coal is also used extensively in cement manufacture which uses about 0.9 million tonnes per year. The current developed world traded market for wood charcoal is approximately 1 million tonnes/year (OMC 2006).

Steam treatment of charcoal is used to create the highly valued activated carbon. The special property of activated carbon is its ability to preferentially absorb chemicals, ions and odours. This property is utilised widely for water treatment, gold recovery and in the food and beverage industry. The world market for activated carbon is around 700,000 tonnes/year (140,000 tonnes/year for water treatment alone) and is currently increasing by about 4-5% each year (OMC 2006). The Australian market for activated carbon (excluding gold refining) is approximately 3,000 tonnes/year and activated carbon is conservatively worth an estimated $1,800/tonne.

The metallurgical industry faces increasing pressure to reduce emissions of greenhouse gases from production of metals. The substitution of fossil carbon by renewable carbon from biomass has the potential to radically reduce the net carbon emissions from metallurgical processes. The high reactivity and low sulphur content of charcoal makes it an attractive metallurgical reductant. The extent of substitution that is technically possible depends on the process. For example, in blast furnace iron making, perhaps 20% of the fossil carbon in coke could be replaced by renewable carbon as an injectant, due to the need to maintain a strong and coherent coke bed in the furnace. On the other hand, in new technologies such as bath smelting (eg. HIsmelt) which use granular carbon rather than lump size high strength coke, potentially all of the fossil carbon could be replaced by renewable carbon. It may also be possible to substitute charcoal for coal in other processes such as synthetic rutile production in rotary kilns where high reactivity is beneficial and the strength of the carbon is less critical. This opens up a large potential range of markets for wood carbons as reductants.

The economics of replacing coal by charcoal poses a significant challenge. A preliminary economic analysis of the cost of replacing coal by charcoal in a HIsmelt-type process is shown in Figure 12. Using a reported charcoal cost of A$435/t and a thermal coal price of A$100/t, it was estimated that the production cost of pig iron would increase by about A$234/t in completely changing from coal to charcoal, assuming that there

Figure 12. The relationships between charcoal costs, coal costs and iron costs.



Prepared by: David Landberg CSIRO Minerals

Table 12. Recent historical, and predicted, volumes and values of Australia metallurgical coal exports.

Recent Years	Unit	2000-01	2001-02	2002-03	2003-04	2004-05
Volume	Mt	105.5	105.8	107.8	111.7	124.9
Value	A$m	7331	8688	7810	6671	10588
Unit value	A$/t	69.49	82.10	72.45	59.72	84.78
ABARE Forecast	**Unit**	**2005-06**	**2006-07**	**2007-08**	**2008-09**	**2009-10**
Volume	Mt	131.0	135.0	142.0	152.0	155.0
Value	A$m	17169	16498	13187	11171	9331
Unit value	A$t	131.10	122.20	92.90	73.50	60.20

(Source: ABARE 2005b)

were no significant increases in capital cost in making this change. This increase would represent an approximate doubling in the cost of pig iron. In order for charcoal to be competitive with coal the following potential advances would need to be developed:

- Recognition of the value of carbon emission reduction and other potential environmental credits
- Development of more sophisticated charcoal production processes to utilize potential co-products such as bio-oil and waste heat
- Use of lower value woody biomass fractions for charcoal production.

Recent research by the Centre for Sustainable Resources Processing and the CRC PBMDS shows that there is potential to greatly reduce the charcoal cost and to increase the reactivity of the charcoal by using the twig and leaf fraction of mallee biomass. This material could be valued at ~$10 green tonne and be converted to charcoal at <$100/tonne bringing it well into the competitive range. The final report from this work is due shortly.

Liquid Fuels from Woody Biomass

In our earlier report (Bennell *et al.* 2008) ethanol production and biodiesel production from woody biomass were identified as two potential FloraSearch industries. At the time, two factors downgraded the priority of these industry types: 1/ the relatively low price of mineral oil based fuels; and 2/ the infant stage of the technology required to convert woody biomass to ethanol or biodiesel. In the last two years we have seen changes in both of these areas.

The world price of oil has escalated from around US$25 per barrel in 2001 to over US$60 per barrel in 2006 (EIA 2006, Figure 13) and initially, predictions were that the current high price was only a short term prospect. Currently there are no clear indicators to suggest that oil will return to around US$35 per barrel as was often prophesised in 2004.

This sudden development has caught economic forecasters by surprise. For example, Enecon (2002), using information provided by the Centre for International Economics, concluded that '…. the prospect for the next 15 years at least is for declining rather than increasing crude oil prices.' They used a crude oil price of US$22/barrel in their assessment of the comparative costs of ethanol, methanol (manufactured from woody feedstocks) and petrol, projected for the year 2015. It appears that if they had used the current crude oil price (>US$60/barrel) in their projections, ethanol from woody feedstocks would have been very competitive with petrol.

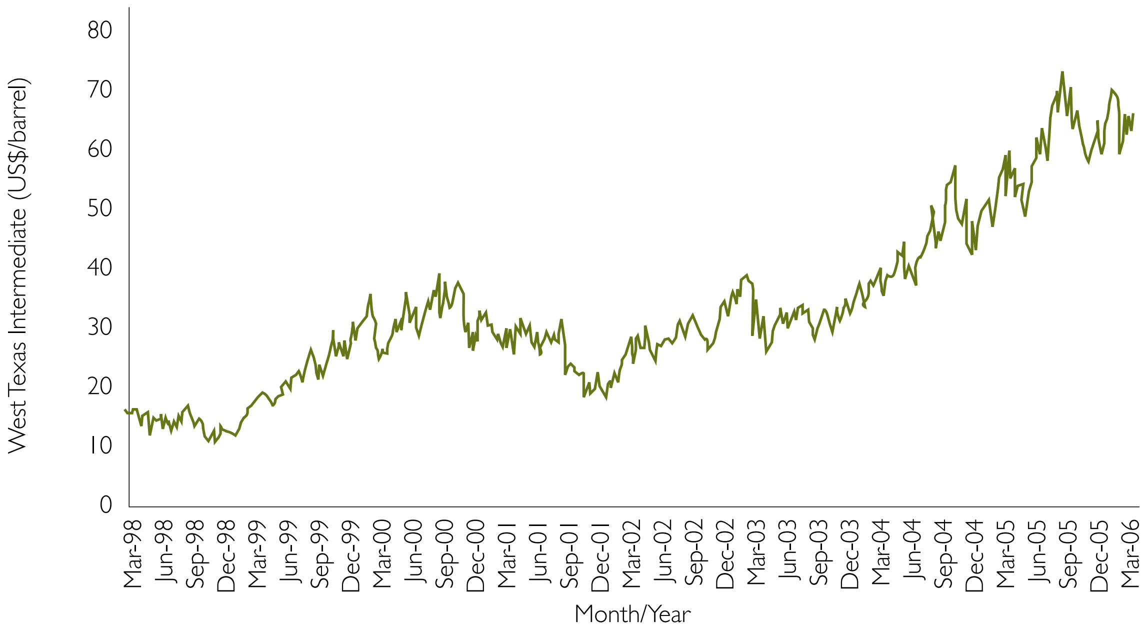
The Biofuels Taskforce (2005) has recently reported to the Prime Minister on status, potential and issues of biofuels development and adoption in Australia. This report states a target of 350ML (see Figure 14 for monthly volumes of petrol and diesel fuel sales for recent years) of biofuels by 2010 and draws upon ABARE analyses of the viability of ethanol and biodiesel in the current policy and market environment. They report that biofuels are currently competitive and will remain so until around 2015 when current government excise assistance is reduced. They recommend that the potential of lignocellulosic feedstocks for ethanol production be thoroughly assessed before any major commitment is made to other ethanol feedstocks and production opportunities.

ABARE's models are based on an assumed oil price of US$32/barrel and an US$/A$ exchange rate of 0.65. They also state, *"Should the long-term oil price be higher, all other things being equal, the commercial viability prospects of biofuels would improve."* They conclude, based on an US$/A$ exchange rate of 0.65, that ethanol producers would remain viable beyond 2015 with a oil price of US$42-47/barrel without government assistance, and biodiesel producers would require an oil price of US$52-62/barrel to remain viable without assistance.

The technologies of using woody biomass to produce ethanol have also progressed in the last two years. Globally, there has been significant investment and progress in lignocellulosic ethanol technologies for bio-fuels. In the USA a large increase in ethanol as a motor fuel is expected because of two policy initiatives: a US$ 0.51 tax credit per gallon of ethanol used as motor fuel and a new mandate for up to 7.5 billion gallons of "renewable fuel" to be used as a petrol supplement by 2012. Farrell *et al.* (2006) propose that this demand is increasing the likelihood that lignocellulosic biomass (wood and agricultural residue) will become an important feedstock for the production of bio-fuel. These materials are typically comprised of cellulose (40-60%), hemicellulose (20-40%) and lignin (10-25%) that will be a residue and can be used as a fuel for energy production (Hamelinck *et al.* 2003).

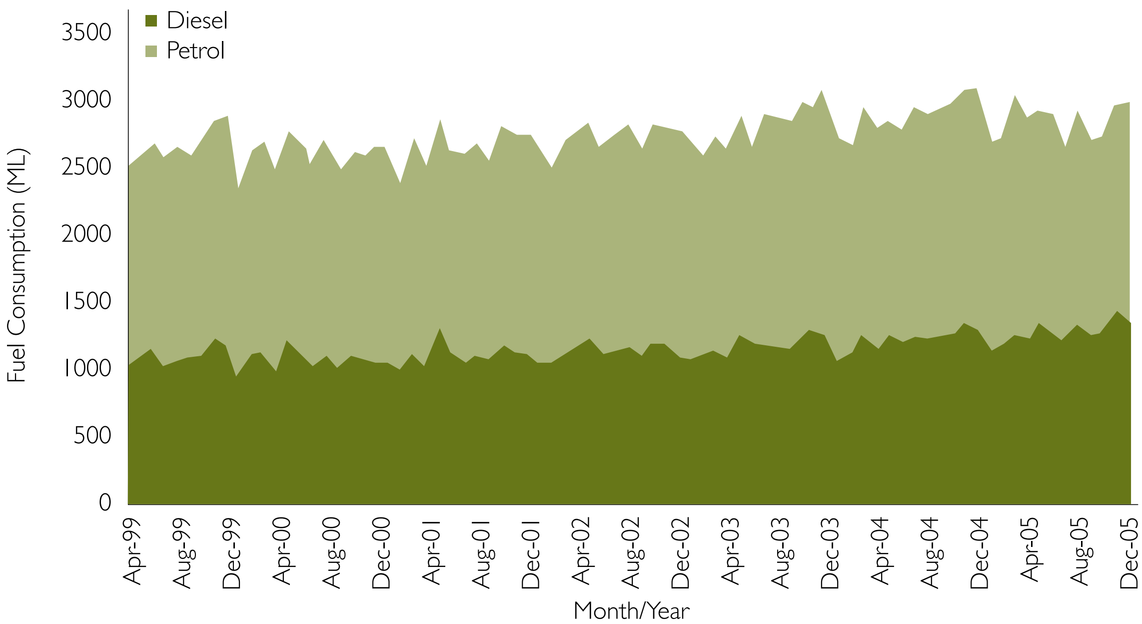
Lignocellulosic biomass can be converted to ethanol by hydrolysis where the cellulosic part is converted to sugars and subsequent fermentation converts these sugars to ethanol. To increase the yield of hydrolysis

Figure 13. Indicative world oil prices (West Texas Intermediate) in recent years.



(Source: EIA 2006)

Figure 14. The monthly volume of Australian petrol and diesel fuel sales in recent years.



(Source: DITR 2006)

a pre-treatment step softens the biomass and breaks down cell structure to a large extent. There are several options for pre-treatment and hydrolysis but current technological development is focused on enzymic hydrolysis which requires very mild process conditions, while giving good yield, lower capital investment and less environmental risk. This technology is relatively immature requiring an expected ten years before being industrially adopted but it provides the possibility for significant improvements in production costs.

A number of pilot plants have been commissioned that will adopt these new technology options and include Iogen's plant (http://www.iogen.ca/) in Ottawa, Canada, that can process 40 t/day of wheat straw and poplar. Abengoa (http://www.abengoabioenergy.com/) is building a 200 million l/yr plant utilising 50% agricultural waste for feedstock.

Biodiesel production is mostly derived from oilseed plants such as canola versus pyrolysis from woody feedstock. Although technically possible the technology is not yet practical.

Other Extractives

There are probably many chemicals that might be commercially extracted from large volume biomass feedstocks. The FloraSearch project recognises the potential economic importance of additional revenue that might accrue from being able to extract an additional product.

One such product has emerged over the past couple of years due to the work of Professor Bill Foley at the Australian National University. There is a class of chemicals that occur in the leaves of many species of *Eucalyptus* called formylated phloroglucinol compounds. One such compound, sideroxylonal, has been shown to have potent anti-fouling properties when applied to the hulls of ships. One of the main mallee species used in WA, *Eucalyptus loxophleba* spp *lissophloia*, has been shown to have the highest recorded content of sideroxylonal. This has resulted in this species being elevated in ranking as a FloraSearch development species.

Sideroxylonal content is strongly correlated with eucalyptus oil content. It is not steam extractable and would need a separate process but it appears that such a step could be readily incorporated into an integrated process.

Summary of FloraSearch Commodity Values 2006

The estimated 2006 value and likely range of each FloraSearch industry commodity type at corresponding mill gate, port, delivery centre or in situ locations is listed in Table 13.

Table 13. Summary of estimated 2006 delivered feedstock values by industry type.

Industry and Commodity Type	Delivery Location	Likely delivered range [$/freshweight tonne]	Likely delivered value [$/freshweight tonne]	Market Price Trend
Export pulp - woodchip	Port	80 - 100	90	increasing to stable
Australian pulp - woodchip	Mill	75 - 95	85	increasing to stable
Australian MDF - woodchip	Mill	50 - 75	65	increasing
Australian particleboard - woodchip	Mill	30 - 53	43	stable
Electricity generation - whole plant biomass	Powerplant	25 - 31	28	increasing
Eucalyptus bulk oil - leaf	Mobile Processing Plant	60 - 100	80	increasing
Eucalyptus essential oil - leaf	Mobile Processing Plant	190 - 230	210	decreasing to stable
Integrated wood processing - whole plant biomass	Processing Plant	32 - 40	36	increasing
Carbon sequestration - whole plant biomass	In situ	5 - 46	20	volatile price / increasing volume
Fodder - Saltbush leaf (Autumn)	In situ/ Paddock/Mill	55 -123	65	increasing
Fodder - Saltbush leaf (Spring)	In situ/ Paddock/Mill	40 - 65	45	increasing
Fodder - Acacia leaf (Autumn)	In situ/ Paddock/Mill	25 - 40	33	increasing
Fodder - Acacia leaf (Spring)	In situ/ Paddock/Mill	18 - 30	23	increasing
Activated charcoal - woodchip	Processing Plant			increasing
Industrial carbon - woodchip	Port or Smelter			increasing to stable
Liquid fuels - whole plant biomass	Processing Plant/Refinery			increasing to stable

3. Species selection and evaluations

Product Testing

The aim of this section is to identify the species sampled since the 2004 report and describe their specific attributes, which in turn supports exclusion from, or inclusion in, a set of development species. Each species has attributes making it suitable for consideration for a particular product type. Products selected as having the highest priority were, pulp and paper, wood composites, bioenergy, fodder and essential oils, with testing relating to each of these product areas. In addition each selected species has biotic characteristics relating to growth and productivity potential. Important aspects are the potential yield of each species, the form of the plant, and the ease with which the plant can be established. Species such as *Codonocarpus cotinifolius* that proved difficult to propagate or establish in trials have been down graded.

Phase 1 Species Evaluation

As of June 2004 FloraSearch had sampled the majority of the most highly ranked prospective species, however, a remaining suite of taxa (generally less well known and accessible taxa) were sampled and evaluated during the 2004-2006 period to fill in the gaps in the Phase 1 database. Another 57 species have undergone the initial sampling process since the 2004 report (Table 14).

Of these Phase 1 species *Eucalyptus dawsonii, Eucalyptus tricarpa* and *Eucalyptus argophloia* were recorded as presenting the best growth figures. *Eucalyptus dawsonii* also presented the second best biomass production rates. With moderate leaf oil content of 2.1%dm and a very high basic wood density this species could do well as a biomass energy prospect. *Eucalyptus argophloia* has more moderate biomass rates but with a lower basic wood density and a leaf oil content of 3%dm it could prove useful as a multi-purpose tree, especially if specimens with lower basic wood density can be found to make it a suitable candidate for pulp products.

Corymbia tessellaris, *Eucalyptus dawsonii, Angophora melanoxylon* and *Angophora costata* ssp. *leiocarpa* were recorded as presenting the best biomass production rates of the new phase one species tested. *Corymbia tessellaris* while growing slower than *Eucalyptus dawsonii* has the highest stemwood production recorded and a lower basic wood density. If younger specimens can be found with slightly lower wood density this species also shows some prospect in the pulp products area as well. *Angophora melanoxylon* has a similar growth figure to *Corymbia tessellaris* but much denser wood and lower biomass rates making it less attractive as a prospective biomass species. *Angophora costata* ssp. *leiocarpa* on the other hand has a more attractive growth rate and a basic wood density within the pulping range. With a moderate stemwood production rate similar to *Angophora melanoxylon* it has some possibilities in the production of pulp.

Acacia longifolia ssp. *longifolia, Eucalyptus mannifera, Angophora floribunda* and *Eucalyptus arenacea* returned the lowest basic density figures but were out performed by *Angophora costata* ssp. *leiocarpa* in growth rate and biomass production. As pulpwood prospects, they would have to fill a specific niche or provide secondary products to compete with better performing species. Of those species tested for pulping properties *Angophora melanoxylon* and *Alphiltonia excelsa* had figures that indicated prospects in manufacturing paper but their basic wood densities where higher than optimal.

As a prospective fodder species *Rhagodia parabolica* stood out as the best of the fodder species tested, having the highest metabolisable energy rates and a mid range crude protein score. *Rhagodia parabolica* also had the third highest green biomass production rates of the Phase 1 species tested. *Atriplex istidea* and *Atriplex paludosa* also provided good metabolisable energy rates but had lower crude protein levels. All three species present possibilities for in situ grazing.

Acacia farnesiana easily had the best crude protein levels. With mid level metabolisable energy rates it is probably held back by its extremely thorny nature and very moderate biomass production. *Pultenaea daphnoides* and *Acacia austfeldii* both have a good combination of crude protein and metabolisable energy rates but may not produce enough biomass to be included in fodder systems on their own.

Acacia austfeldii, Acacia stricta, Acacia iteaphylla and *Acacia rigens* all have acceptable crude protein levels but are lacking in metabolisable energy and would have to be combined with other plants with higher metabolisable energy rates to be of value. All, with the exception of *Acacia stricta*, are medium sized shrubs suitable for an in situ grazing situation. *Acacia stricta* is a small understorey tree and probably limited in its usefulness.

Of the species sampled since the 2004 report (Table 14), four tree species and three fodder shrub species suggest themselves for further evaluation. These species are:

- *Eucalyptus dawsonii*
- *Eucalyptus argophloia*
- *Corymbia tessellaris*
- *Angophora costata* ssp. *leiocarpa*
- *Rhagodia parabolica*
- *Atriplex isatidea*
- *Atriplex paludosa*

Phase 2 Species Evaluation

For those species and taxa where preliminary data and research suggested that those taxa had higher prospect of promotion to the "development" species level of selection, additional populations and provenances were sampled.

The secondary data provides an indication of the variation in physical and chemical attributes of selected plants and has been used to increase or decrease the priority of those taxa in the species selection process and identify individual provenances worthy of further investigation. Results to date suggest some caution is required when basing a decision of species' selection or rejection on a limited number of observations.

Forty-seven species have been re-sampled in the initial stages of Phase 2 evaluations (Table 15). *Eucalyptus globulus* ssp. *globulus* easily grew the fastest followed by *Eucalyptus occidentalis, Eucalyptus viminalis, Eucalyptus camaldulensis, Eucalyptus gomphocephala* and *Eucalyptus cladocalyx* and *Rhagodia parabolica.*

Eucalyptus globulus ssp. *globulus* also recorded the second highest biomass rates, has a leaf oil content of 2% dm and has a basic wood density well within the wood pulping range, making it an extremely versatile species and justifying its past selection as a forestry species. However, *Eucalyptus gomphocephala* produced far more biomass and perhaps should be considered for biomass energy industries. *Eucalyptus gomphocephala* also has a basic wood density not too far above the upper range of pulpwood products and could be a prospect in this field if less dense individuals can be found within the population, as it produces a respectable pulp yield and tested well for paper manufacture.

Sampling of *Eucalyptus cladocalyx* has detected specimens with a basic wood density under 650 kg/m^3, marking it as a species that could possibly have applications in the pulpwood market as well as the biomass energy industry. *Eucalyptus occidentalis, Eucalyptus viminalis,* and *Eucalyptus camaldulensis* all have similar acceptable biomass production rates and suitable wood density levels for pulp wood products.

Acacia mearnsii and *Eucalyptus petiolaris* have a similar biomass accumulation rate but have wood densities a little above the optimal range for wood pulp. However, both could prove valuable to the biomass energy industry and have some potential for secondary income streams from leaf oil (2.1% dm) in the case of *Eucalyptus petiolaris* and harvested fodder and tannins in the case of *Acacia mearnsii.*

Gyrostemon ramulosus recorded the lowest basic wood density and could be suitable for paper production as it scored well in both pulp yield and paper testing. *Gyrostemon ramulosus* also returned high metabolisable energy and crude protein rates and could provide a second stream of income from the harvested fodder market. However this dry country species is related to *Codonocarpus cotinifolius* and may prove difficult to establish.

Maireana pyramidata is the best of the phase two fodder only species that have been tested so far. It has very good crude protein levels but lacks a little in the metabolisable energy and is slow at biomass production

Eucalyptus porosa and *Acacia salicina* are two dryland species that have potential for roles in the pulp wood area as multi-purpose trees. Both have reasonable pulp yields and *Acacia salicina* tested well for paper manufacturing. *Eucalyptus porosa* has a leaf oil content of 2.1% dm but both species have lower productivity rates than many of the species discussed to this point, restricting their use to lower rainfall areas.

Of the Phase 2 species sampled so far (Table 15), eight tree species and one fodder shrub species suggest themselves for further evaluation. These species are:

- *Eucalyptus globulus*
- *Eucalyptus occidentalis*
- *Eucalyptus gomphocephala*
- *Eucalyptus cladocalyx*
- *Eucalyptus viminalis*
- *Eucalyptus petiolaris*
- *Gyrostemon ramulosus*
- *Acacia mearnsii*
- *Maireana pyramidata*

Table 14. FloraSearch Phase 1 species testing results (2004-2006).

Phase 1 Provenances	Avg. Age [years]	Annual Rainfall [mm]	Avg. Growth Rate [m/yr]	Avg. Plant Green Biomass Rate [kg/yr]	Max. Plant Green Biomass Rate [kg/yr]	Avg. Plant Stemwood Volume Rate x1000 [m³/yr]	Max. Plant Stemwood Volume Rate x1000 [m³/yr]	Avg. Growth Rate [m/yr @500mm]	Avg. Plant Green Biomass Rate [kg/yr @500mm]	Avg. Plant Stemwood Volume Rate x1000 [m³/yr @500mm]	Trees Per Hectare [Observed]	Avg. Green Biomass Rate [t/ha/yr @500mm]	Avg. Stemwood Volume Rate [m³/ha/yr @500mm]	Basic Density [kg/m³]	Pulp Yield @18Kappa [%dm]	Paper Test Score [Max. 20]	Crude Protein [%dm]	Digestibility [%dm]	Metabolisable Energy [MJ/kg dm]
Acacia ausfeldii [Mudgee]	10.7	707	0.28	0.70	2.03	0.25	0.88	0.20	0.49	0.18	1860	0.66	0.21	685			16.7	49.7	6.9
Acacia calamifolia [Marray Bridge]	6.0	371	0.33	4.70	8.87	2.14	4.30	0.44	6.33	2.88	756	4.90	2.23				13.7	49.8	6.9
Acacia elata [Bilpin]	10.2	1323	1.01	7.44	13.30	3.77	7.04	0.38	2.81	1.42	6279	18.86	9.60	609	53.8	10	14.8	48.0	6.6
Acacia farnesiana [Gawler Ranges]	4.0	637	0.38	3.44	6.25	1.40	2.78	0.30	2.70	1.10	769	2.11	0.86				20.9	53.6	7.6
Acacia gillii [Warunda]	4.8	475	0.73	1.30	2.16	0.43	0.83	0.77	1.37	0.45	2560	3.45	1.13	814			10.2	49.0	6.9
Acacia hakeoides [Monarto]	3.7	371	0.41	3.02	9.91	1.20	5.00	0.56	4.07	1.61	752	5.64	2.64	905			14.9	48.5	6.7
Acacia iteaphylla [Gawler Ranges]	5.5	323	0.48	1.18	1.97	0.40	0.76	0.75	1.83	0.61	2531	4.57	1.52	818			15.0	45.6	6.2
Acacia leiophylla [White Lagoon]	8.8	459	0.71	10.54	14.59	5.43	7.66	0.77	11.48	5.92	1040	14.27	7.22	821			11.8	51.7	7.3
Acacia ligulata [Kingston On Murray]	8.5	247	0.21	3.09	3.70	0.92	1.09	0.43	6.25	1.85	1062	6.47	1.91	854			10.7	61.1	8.7
Acacia longifolia ssp. *longifolia* [Heathfield]	7.0	1005	0.91	13.59	26.83	7.17	15.09	0.45	6.76	3.57	634	5.23	2.80	502			13.4	45.9	6.3
Acacia mitchellii [Caroline State Forest]	1.5	769	0.71	2.24	6.06	0.52	2.23	0.46	1.46	0.34	1667	2.43	0.56				10.5	53.6	7.9
Acacia montana [Murray Bridge]	6.0	371	0.35	5.34	9.12	2.47	4.44	0.47	7.20	3.33	738	6.22	2.92				12.2	53.9	7.9
Acacia oswaldii [Kingston On Murray]	8.5	253	0.16	0.67	0.94	0.13	0.24	0.31	1.32	0.25	7249	9.28	1.80	879			11.0	48.9	6.8
Acacia ramulosa [Lake Gairdner]	22.0	211	0.22	5.36	8.16	2.82	4.56	0.51	12.71	6.69	276	3.21	1.69	936			11.1	44.7	6.1
Acacia rigens [Murray Bridge]	12.5	340	0.21	3.37	4.79	0.80	1.26	0.31	4.95	1.18	581	3.11	0.76	812			14.9	45.4	6.2
Acacia stricta [Kangaroo Flat]	6.7	746	0.48	0.76	1.06	0.22	0.38	0.32	0.51	0.15	2500	1.28	0.37				16.1	53.2	7.8
Alphitonia excelsa [Mallee Springs]	8.5	664	0.74	6.23	17.93	3.15	9.74	0.56	4.69	2.37	4463	8.60	3.80	746	43.4	1			
Angophora costata ssp. *leiocarpa* [Narrabri]	17.0	613	0.96	29.46	69.01	18.51	45.99	0.78	24.03	15.10	1665	41.18	25.19	557	40.3	0			
Angophora floribunda [Gunnedah cult.]	11.1	641	0.75	25.13	36.90	14.22	21.51	0.58	19.60	11.10	1111	21.78	12.33	545	39.0	0			
Angophora melanoxylon [Pilliga]	24.5	540	0.51	28.10	80.44	18.01	54.29	0.47	26.02	16.68	558	10.56	6.58	675	44.7	1			
Atriplex cinerea [Lady Bay]	15.0	538	0.09	1.17	1.93	0.50	0.88	0.09	1.09	0.46	594	0.59	0.25				17.7	78.8	11.9
Atriplex isatidea [Point Labatt]	3.8	386	0.54	7.37	12.87	3.38	6.36	0.70	9.54	4.38	760	4.83	2.05				12.5	65.7	9.7
Atriplex paludosa [Streaky Bay]	2.3	369	0.21	0.96	1.10	0.11	0.21	0.29	1.30	0.14	8000	10.40	1.15				10.0	65.5	9.6
Corymbia maculata [Tamworth cult.]	7.1	652	1.07	11.57	24.00	5.98	12.98	0.82	8.87	4.59	1111	9.86	5.10	681	<43.3	0			
Corymbia tessellaris [Wee Waa]	38.0	574	0.55	76.48	115.99	52.55	83.98	0.48	66.62	45.77	195	14.50	10.16	682					
Eucalyptus albopurpurea [Tulka]	19.9	529	0.32	3.62	9.41	1.83	5.38	0.31	3.42	1.73	1660	4.61	2.10	803					
Eucalyptus angulosa [Port Lincoln]	17.0	527	0.29	4.89	10.51	2.53	5.73	0.28	4.64	2.40	2103	9.28	4.77	852					
Eucalyptus arenacea [Fairview CP]	20.0	527	0.30	13.44	25.22	7.67	14.96	0.28	12.75	7.28	393	3.43	1.90	557					
Eucalyptus argophloia [Bogibri]	7.0	710	1.35	22.27	41.90	12.06	23.75	0.95	15.68	8.49	625	9.80	5.31	679					
Eucalyptus banksii [Tingha]	11.0	885	1.05	29.41	57.73	17.14	35.39	0.59	16.62	9.69	2082	23.64	13.44	817					
Eucalyptus calcareana [Streaky Bay]	35.0	363	0.14	4.59	10.24	2.50	5.90	0.20	6.32	3.45	235	1.57	0.86	922					

Table 14. Continued

Phase 1 Provenances	Avg. Age [years]	Annual Rainfall [mm]	Avg. Growth Rate [m/yr]	Avg. Plant Green Biomass Rate [kg/yr]	Max. Plant Green Biomass Rate [kg/yr]	Avg. Plant Stemwood Volume Rate x1000 [m³/yr]	Max. Plant Stemwood Volume Rate x1000 [m³/yr]	Avg. Growth Rate [m/yr @500mm]	Avg. Plant Green Biomass Rate [kg/yr @500mm]	Avg. Plant Stemwood Volume Rate x1000 [m³/yr @500mm]	Trees Per Hectare [Observed]	Avg. Green Biomass Rate [t/ha/yr @500mm]	Avg. Stemwood Volume Rate [m³/ha/yr @500mm]	Basic Density [kg/m³]	Pulp Yield @18Kappa [%dm]	Paper Test Score [Max. 20]	Crude Protein [%dm]	Digestibility [%dm]	Metabolisable Energy [MJ/kg dm]
Eucalyptus calycogona [Loxton]	8.5	261	0.32	3.05	3.82	0.61	0.74	0.61	5.84	1.17	289	1.65	0.33	708					
Eucalyptus cyanophylla [Loxton]	9.5	261	0.30	3.73	5.60	0.62	1.08	0.58	7.14	1.18	644	4.61	0.76	794					
Eucalyptus dawsonii [Denman]	10.0	597	1.35	51.28	141.28	31.74	92.62	1.13	42.95	26.58	1150	24.45	14.12	876					
Eucalyptus dealbata [Gunedah]	40.0	641	0.18	2.02	3.44	1.03	1.82	0.14	1.58	0.81	100	0.16	0.08	834					
Eucalyptus diversifolia [Port Lincoln]	18.0	527	0.31	7.66	13.29	4.12	7.40	0.29	7.27	3.91	2543	16.75	8.93	742					
Eucalyptus dives [Weabonga]	9.8	923	1.01	34.78	68.43	20.58	42.94	0.55	18.84	11.15	562	12.54	7.78	619	39.4	0			
Eucalyptus dumosa [Bowhill]	30.0	323	0.16	2.45	4.29	1.24	2.26	0.25	3.80	1.93	1091	3.23	1.61	951					
Eucalyptus dwyeri [Pilliga]	16.7	701	0.58	10.74	18.85	5.89	10.71	0.41	7.66	4.20	1224	10.36	5.75	729	37.0	0			
Eucalyptus flindersii [Hawker]	31.7	333	0.17	2.70	6.79	1.40	3.78	0.26	4.06	2.11	2955	9.75	4.95	709					
Eucalyptus froggattii [Bendigo]	13.0	539									100			793					
Eucalyptus intertexta [Brachina George]	23.3	300	0.27	6.33	13.60	3.48	7.65	0.46	10.54	5.80	2134	19.15	10.31	888					
Eucalyptus lansdowneana [Gawler Ra.]	80.0	306	0.08	4.55	5.57	2.63	3.27	0.12	7.44	4.30	138	1.00	0.58	902					
Eucalyptus mannifera [Bendemeer]	16.0	806	0.60	26.05	67.10	15.88	43.15	0.37	16.16	9.85	252	3.78	2.27	544					
Eucalyptus moluccana [Hunter Valley]	13.0	756	0.72	15.00	36.43	8.38	21.75	0.48	9.92	5.55	1159	7.77	4.17	841					
Eucalyptus oleosa [Loxton]	10.4	261	0.28	3.89	4.21	0.81	0.96	0.54	7.45	1.55	762	5.71	1.20	792					
Eucalyptus rossii [Coonabarabran]	17.5	787	0.80	21.85	66.71	13.54	46.23	0.51	13.88	8.60	4757	45.57	25.75	737					
Eucalyptus rugosa [Waitpinga]	17.5	593	0.17	0.50	0.86	0.19	0.36	0.14	0.43	0.16	5041	2.17	0.80	883					
Eucalyptus tereticornis [Rutherglen cult.]	15.0	617	0.45	7.66	11.35	4.03	6.14	0.36	6.21	3.26	833	5.17	2.72	697	38.2	0			
Eucalyptus tricarpa [Bendigo]	7.3	551	1.05	15.14	23.88	7.94	12.94	0.96	13.74	7.20	833	11.45	6.00	757					
Eucalyptus yumbarrana [Minnipa]	35.0	294	0.11	1.97	7.43	1.03	4.17	0.19	3.35	1.76	1364	7.38	4.00	801					
Hakea ednieana [Brachina George]	36.7	300	0.10	1.17	2.44	0.54	1.28	0.16	1.96	0.90	354	0.79	0.38	755					
Kunzea ericoides [Beechworth]	15.0	954	0.53	16.83	16.83	9.41	9.41	0.28	8.82	4.93	100	0.88	0.49	827					
Kunzea ericoides [Bright]	7.0	1216	0.68	6.54	20.34	3.25	10.83	0.28	2.69	1.33	100	0.27	0.13	773					
Melaleuca bracteata [Weetawah]	48.2	705	0.28	30.08	42.36	19.83	29.08	0.20	21.33	14.07	666	15.84	10.20	769					
Pultenaea daphnoides [Kemmiss Hill]	3.7	788	0.51	2.80	5.04	1.05	2.07	0.33	1.78	0.67	2488	3.99	1.44				16.7	49.4	7.0
Rhagodia parabolica [Gawler Ranges]	12.0	286	0.10	2.00	3.05	0.89	1.42	0.17	3.49	1.55	2500	8.72	3.88				15.8	66.3	9.8

Table 15. FloraSearch Phase 2 species testing results (2004-2006).

Phase 2 - Provenances	Avg. Age [years]	Annual Rainfall [mm]	Avg. Growth Rate [m/yr]	Avg. Plant Green Biomass Rate [kg/yr]	Max. Plant Green Biomass Rate [kg/yr]	Avg. Plant Stemwood Volume Rate x1000 [m^3/yr]	Max. Plant Stemwood Volume Rate x1000 [m^3/yr]	Avg. Growth Rate [m/yr @500mm]	Avg. Plant Green Biomass Rate [kg/yr @500mm]	Avg. Plant Stemwood Volume Rate x1000 [m^3/yr @500mm]	Trees Per Hectare [Observed]	Avg. Green Biomass Rate [t/ha/yr @500mm]	Avg. Stemwood Volume Rate [m^3/ha/yr @500mm]	Basic Density [kg/m^3]	Pulp Yield @18Kappa [%dm]	Paper Test Score [Max. 20]	Crude Protein [%dm]	Digestibility [%dm]	Metabolisable Energy [MJ/kg dm]
Acacia decurrens [Parr Conserv. Area]	13.7	1020	0.87	12.83	37.87	7.18	22.68	0.43	6.29	3.52	1861	7.47	3.97	698	51.8	4	14.7	47.8	6.6
Acacia hakeoides [Monarto]	2.0	371	0.58	3.30	4.24	1.10	1.53	0.77	4.45	1.49	2226	8.83	2.82				14.9	48.5	6.7
Acacia iteaphylla [Napperby]	4.0	483	0.88	4.53	7.63	1.93	3.48	0.91	4.69	2.00	2023	9.03	3.81	772			14.6	42.1	5.6
Acacia linearifolia [Mudgee]	31.7	707	0.30	3.34	6.46	1.77	3.53	0.21	2.36	1.25	1840	4.35	2.29	728			17.6	53.7	7.6
Acacia longifolia ssp. *sophorae* [Lady Bay]	13.3	538	0.20	8.60	19.51	4.63	11.33	0.18	8.00	4.30	217	1.90	1.02				15.6	46.5	6.4
Acacia mearnsii [Armidale]	15.3	804	0.95	51.14	82.60	32.02	57.75	0.59	31.80	19.91	205	5.41	3.29	698			18.8	43.4	5.8
Acacia neriifolia [Moonbi]	6.5	692	1.27	9.54	16.89	4.69	9.04	0.92	6.89	3.39	282	1.86	0.91	706			19.1	45.9	6.3
Acacia oswaldii [Murray Bridge cult.]	12.5	340	0.16	3.57	4.05	1.07	1.17	0.24	5.25	1.58	390	2.03	0.61	891			11.7	48.1	6.7
Acacia pycnantha [Murray Bridge]	7.5	340	0.42	0.38	0.41	0.07	0.09	0.61	0.57	0.11	6702	3.77	0.71	745			13.0	53.4	7.5
Acacia pycnantha [Murray Bridge]	13.5	340	0.30	3.77	6.41	0.83	1.17	0.45	5.54	1.22	2038	11.21	2.43	790					
Acacia retinodes var. *uncifolia* [Waitpinga]	10.8	621	0.46	5.70	11.81	2.85	6.18	0.37	4.59	2.30	2292	16.04	8.26	829			16.6	53.2	7.8
Acacia rivalis [Bunyaroo George]	10.0	335	0.40	3.12	5.45	1.44	2.65	0.59	4.65	2.15	723	2.95	1.34	832			12.1	51.8	7.3
Acacia salicina [Tamworth cult.]	6.1	652	0.82	5.76	8.35	2.68	4.03	0.63	4.42	2.05	1111	4.91	2.28	671	44.7	1			
Alectryon oleifolius [Gawler Ranges]	43.3	286	0.10	2.08	3.87	1.07	2.12	0.18	3.63	1.87	100	0.36	0.19				9.6	48.2	6.8
Allocasuarina verticillata [Murray Bridge]	12.5	340	0.45	6.43	9.01	3.31	4.20	0.67	9.46	4.87	703	6.56	3.40	702					
Atriplex nummularia [Cowell cult.]	30.0	298	0.08	1.74	3.72	0.86	1.94	0.14	2.92	1.45	1577	4.61	2.29						
Atriplex nummularia [Waikerie cult.]	7.5	251	0.25	3.81	6.75	1.03	1.61	0.50	7.60	2.06	1183	8.46	2.33	785					
Atriplex nummularia [Waikerie cult.]	7.5	251	0.16	0.70	0.92	0.21	0.27	0.31	1.40	0.42	1819	2.48	0.79	782					
Callitris gracilis [Kingston On Murray]	8.5	253	0.25	0.52	0.58	0.22	0.38	0.49	1.03	0.44	868	0.89	0.40	623					
Eucalyptus blakelyi [Tamworth cult.]	7.1	652	0.87	14.78	23.61	7.69	12.75	0.67	11.33	5.90	1111	12.59	6.55	529	38.9	0			
Eucalyptus camaldulensis [Culburra cult. (P05)]	10.8	460	1.06	34.66	92.40	20.69	57.96	1.15	37.68	22.49	513	18.32	11.01	511					
Eucalyptus cladocalyx [Culburra cult. (P18B)]	6.7	460	0.84	7.23	22.57	3.56	12.08	0.91	7.86	3.87	793	6.19	3.05	589					
Eucalyptus cladocalyx [Culburra cult. (P34A)]	6.7	460	0.74	8.73	22.04	4.26	11.77	0.81	9.49	4.63	419	3.84	1.86	613					
Eucalyptus diversifolia [Culburra (P37A)]	12.8	460	0.43	13.76	19.32	4.04	5.67	0.47	14.96	4.39	1279	13.74	3.91	577					
Eucalyptus globulus [Culburra cult. (P05)]	10.7	460	1.17	21.25	67.97	12.26	41.57	1.27	23.10	13.33	898	22.74	13.19	529					
Eucalyptus globulus ssp. *globulus* [cult.]	4.9	606	3.65	73.89	98.38	42.78	58.15	3.01	60.97	35.30	1143	69.56	40.26	478					
Eucalyptus gomphocephala [Culburra cult. (P23B)]	12.0	460	1.03	94.12	172.94	60.85	115.27	1.12	102.30	66.14	334	34.89	22.59	695	41.4	1			

Table 15. Continued

Phase 2 - Provenances	Avg. Age [years]	Annual Rainfall [mm]	Avg. Growth Rate [m/yr]	Avg. Plant Green Biomass Rate [kg/yr]	Max. Plant Green Biomass Rate [kg/yr]	Avg. Plant Stemwood Volume Rate x1000 [m³/yr]	Max. Plant Stemwood Volume Rate x1000 [m³/yr]	Avg. Growth Rate [m/yr @500mm]	Avg. Plant Green Biomass Rate [kg/yr @500mm]	Avg. Plant Stemwood Volume Rate x1000 [m³/yr @500mm]	Trees Per Hectare [Observed]	Avg. Green Biomass Rate [t/ha/yr @500mm]	Avg. Stemwood Volume Rate [m³/ha/yr @500mm]	Basic Density [kg/m³]	Pulp Yield @18Kappa [%dm]	Paper Test Score [Max. 20]	Crude Protein [%dm]	Digestibility [%dm]	Metabolisable Energy [MJ/kg dm]
Eucalyptus gracilis [Loxton cult.]	6.6	261	0.27	1.62	2.03	0.21	0.27	0.52	3.10	0.41	620	1.97	0.25	824					
Eucalyptus incrassata [Culburra cult. (P37A)]	12.7	460	0.28	7.24	10.95	1.49	2.41	0.30	7.87	1.62	712	4.57	0.90	711					
Eucalyptus largiflorens [Loxton cult.]	10.5	261	0.36	3.11	3.75	1.24	1.62	0.69	5.95	2.38	910	5.35	2.11	668	49.3	11			
Eucalyptus nortonii [Beechworth]	8.0	864	0.94	10.28	21.06	5.28	11.38	0.54	5.95	3.05	100	0.60	0.31	658	46.9	11			
Eucalyptus occidentalis [Culburra cult. (P18A)]	5.7	460	1.71	34.10	61.13	19.11	35.15	1.86	37.07	20.77	708	25.30	14.19	641					
Eucalyptus occidentalis [Culburra cult. (P34A)]	6.5	460	1.86	34.07	45.00	18.93	25.49	2.03	37.03	20.57	645	22.50	12.45	593					
Eucalyptus occidentalis [Culburra cult. (P34A)]	6.7	460	1.22	13.90	25.73	7.32	13.93	1.32	15.11	7.95	762	11.16	5.86	591					
Eucalyptus petiolaris [Koppio]	40.0	496	0.35	37.51	109.63	26.51	83.04	0.35	37.81	26.72	284	7.53	5.10	695	42.9	1			
Eucalyptus porosa [cult. (Cattle)]	6.8	387	0.58	7.45	9.17	1.72	2.26	0.75	9.62	2.22	1127	10.13	2.20	567					
Eucalyptus porosa [Loxton cult.]	9.5	261	0.25	2.24	2.34	0.46	0.55	0.48	4.29	0.89	546	2.34	0.48	649					
Eucalyptus porosa [Murray Bridge]	12.4	340	0.43	7.91	13.52	3.39	5.58	0.63	11.64	4.98	589	6.20	2.65	687	46.9	10			
Eucalyptus sideroxylon [Tamworth cult.]	7.1	652	0.91	12.43	18.74	6.43	9.92	0.70	9.53	4.93	1111	10.59	5.48	736	42.3	1			
Eucalyptus socialis [Loxton cult.]	10.5	261	0.31	7.67	9.76	1.54	1.77	0.60	14.70	2.95	309	4.56	0.91	742					
Eucalyptus viminalis [Culburra cult. (P47A)]	5.7	460	1.74	35.86	97.11	20.58	58.05	1.89	38.97	22.37	526	19.57	11.34	466					
Gyrostemon ramulosus [Buckleboo Stock Route]	23.3	295	0.18	3.93	8.09	2.05	4.51	0.31	6.66	3.48	1615	10.42	5.41	344	43.2	1	24.1	68.4	10.1
Hakea francisiana [Gawler Ranges]	26.0	310	0.23	2.76	4.99	1.40	2.71	0.38	4.45	2.26	2304	5.05	2.37	784					
Maireana pyramidata [Gawler Ranges]	50.0	286	0.02	0.18	0.26	0.07	0.10	0.04	0.31	0.12	123	0.04	0.01				18.3	59.5	8.6
Melaleuca armillaris ssp. *akineta* [Mt. Wudinna]	10.0	302	0.32	3.68	6.96	1.73	3.47	0.52	6.09	2.86	539	3.20	1.50	765					
Melaleuca uncinata [Murray Bridge]	12.4	340	0.15	1.42	1.61	0.58	0.67	0.22	2.08	0.86	507	1.06	0.43	722					
Viminaria juncea [Nangkita]	7.0	639	0.67	5.25	7.47	2.47	3.61	0.52	4.11	1.93	1057	4.91	2.33		50.3	9	10.2	47.8	6.6

Species Productivity

The evaluation of species productivity is a complicated process compounded by individual species/provenance/genetic responses to rainfall and other climatic variables, soil structures and chemistry, local hydrology, establishment practices, and silvicultural design and management. The yield of biomass components (wood, bark, twig and leaf fractions) is also influenced by these factors and the proportion of each fraction changes throughout the life of each individual plant. It is well recognised that to fully and accurately evaluate the primary productivity and product yield of plantations of each species requires intensive study over a number of environments for many years. Very accurate predictions can only come from masses of well collected and intensive data.

Limitations of Existing Data

The short-term productivity (1-10 years) of many of the subject species reviewed and evaluated by the FloraSearch team is poorly known for the low rainfall regions of Australia. A few of the species have been the subject of long harvest cycle crop trials in the low rainfall regions (e.g. *Eucalyptus occidentalis, E. cladocalyx, E. camaldulensis*) where the focus has been on stemwood production rates for solid timber products. Most forestry productivity research has focused on long-cycle stemwood volumes and been conducted in higher rainfall regions (typically >800 mm mean annual rainfall) with fewer studies in the mid-rainfall zone (650-800 mm). However, over the last few years some oil mallee species (e.g. *Eucalyptus polybractea, E. loxophleba* ssp. *lissophloia, E. horistes*) have been the subject of preliminary evaluations of product yield and biomass productivity.

The currently available productivity and yield data for Australian low rainfall species and plantations is limited. For a few species opportunities exist to undertake first time measurement (or more detailed re-measurements) on limited experimental plantations or farmer woodlots and revegetation sites.

Review of Existing Data and Establishment of New Field Trials

The FloraSearch project in conjunction with the Field Trial of Woody Germplasm (FTWG) project is in the process of assimilating species plantation and productivity data from a variety of sources:

- Productivity assessment conducted during FloraSearch surveys as part of their sample collection process
- Growth and health observations made at Currency Creek Arboretum of Australian Eucalypt species (Dean Nicolle, pers. comm.)
- State-based datasets on dryland plantation species in SA, WA, Victoria and NSW
- CSIRO's TreDat database on Australian field trials
- Published productivity data from the scientific literature
- Private woodlot and revegetation projects.

The scale, detail and quality of these primary datasets were far from uniform. The resulting database provides reasonable information of a few core dryland species such as *Eucalyptus occidentalis*, *E. cladocalyx* and *E. camaldulensis*. However, this process has identified several sites containing species of interest to the FloraSearch and FTWG projects which will be included in future surveys.

To boost the limited data available on targeted species and provide new data on previously untried species, it was critical to establish new trial sites across the lower rainfall regions of southern Australia. In 2004 the FTWG and FloraSearch projects initiated a series of seven field trial sites in SA (three), WA (three) and Victoria (one) to evaluate the potential of a number of prospective species in the FloraSearch study area. A further two trial sites were to be planted in NSW in 2004 but drought conditions prevailed. In 2005 a single trial sites was established in NSW and the three SA sites expanded to contain additional species and provenances, and a selection of fodder species. In 2006 a series of provenance and germplasm improvement trials will be conducted at sites across SA (two), WA (two), NSW (two) and Victoria (one).

The FloraSearch/FTWG "productivity database" provides a currently limited dataset that has been used to create simple empirical models for most species of interest to the FloraSearch project. These simple species models are based on linear relationships between observations of productivity from young age plot, patch or block plantations (typically less than 12 years old) and climate/soil productivity indices from BiosEquil models (Raupach *et al.* 2001).

As more productivity data becomes available from new assessment of existing trials, new FloraSearch/FTWG trial sites, FloraSearch and other state-based surveys, farmer woodlots, revegetation projects and other published data they will be incorporated into the "productivity database". This information can then be used to refine existing simple productivity models and may then contribute to the parameterisation of more complex process models such as 3PG and others.

Many of the FloraSearch species were targeted in part for their ability to coppice (or pollard), that is, to resprout from rootstock or lower trunk section after harvesting. The main advantages of coppicing species is that they do not require expensive replanting after harvest, the energy stored in their rootstock allows the plants to grow more rapidly than seedling stock, and they are more efficient at utilising rainfall due to their more extensive root mass. Mallee form Eucalypt species are renown for their ability to coppice, however, the majority of Eucalypts are also capable of coppice growth, as are many other FloraSearch genera (e.g. some *Acacia* spp., *Atriplex* spp., some *Casuarina* spp., *Viminaria* spp.).

Improving Techniques for Productivity Assessments

To fully assess the productivity of plantations requires either very detailed measurements and sub-sampling or destructive harvesting of plant biomass. These processes are very labour intensive and time consuming, and with destructive harvesting there is no opportunity to re-measure the plants as they grow older. Realising the limitations in time, resources and plant materials available to the FloraSearch project, it was important to develop rapid assessment techniques to estimate the total productivity of individual plants and their biomass components (i.e. wood, bark, twig, leaf fractions). To develop robust allometric relationships between simple plant measurements and the yield of biomass fractions would allow us to rapidly increase the speed of individual plant assessments and also allow the variations within plantations and at other locations to be more readily determined.

In 2004 and 2005 the FloraSearch team undertook biometric measurements and destructive sampling of a range of mallees, shrubs and small trees. In the low rainfall Riverland and Lower Murray regions of SA, 54 individual plants (average age 10 years) were measured and destructively sampled to develop generalised, genera and lifeform specific, allometric equations (Hobbs and Bennell 2005). In WA, FloraSearch has conducted similar surveys and destructive sampling for a few key species including *Eucalyptus polybractea*, *E. horistes*, *E. loxophleba* ssp. *lissophloia*, *Acacia saligna* and *Casuarina obesa.* A summary of those biometric relationships can be found in Table 17.

In South Australian studies the green biomass and biomass fraction model equations take the form:

$$y = e^{a.\ln(x+1)1+c} - 1$$

where y = green biomass [kg plant^{-1}], x = predictor morphological variables, a = predictor factor and c = intercept of the linear regression (see Table 16 for details). The generalised green biomass model developed from SA data is highly significant and robust (r^2= 0.84). Simple height and stem diameter observations (to determine the outer bark stemwood volume of an individual plant) can be used to reasonably predict standing green biomass using the formula:

$$\textit{Total Green Biomass [kg plant}^{-1}] = e^{0.9243 \times \ln((\text{Stemwood Volume} \times 1000\,[m^3]) + 1) + 0.9529} - 1$$

Lookup tables of biomass fractions for each group or species can then be applied to determine yields of each biomass fraction (see Appendix A).

In Western Australian studies, site level regression equations have been developed for simple biometric to green standing biomass for a number of species (Table 17).

The robustness of the generalised (non species specific) allometric model of Hobbs and Bennell (2005) has been tested against data gathered from WA plantations (Figure 15). The model has proven to be a good predictor of green biomass for several other species, including *Eucalyptus polybractea* (correlation coefficient r^2=0.96), *E. occidentalis* (r^2=0.92) and *Casuarina obesa* (r^2=0.88).

Further plantation productivity assessments, plant biometric and allometric relationships are currently being developed for mainly tree species growing in the low rainfall Upper South East region of SA. Target species of that study include *Eucalyptus occidentalis*, *E. cladocalyx*, *E. viminalis* ssp. *cygnetensis*, *E. porosa*, *Acacia mearnsii*, and several other mallee and tree species native to that region. Refined and robust allometric equations allow more rapid site and species assessments.

Productivity Evaluations from Existing Trials and Data

Data has been collated from TreDat trials database (CSIRO/Ensis 2005), FloraSearch surveys and state-based records. Most of this data contains information on height and stem diameters to allow calculations of stemwood volumes, however, other more detailed FloraSearch research provides information on whole tree/shrub green biomass and proportions of biomass fractions (stem, twig, leaf). Using the robust allometric equation of Hobbs and Bennell (2005) the green biomass of all plants and plot area has been estimated. Figure 16 and Figure 17 demonstrate one of several analyses undertaken to evaluate productivity based on existing data. The two plots combined illustrate the difference between site averages and best performing plots and germplasm selection. It also illustrates the need to select the most appropriate species and germplasm to match each site.

More detailed productivity assessments of high priority FloraSearch species are currently being undertaken within the FloraSearch and FTWG projects. This more detailed information will add refinement and confidence in future predictive models of plant and paddock productivity. This analysis is of course limited to the species already chosen by others in previous research and do not include all species of interest to the FloraSearch project. To remedy this lack of productivity data on some species and provenances a series of field trials has been established across southern Australia in 2004 and 2005 with many more additions in 2006 and beyond.

The oldest plots of the current FloraSearch/FTWG field trials project are only 20 months old. Limited one-year-old height and six month survival data provides an indicative guide to some of the best performing species. The following table provides a subset of that data with a particular focus on species likely to be important to FloraSearch industries in the future (Table 18).

Table 16. Correlations between plant morphological measures and above ground green biomass (kg $plant^{-1}$) from the SA biometrics study, including allometric model parameter values.

Variable (y)	Predictor (x)	n	r^2#	Allometric Model Parameters Factor (*a*)	Intercept (*c*)
Total Green Biomass	Basal Area [cm^2]	54	0.57***	0.8405	-1.3258
	Basal Area [cm^2] x Height [m]	54	0.62***	0.5909	-0.7962
	Height [m] x Crown Area [m^2]	54	0.78***	0.7975	1.1352
	Height [m] x Crown Area [m^2] x Foliage Density [%]	54	0.81***	0.7309	-1.6831
	Stemwood Volume x 1000 [m^3]	54	0.84***	0.9243	0.9529
	Stemwood Volume x 1000 [m^3] x Foliage Density [%]	54	0.79***	0.7607	-1.7423
Wood & Bark	Stemwood Volume x 1000 [m^3]	54	0.77***	1.1978	-0.9743
Twig & Bark	Stemwood Volume x 1000 [m^3]	54	0.68***	0.6126	0.7501
Wood & Bark + Twig & Bark	Stemwood Volume x 1000 [m^3]	54	0.89***	0.9838	0.3929
Leaf, Fine Twig & Bark	Foliage Density [%]	54	0.13**	0.5440	0 ns
	Height [m] x Crown Area [m^2]	54	0.58***	0.6120	0.6216
	Height [m] x Crown Area [m^2] x Foliage Density [%]	54	0.76***	0.6309	-2.0190
	Stemwood Volume x 1000 [m^3]	54	0.59***	0.6955	0.5168
	Stemwood Volume x 1000 [m^3] x Foliage Density [%]	54	0.72***	0.6461	-2.0003
Total Green Biomass	Height [m] x Crown Area [m^2] x Foliage Density [%]				
Acacias		15	0.81***	0.8645	-2.5101
Eucalypts		24	0.82***	0.7377	-1.8059
Non Eucalypts		30	0.80***	0.7694	-1.8711
Non Eucalypts/Acacias		15	0.76***	0.7355	-1.6801
Mallee		21	0.84***	0.7659	-2.0462
Shrub		24	0.74***	0.7151	-1.5668
Total Green Biomass	Stemwood Volume x 1000 [m^3]				
Acacias		15	0.84***	0.9519	0.9099
Eucalypts		24	0.87***	0.7687	1.5469
Non Eucalypts		30	0.90***	1.0344	0.5191
Non Eucalypts/Acacias		15	0.95***	1.0136	0.4092
Mallee		21	0.91***	0.8009	1.5142
Shrub		24	0.91***	1.2410	0 ns

(n=number of observations. # correlation coefficients & significance levels: * $p<0.05$; ** $p<0.01$; *** $p<0.001$. ns=not significant)

Table 17. Site allometric relationships for selected species from Western Australian biometric studies.

Species	Plant Age	Site Location	Allometric Equation	Number of plants sampled
Acacia saligna	31 months	East Beverley	ln(Total Green Biomass [kg plant^{-1}]) = 0.03945 x ln(CVI) + 0.92524 x ln(SBA) - 0.06838 (Nstems) + 1.39035	56
Eucalyptus loxophleba ssp. lissophloia	Coppice, age 2 to 3 years	Multiple sites	Total Green Biomass [kg plant-1] = (0.202xCVI+1.3514)2	889
Eucalyptus polybractea	Coppice, age 2 to 3 years	Multiple sites	Total Green Biomass [kg plant^{-1}] = $(0.2093 \times CVI + 1.4663)^2$	999
Eucalyptus polybractea	Saplings, 9 years	Kalannie	ln(Total Green Biomass [kg plant-1]) = 0.17808(Ht) + 1.09582 x ln(SBA) -0.01283(Nstems) - 2.19801	115
Eucalyptus polybractea	Saplings, 2 to 4 years	Gibson	ln(Total Green Biomass [kg plant-1]) = (0.11235xA + 0.50312 x ln(CVI) + 0.55390 x ln(SBA) - 0.00238(Nstems) + 3.38805)/1000	145

Where: CVI = Crown Volume Index (m^3)
SBA = Stem Basal Area at 10cm above ground (cm^2)
Ht = Tree Height (m)
Nstems = Number of stems at 10cm above ground
A = Plant Age (years; integer values)

Figure 15. The robustness of the Hobbs and Bennell (2005) allometric model demonstrated by testing again independent WA plant observations.

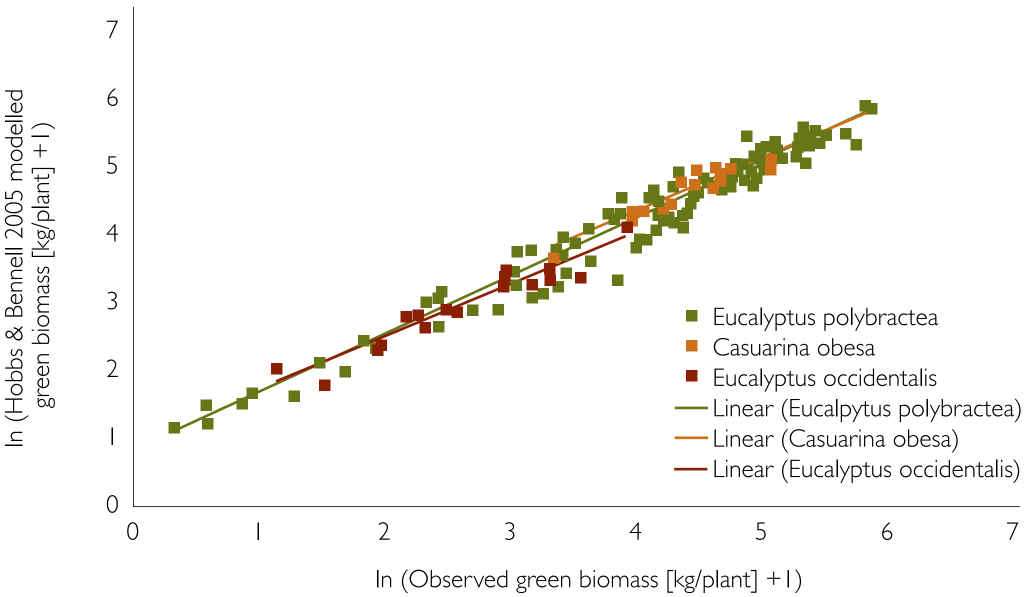


Figure 16. Average annual biomass productivity of all survey data and TreDat data.

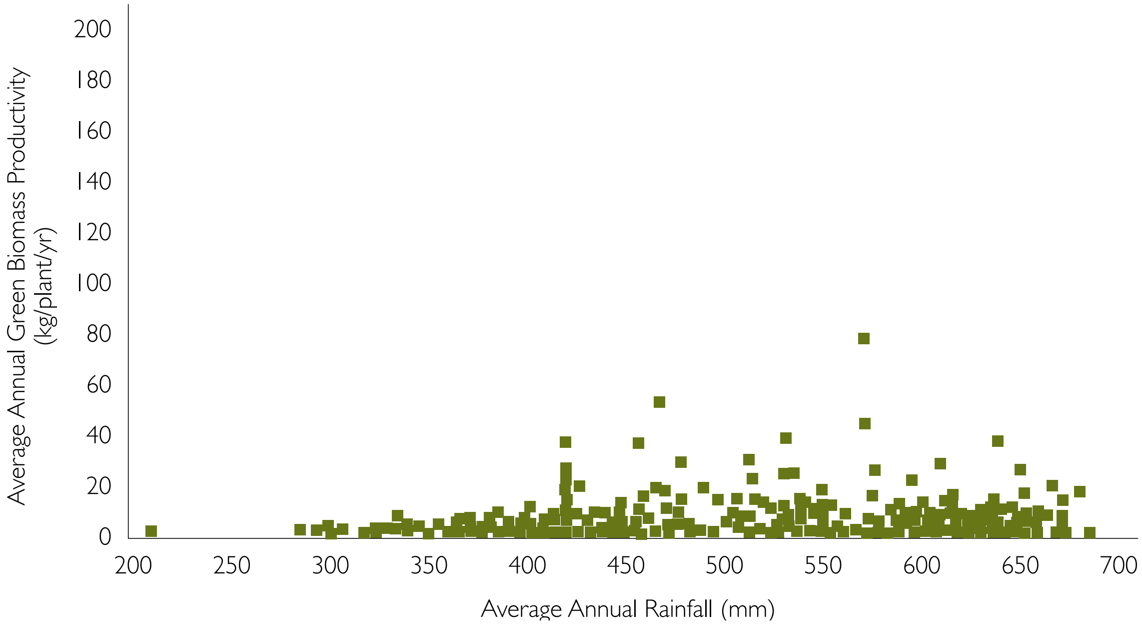


Figure 17. Plot maximum annual green biomass productivity of all survey data and TreDat data.

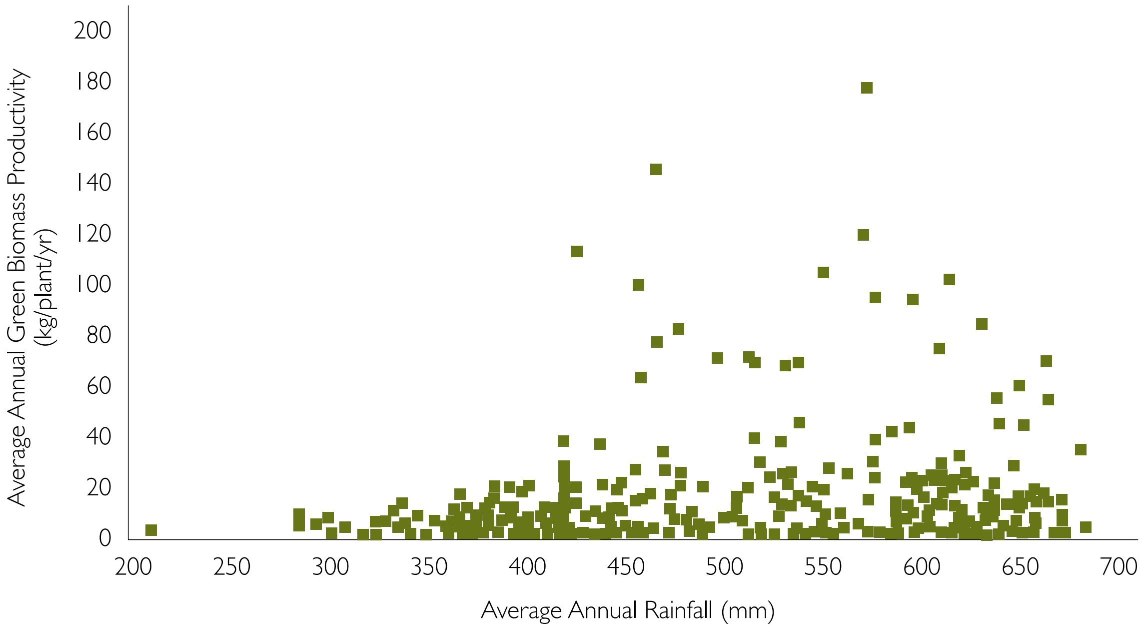


Table 18. Some of the average fastest growing plant provenances observed at South Australia and Victorian field trials of woody germplasm trial sites planted in 2004.

Provenance	Survival				Average Height [m]				Rainfall Adjusted	
	SA Murray Bridge	SA Roseworthy	SA Lucindale	Vic Rutherglen	SA Murray Bridge	SA Roseworthy	SA Lucindale	Vic Rutherglen	Av. Survival	Av. Height [m]
Atriplex nummularia [Eyre's Green]	99%				1.07				100%	1.49
Acacia mearnsii [Bungendore CS18975]	98%				1.01				100%	1.41
Acacia saligna (wheatbelt form) [Parkeyerring RSU]	100%	75%	54%	99%	1.05	1.12	0.68	2.21	82%	1.36
Viminaria juncea [Mt. Compass]	90%	91%	14%	100%	1.10	1.25	0.63	2.41	75%	1.46
Acacia retinodes var. *retinodes* (hill form) [Bull Creek]	91%			98%	0.61			1.68	93%	1.16
Eucalyptus camaldulensis var. *camaldulensis* [Lake Albacutya CS20561]	94%	98%	27%	99%	0.91	1.28	0.66	2.29	78%	1.38
Acacia deanii ssp. *deanii* [Biloela CS16922]	93%				0.72				100%	1.01
Eucalyptus occidentalis [Redhill]	91%	91%	45%	99%	0.86	1.04	0.70	1.87	83%	1.21
Acacia retinodes var. *retinodes* (hill form) [Eden Valley]	96%				0.66				100%	0.92
Eucalyptus cladocalyx [Wirrabara]	94%	93%	35%	100%	0.71	1.01	0.73	1.83	80%	1.14
Acacia pycnantha [McLaren Flat]	98%				0.63				100%	0.89
Acacia retinodes var. *retinodes* (swamp form) [BSC]	96%	92%	17%	99%	0.85	0.70	0.85	2.06	76%	1.17
Eucalyptus leucoxylon ssp. *leucoxylon* [Wirrabara CS20274]	98%				0.61				100%	0.85
Casuarina cunninghamiana ssp. *cunninghamiana* [Coonabarabran CS15001]	68%	98%		100%	0.40	0.65		1.49	94%	0.89
Eucalyptus petiolaris [Ungarra]	98%	83%	47%	99%	0.69	0.67	0.79	1.59	83%	0.99
Eucalyptus viminalis ssp. *cygnetensis* [Williamstown CS16025]	90%	97%	28%	100%	0.63	0.73	0.77	1.87	79%	1.04
Eucalyptus porosa [Laura]	96%			99%	0.45			1.25	93%	0.86
Indigofera australis [Scott Creek]	74%			100%	0.45			1.13	94%	0.81
Atriplex nummularia [Yando]	99%	97%	47%	100%	0.74	1.02	0.69	1.08	75%	0.98
Alyogyne huegelii [Yorke Peninsula]	76%			99%	0.37			1.16	93%	0.77
Average Annual Rainfall [mm]	357	402	519	570	357	402	519	570	500	500

Species Selections for Further Development

The combination of product testing from FloraSearch Phase 1 and Phase 2 and WA Search, climatic and site suitability evaluations and productivity evaluations allows us to identify those species and provenances that are suitable for germplasm development and the focus of more detailed research. The following tables contain summaries of key product testing results and productivity evaluation to highlight and prioritise species suitable for promotion and development (Table 19).

The rank of each of these species is dependant on specific industry requirements, planted distributions potential and their growth potential. In summary, those species with high pulp yields, low density and high paper scores (good yields and paper testing qualities) are most highly ranked for pulp and fibreboards and particleboards. High growth and wood densities are best for bioenergy related industries and carbon sequestration. Species with high oil contents are prized for oil extraction and integrated wood processing. Maximum metabolisable energy and crude protein are valued for fodder industries. The most prized species are ones that rank highly across as many different product areas.

Table 19. The most highly ranked potential FloraSearch development and focus species.

Species	Min. Basic Density [kg/m³]	Max. Basic Density [kg/m³]	Pulp Yield [%dm @ 18Kappa]	Paper Score [Max.of 20=Best]	Oil Yield [%dm]	Crude Protein [%dm]	Digestibility [%dm]	Metabolisable Energy [MJ/kg]	Plant Growth Rate [green kg/plant/yr/500mm]	Plant Stemwood Volume Rate [m³/plant/yr/500mm x1000]	Plot Growth Rate [green t/ha/yr/500mm]	Plot Stemwood Volume Rate [m³/ha/yr/500mm]
Acacia decurrens	698	704	51.8	4		14.3	50.0	7.0	34.73	21.66	7.47	3.97
Acacia lasiocalyx	648	648	51.6	17								
Acacia leucoclada	627	748	49.8	11		17.2	48.1	6.7	11.78	6.37	1.18	0.64
Acacia mearnsii	686	759	54.8	12		18.8	43.4	5.8	31.80	19.91	5.41	3.29
Acacia retinodes	586	829	55.7	10					10.07	5.23	8.39	4.35
Acacia salicina	538	717	45.3	12		14.3	62.3	8.9	25.89	13.74	6.45	3.16
Acacia saligna	585	585	45.2	12					16.11	7.79	17.19	8.31
Anthocercis littorea	418	418	49.7	8								
Atriplex nummularia	782	785				20.4	75.6	11.1	7.60	2.06	8.46	2.33
Atriplex paludosa						10.0	65.5	9.6	1.30	0.14	10.40	1.15
Atriplex vesicaria						20.1	69.4	10.1	1.01	0.12	2.02	0.04
Casuarina obesa	613	613	41.8	1					9.60	4.64	4.00	1.93
Chenopodium nitrariaceum						20.8	78.6	11.5	1.25	0.52	1.69	0.07
Codonocarpus cotinifolius	397	559	46.5	6								
Eremophila longifolia	672	672	<38	0		13.2	75.4	11.0	2.88	1.21	2.88	0.12

Table 19. Continued

Species	Min. Basic Density [kg/m³]	Max. Basic Density [kg/m³]	Pulp Yield [%dm @ 18Kappa]	Paper Score [Max.of 20=Best]	Oil Yield [%dm]	Crude Protein [%dm]	Digestibility [%dm]	Metabolisable Energy [MJ/kg]	Plant Growth Rate [green kg/plant/yr/500mm]	Plant Stemwood Volume Rate [m³/plant/yr/500mm x1000]	Plot Growth Rate [green t/ha/yr/500mm]	Plot Stemwood Volume Rate [m³/ha/yr/500mm]
Eucalyptus aromaphloia	540	540	45.4	2	4.4				6.40	3.19	1.01	0.48
Eucalyptus camaldulensis	502	511	38.3	0	2.3				37.68	22.49	24.42	13.23
Eucalyptus cladocalyx	589	753	49.6	12	0.1				55.11	33.20	22.19	13.33
Eucalyptus cneorifolia	854	854			1.5				17.07	9.42	11.38	6.28
Eucalyptus dawsonii	876	876			4.2				42.95	26.58	24.45	14.12
Eucalyptus globulus	656	656	46.7	11	5.6				4.39	2.16	0.44	0.22
Eucalyptus gomphocephala	695	695	41.4	1	0.1				102.30	66.14	34.89	22.59
Eucalyptus horistes	835	835			4.7							
Eucalyptus incrassata	711	768	48.6	3	2.8				7.87	1.62	4.57	0.90
Eucalyptus largiflorens	668	668	49.3	11	0.9				5.95	2.38	5.35	2.11
Eucalyptus loxophleba	707	707	48.7	7	6.0				9.44	4.56	0.94	0.46
Eucalyptus nortonii	639	658	46.9	11	0.7				20.10	10.60	5.03	2.65
Eucalyptus occidentalis	591	641	49.4	6	1.4				37.07	20.77	25.30	14.19
Eucalyptus oleosa	792	792			4.6				7.45	1.55	5.71	1.20
Eucalyptus ovata	504	504	49.8	3	3.9				4.68	2.36	1.08	0.54
Eucalyptus petiolaris	664	695	42.9	9	2.1				37.81	26.72	7.53	5.10
Eucalyptus polybractea	770	851	53.8	12	8.0				23.63	11.74	24.42	12.12
Eucalyptus porosa	641	687	49.9	10	2.1				11.64	4.98	10.13	2.65
Eucalyptus rudis	553	553	48.4	8	0.7							
Eucalyptus viminalis	532	568	44.3	6	3.4				17.57	9.12	9.51	5.19
Gyrostemon ramulosus	344	384	44.5	5		24.1	68.4	10.1	6.66	3.48	10.42	5.41
Maireana pyramidata						25.8	68.5	9.9	0.62	0.12	1.25	0.03
Maireana rohrlachii						27.3	64.7	9.3	0.58	0.03	1.15	0.01
Myoporum platycarpum	685	685	49.6	8		10.2	57.9	8.2	4.81	2.22	1.05	0.49
Nitraria billardierei						18.5	81.3	12.0	0.73	0.06	1.46	0.01
Rhagodia parabolica						15.8	66.3	9.8	3.49	1.55	8.72	3.88
Taxandria juniperina	501	501	54.3	18								
Viminaria juncea	436	436	50.3	9		10.2	47.8	6.6	4.11	1.93	4.91	2.33

4. Development and focus species

Overview

The following pages provide a brief synopsis of information on those species currently ranked as having greatest potential for development and requiring further intensive evaluation (Table 19). Based on current information a few highest priority "development" species have been promoted to a "focus" group which are subject to even more detailed evaluations, product testing and field trials in 2006 and beyond. Provenances and selections of two of these focus species (*Acacia saligna* and *Atriplex nummularia*) have been chosen for germplasm improvement and field trials, with planting commencing in mid-2006.

The selection of development and focus species has been a major objective of FloraSearch Phase 2 and the selection process is described in Chapter 3. The Western node also undertook this process for WA species as part of the Search project (Olsen *et al.* 2004) and ongoing evaluation and observation of species characteristics has led to a shortened list of the most prospective species being put forward. Development species are those considered to have characteristics of high quality feedstock for the product area identified, adaptability to a significant portion of the study area, biological attributes that suit them to domestication, and productive potential that together suggest this species is worthy of ongoing evaluation as a commercial species. Focus species are those with the above attributes but where there is a high level of confidence by FloraSearch scientists and external reviewers that the species is worthy of domestication as a commercial crop species. This chapter presents a discussion of the focus species for which plant improvement programs are being initiated and a short description of most prospective of the development species for eastern Australia and Western Australia.

The focus species for which plant improvement work will be undertaken in eastern Australia and Western Australia is Oldman Saltbush (*Atriplex nummularia*). This species will be the focus of FloraSearch Phase 3 work by the eastern node. The focus species for Western Australia is *Acacia saligna* with most of the plant improvement work centred in that state.

Focus Species
Atriplex nummularia (East and West)
Acacia saligna (West)

The species identified as development species for eastern Australia and Western Australia are described in more detail below. Photographs, a map of herbarium records and estimated region of adaptability (bioclimatic modelling) is provided for each species along with notes on cultivation and crop potential. For the most prospective a short general description is included. This list will still be subject to update as outstanding testing results are received after the reporting date.

A further group of less prospective species is still being considered by the WA node, and further updates may occur as more knowledge is gained. The test and productivity estimate data for eastern and western node species is provided in Table 19.

Development Species – Eastern
Acacia decurrens
Acacia mearnsii
Acacia retinodes var. *retinodes (hill form)*
Acacia retinodes var. *retinodes (swamp form)*
Eucalyptus aromaphloia ssp. *sabulosa*
Eucalyptus cladocalyx
Eucalyptus globulus ssp. *bicostata*
Eucalyptus occidentalis
Eucalyptus oleosa
Eucalyptus ovata
Eucalyptus petiolaris
Eucalyptus polybractea
Eucalyptus porosa
Eucalyptus viminalis ssp. *cygnetensis*
Viminaria juncea
Development Species – Western
Acacia lasiocalyx
Anthocercis littorea
Casuarina obesa
Codonocarpus cotinifolius
Eucalyptus rudis
Eucalyptus horistes
Eucalyptus loxophleba ssp. *lissophloia*
Taxandria juniperina

Cattle grazing an Oldman Saltbush (*Atriplex nummularia*) plantation

Focus Species

Atriplex nummularia – Oldman Saltbush

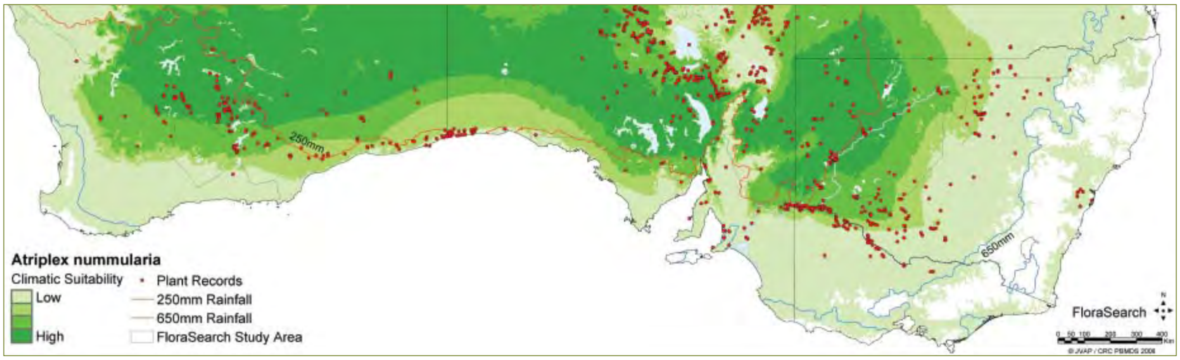
Background

Approximately 50 000 hectares of chenopod fodder shrubs, generally *Atriplex nummularia*, have been established as plantations in Australia (Lefroy 2002). The species is widely planted in semi-arid to arid regions of Chile and in many middle-eastern countries including Morocco where more than 50,000 hectares have been planted (Le Houerou 2000). Well-maintained plantations of Oldman Saltbush in South Africa and North Africa have lasted for over 40 years (Le Houerou 2000). The Australian plantings have generally been made on saline soils to reclaim them or on non-saline soils to prevent dryland salinity and increase landscape resilience and productivity.

Atriplex nummularia is an erect shrub to 3 m and predominantly dioecious. There are three subspecies, ssp. *nummularia,* ssp. *omissa* and ssp. *spathulata*. The distribution is described in the accompanying figure.

Atriplex nummularia is a productive drought tolerant fodder shrub with a high grazing capacity that has been long recognised as an important browse species in arid and semi-arid rangeland communities (Watson 1990). It is used by an increasing number of farmers who graze it each year from February to April before the annual clover pasture becomes established (Slavich *et al.* 1999). The species has potentially high biomass accumulation rates under non-limiting conditions and is highly tolerant to drought and salinity (Slavich *et al.* 1999).

The ability of saltbush to produce forage on saline land has resulted in substantial saltbush areas being established on farms across southern Australia over the past few decades. Physiological adaptations of *Atriplex* spp. including the accumulation of high concentrations of sodium and chloride within cell vacuoles and compatible organic solutes in cytoplasm



The distribution and bioclimatic map of *Atriplex nummularia.*

help offset the growth limiting attributes of soil salinity (Islam and Adams 2000). Low salinity levels do not appear to have a deleterious effect on the growth of *Atriplex* spp. and may actually stimulate growth (Khan *et al.* 2000). However high salinity levels may cause a reduction in total growth of *Atriplex* spp. especially in leaf biomass (Khan *et al.* 2000).

In recent years *Atriplex* spp. have increasingly been recognised as having limitations as fodder for stock because of their high concentrations of salts and other metabolites and due to the small proportion of total nitrogen present in readily digestible forms (Islam and Adams 2000). The high levels of salt in *Atriplex* browse forced animals to increase water intake with consequential influences on rumen physiology and metabolism (Abu-Zanat and Tabbaa 2006). Saltbush species contain secondary chemical compounds which may restrict grazing or feed intake by herbivores (Abu-Zanat and Tabbaa 2006). There has been a view that protein concentrations are the major index of nutritive value and can be calculated from the concentrations of total nitrogen using a conversion factor (Islam and Adams 2000). Little if any attention has been given to the metabolic fractions of nitrogen and phosphorous in native Australian shrub species or indeed for many other, non-agricultural trees and shrubs (Islam and Adams 2000). Chemical analyses often overestimate digestibility especially protein since protein is often bound to lignin and tannins which prevent its breakdown (Lefroy *et al.* 1992). This question is a topic of current research by the CSIRO Livestock Industries group in Perth and is part of the Enrich project.

It is now widely understood that a complimentary source of carbohydrate needs to be provided with the saltbush to achieve a balanced feed ration. One study indicated that there are disadvantages with a pure saltbush diet compared to a mixed diet of saltbush and hay. Sheep fed with different saltbush species lost weight at about 200g per day while sheep on an equal mixture of oaten hay and *A. undulata* gained 70g per day over the three week trial. The likely advantages of the mixed diet are a lowered salt intake than the pure saltbush diet and higher crude protein than the pure hay (Lefroy *et al.* 1992). The establishment of companion grasses in saltland such as *Puccinellia ciliata* and *Agropyron elongatum* becomes equally important as does the grazing of saltland in conjunction with crop residues and dry pasture (Lefroy *et al.* 1992)

Selection of saltbush genotypes for commercial planting in Australia has been largely based on agronomic factors with little consideration for nutritive value or palatability. Ruminants select a diet that is higher in digestible nutrients and lower in toxins than the average of available plant material, indicating that feed selection is not random (Norman *et al.* 2004). This feed preference depends on the palatability of the specific feeds available and the ability of the animal to distinguish between feeds (Norman *et al.* 2004). Palatability of a forage is dependent on a number of factors including nutritive value, anti-nutritive factors and toxins, accessibility of the feed, social learning and learned aversion cues (Norman *et al.* 2004).

The place of cultivated browse plants is often limited by the marked seasonal nature of their feed advantage and the higher costs involved in growing and managing trees and shrubs compared to other forage plants (Lefroy *et al.* 1992). Economic modelling has identified the most profitable strategy for using the saltbush stands as grazing with sheep at high stocking rates for 1-2 months in autumn and early winter – a time when pasture feed is usually scarce (Morcombe *et al.* 1996). The increased cost of a shrub-based system arises from establishing and managing the shrubs, the time to reach a productive age, the persistence of the plant under grazing pressure and the ability of the plant to produce feed when it is most needed (Lefroy *et al.* 1992)

Plant Improvement Program for Oldman Saltbush

The role of perennial fodder species in Australian farming systems is gaining pace with animal production becoming more profitable with respect to cropping, the role of perennials in managing natural resource issues and the growing realisation that the risk of climate change will drive development of more resilient production systems particularly in the margin fringes of the wheat-sheep belt. Saltbush will be a backbone species in future grazing systems on non-saline lands based on its productive potential and adaptability to the low rainfall farming region.

This potential is not matched by the development of improved planting material that exploits the genetic variability readily available to plant breeders within Australia. While the products of selection work undertaken in South Africa and local selections from planted populations are available locally there has been no systematic effort to improve productivity and nutritive value of the species. FloraSearch has initiated a program with the collaboration of the CSIRO Livestock Industries in Perth to achieve these goals. The main elements of this program are:

- Develop a breeding strategy (Richard Mazanec, DEC, WA)
- Compile a record of experience with the species in Australia and overseas undertaken by the Enrich and FloraSearch program
- Undertake a literature review
- Collect germplasm across the geographic range (Peter Jessop, NSW DPI and Wayne O'Sullivan, DEC, WA)
- Store the collection with the SARDI Germplasm Centre as a national resource (Steve Hughes, SARDI)
- Establish provenance/family trials (WA – salt and upland, SA and NSW)
- Develop evaluation and selection protocols (productivity, nutrition, form, leaf retention and palatability).

A comprehensive germplasm collection of the ssp. *spathulata* and ssp. *nummularia* was completed by February 2006. The planting material for the family/provenance trial have been propagated and planted in trials sites at Tammin, WA, Monarto, SA and Condobolin, NSW.

Acacia saligna – Orange Wattle

Taxonomy and distribution

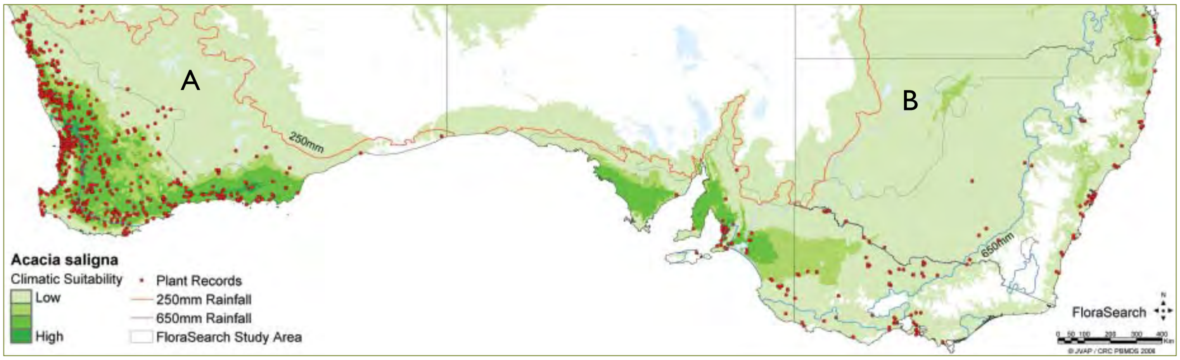
Acacia saligna (Labill.) H. Wendl. is a morphologically variable species with unresolved taxonomic complexity. For a species description refer to Maslin (2001). There is unresolved taxonomic complexity in *A. saligna*, although at present the species is considered to comprise four informal morphological variants, currently known as "Typical", "Forest", "Cyanophylla" and "Tweed River" (see below). For a description of the variants refer to Maslin and McDonald (2004). A genetic study of *A. saligna* found the species to be genetically diverse and revealed at least three "entities" within the species, although the taxonomic status of these is unresolved (George *et al.* 2006). Two of the entities corresponded with the Forest and Typical variants whilst the third entity encompassed both the Cyanophylla and Tweed River variants, which are apparently closely related. The study also found considerable genetic diversity within each of morphological variants, evidence for further taxonomic complexity, and also limited hybridisation between the entities.

Acacia saligna is known by several colloquial names including Orange Wattle, Black Wattle, Golden Wreath

Pictures of Acacia saligna, showing the morphological variants (Maslin and McDonald 2004). Mature specimens of (A) Cyanophylla variant, (B) Typical variant, (C) Tweed River variant and (D) Forest variant (Pictures (B) and (D) courtesy of B. R. Maslin, World Wide Wattle)

Wattle, Blue-Leafed Wattle, Western Australian Golden Wattle and Port Jackson Willow (Fox 1995). The traditional name for the species is *Koojong* (Abbott 1983). Due to the existence of multiple common names we have adopted the generic traditional name, Koojong.

Acacia saligna is endemic to the south-west of Western Australia, occurring within the FloraSearch study area (see below). The species has a widespread distribution extending from Wilgiamia Pool 30 km north east of Kalbarri, to Ponier Rock 65 km south of Balladonia, but also occurring 230 km east-north-east of Kalbarri on Meka, Murgoo and Jingemarra Stations (Maslin 2001). *Acacia saligna* has a discontinuous distribution in south-western Australia, although it is often common in areas where it occurs (Fox 1995; Maslin and McDonald 2004). *Acacia saligna* has been planted widely outside its natural range, both within Australia and internationally. The species has been introduced to SA, Queensland, NSW, Victoria and Tasmania (AVH 2006) (see below). Internationally, *A. saligna* is common, and often naturalized, in most countries around the Mediterranean (Greuter *et al.* 1989). It is also widely distributed in Africa, especially and South Africa (Lock 1989). It is also reported to grow in countries in the Middle East (Le Houerou 2002; Lock and Simpson 1991; Marcar *et al.* 1991; Townsend 1974), South America (Izaguirre and Beyhaut 2003; Perret and Mora 1999), and has been recorded in North America (USDA and NRCS 2006) and New Zealand (Pollock *et al.* 1986).



The distribution and bioclimatic map of *Acacia saligna*. Records from Western Australia show endemic range of the species (A). Records from other states show exotic distribution (B).

Biological features

Acacia saligna comprises variable shrubs or trees, 2-10 m, single or multi-stemmed, mature trunks 5-40 cm diameter at breast height (dbh) and straight or rather crooked, often suckering (Maslin and McDonald 2004). In unfavourable conditions trees live for around five years, although under favourable conditions this may be extended to nearly twenty years (Fox 1995). There is some evidence that trees in South America have reached 30 years (O'Sullivan pers. comm.). In Western Australia the species grows in a variety of habitats but shows a preference for deep sandy soils and land bordering water courses (Doran and Turnbull 1997; Maslin 2001). Similarly, as an exotic the species also grows in a range of habitats but appears to prefer deep sandy soils and areas with additional water (Michaelides 1979).

The endemic range of *A. saligna* experiences a Mediterranean climate. The species grows in an annual rainfall range of between 300 and 1200 mm, that falls mainly in the winter months. Although in drier parts of its range *A. saligna* tends to be found around large granite rocks where runoff is locally increased (Doran and Turnbull 1997; Fox 1995). The species performs better in areas with higher rainfall or additional sources of water. The species does not tolerate constant waterlogging of soil (Fox 1995) but its proximity to water bodies suggests it can tolerate brief heavy inundation. The general temperature requirement for *A. saligna* is a mean of 13-21°C, with mean minimum temperatures of 2-10°C and mean maximum temperature of 26-36°C (Marcar *et al.* 1995). The plants have a low ability to withstand frost, particularly when young, although they do have the ability to re-sprout after damage from heavy frosts (Pollock *et al.* 1986). *Acacia saligna* occurs in a variety of plant communities, but typically in the more open parts of dry sclerophyll forest, temperate woodlands, semi-arid woodlands and mallee (Doran and Turnbull 1997). It does not commonly occur in dense and tall *Eucalyptus* or *Banksia* communities (Fox 1995).

Acacia saligna forms symbiotic associations with nitrogen-fixing bacteria and mychorrizal fungi. It has been found to nodulate with a wide variety of strains of nitrogen fixing bacteria from its natural range (Marsudi *et al.* 1999). It can also nodulate with strains of nitrogen-fixing bacteria from soils outside its natural distribution in Australian and also internationally (Hatimi 1999; Hoffman and Mitchell 1986; Koreish *et al.* 1997; Nasr *et al.* 1999; Quatrini *et al.* 2003; Wolde-Meskel *et al.* 2005; Yates *et al.* 1999). Likewise, *A. saligna* can also form symbiotic relationships with mychorrizal fungi native to soil in south-western Australia (Jasper *et al.* 1989) and also internationally (Hatimi 1999; Hoffman and Mitchell 1986; Quatrini *et al.* 2003).

The gall rust fungus (*Uromycladium tepperianum*) appears to be a major disease of *A. saligna*. It typically afflicts older trees or trees growing in poor conditions, and heavy infestation can lead to the death of the trees (Doran and Turnbull 1997; Fox 1995; Gathe 1971). The fungus is apparently wind dispersed (Morris 1987) and within three years can spread ten km from an original infection site (Morris 1999). A large number of insect species are also found on *Acacia saligna*, some of which have been shown to cause considerable damage to the plant and seeds (Berg 1980a; Berg 1980b; Berg 1980c). The species is also known to be susceptible to anthracnose (Barnard and Schroeder 1984).

A. saligna has become a weed in many areas where it has been introduced, attributable to the species fast growth rate, tolerance of mild drought and poor soil, extensive root system, suckering and coppicing ability, and abundant seed set (Blood 2001; Muyt 2001; Swarbrick and Skarratt 1994). Notably, *A. saligna* was considered one of South Africa's worst weeds, forming dense stands in conservation areas, water catchments and agricultural lands, replacing indigenous vegetation and interfering with agricultural practices (Morris 1999). The weed risk posed by *A. saligna* has been reduced in South Africa by the introduction of the gall rust fungus as a bio-control (Morris 1999).

Cultivation

Acacia saligna has a long history of human utilization. The seed of *A. saligna* was exploited as a source of food by the Aboriginal people of south Western Australia (Bindon 1996; Meagher 1973). It was utilized by early European settlers in Australia as a source of gum, tannin and timber (Maiden 1889). Since then it has been recorded as being used at various times for gum, fuel, livestock forage and shelter, fibre and as an ornamental (Lazarides and Hince 1993; Wiersen and Leon 1999). Within Australia it is used most commonly for revegetation and ecological restoration works, in Western Australia it is used heavily for road-side plantings (Fox 1995; Maslin 1997).

Outside Australia, *A. saligna* is cultivated in North Africa, the Middle East and South America (Crompton 1992). It is extensively utilized in the Mediterranean region, particularly in North Africa, where it is exploited extensively for fodder and firewood (Doran and Turnbull 1997; El-Lakany 1987; Le Houerou 2002; Le Houerou and Pontanier 1987; Stringi *et al.* 1987; Tiedeman and Johnson 1992). It is considered one of the most useful species in the region due to its tolerance to mild drought and poor soil, high biomass productivity, ease of establishment and responsiveness to supplemental irrigation (El-Lakany 1987). It is exploited on a smaller scale, although for similar reasons, in southern Europe (Le Houerou 2002; Tilstone *et al.* 1998), eastern parts of Africa (Jama *et al.* 1989; Thulin 1983) and the Middle East (Lock and Simpson 1991; Sheikh 1981). It has also be introduced into South America and is being increasingly exploited for forage in Chile (Perret and Mora 1999).

Crop potential

Acacia saligna is easy to establish using seed or sucker growth (Angell and Glencross 1993; Doran and Turnbull 1997) and the tree is fast growing (Doran and Turnbull 1997; Michaelides 1979), out-performing most other species in trials conducted as part of the Search Project (Olsen *et al.* 2004). The Search Project also found that *A. saligna* can produce large quantities of biomass, a number of studies found it to produce between 7.8 and 23.7 green tonnes/ha. In the 500 mm rain fall zone of Sicily, on a site with degraded clayey soils, the species produced around 13 tonnes/ha (Stringi *et al.* 1991; Stringi *et al.* 1987). Predicted annual production rates in Israel from a deep soil at field capacity with irrigation was 27 tonnes/ha (Nativ *et al.* 1999). Whilst it tolerates poor conditions yields are severely reduced, for example, in low rainfall (<300 mm) regions of the Mediterranean and South America yields of between 0.7 and 3.5 tonnes per hectare have been reported (El-Lakany 1987; Perret and Mora 1999; Tiedeman and Johnson 1992).

There is reasonable consistency between studies in the proportions of biomass in different plant components. Unpublished work conducted at Narrogin found biomass components to be 16% foliage and 84% woody matter by dry weight. Biomass components in South Africa were found to be 12% foliage and 88% woody-matter (Milton and Siegfried 1981). An Egyptian study found 20% foliage and 79.3% woody-matter (El-Osta and Megahed 1992).

The Search Project (NHT Project Number 973849, Olsen *et al.* 2004) found that the woody biomass of *A. saligna* is acceptable for use as an MDF feed stock and a biofuel. The woody biomass was also found to be moderately suitable for use as a paper and particleboard feed stock. Although the bleaching and strength characters for use as a paper feedstock were low, and the wood density was higher than preferred for particleboard feedstock.

The foliage of *A. saligna* is non-toxic and can be used as livestock feed (Michaelides 1979). Since the species is perennial it also has the benefit that it can provide feed in seasons where other feed-sources are scarce (Doran and Turnbull 1997; Stringi *et al.* 1991). The value of *A. saligna* as a forage has been extensively examined by many workers (Abou El Nasr *et al.* 1996; Ben Salem *et al.* 2002b; Ben Salem *et al.* 1997; Ben Salem *et al.* 1999; Degen 1995; Degen *et al.* 2000; Dumancic and Le Houerou 1981; George 2005; Howard *et al.* 2002; Krebs *et al.* 2003; Le Houerou 1991; Stringi *et al.* 1987). The reported forage value for the species is generally poor, due mainly to low digestibility and high tannin levels. Dry matter digestibility is reported to be below the 55% threshold required for animal maintenance. Condensed tannin levels of around 8% dry matter have been reported. When tannins reach this level they cause palatably problems and livestock will reduce feed intake as a result (Waghorn *et al.* 2002). Some methods for deactivating tannins have been trailed successfully. Administering polyethylene glycol along with *A. saligna* was found to increase feed intake and animals growth (Atti *et al.* 2003; Ben Salem *et al.* 2002a; Degen *et al.* 1998). It may not be economically viable to use polyethylene glycol on wide scale. Alternatively, management methods are available that could make *A. saligna* more acceptable despite high tannin content: inoculating livestock with rumen microbes tolerant of higher tannin levels can be used to provide livestock with a greater ability to consume high tannin feeds (Ben Salem *et al.* 2005a; Norton 1999); if livestock are given access to both high and low tannin feeds they can learn to utilize both synergistically (Provenza *et al.* 2003); and harvesting, chopping and ensiling have been shown to reduce tannin content of *A. saligna* foliage (Ben Salem *et al.* 2005b).

Whilst reported forage quality values from studies of *A. saligna* are low there is considerable variation between studies. For example, the reported digestibility of dry matter varies between 19 and 63%, and condensed tannins vary between 1.4 and 8% (Ben Salem *et al.* 1999; Degen 1995; Krebs *et al.* 2003). After reviewing studies on the feed quality of *A. saligna* Dynes and Schlink (2002) suggested that the suitability of the species as forage appeared to vary depending on seed source. Substantial variation in feed quality between provenances of *A. saligna* may be correlated with genetic variation in the species (George 2005).

Conclusion

There remain some obstacles to extensive use of *A. saligna* as a woody perennial crop. Firstly, the biomass productivity of new woody perennial must be at least 76-90 green tonnes/ha in <400 mm rainfall zones and 95-122 green tonnes/ha in 400-600 mm rainfall zones for a four year phase rotation (Cooper *et al.* 2005). Based on the Flora Search trials the predicted yield for *A. saligna* over a four year period is between 30 to 95 green tonnes/ha. This suggests that *A. saligna* has the potential to achieve economically viable yields but will not always do so, and the factors affecting productivity remain unclear. Secondly, the quality of woody biomass from *Acacia saligna* for use as MDF feed stock and a biofuel are good, but there may be problems for it use as a paper and particleboard feed stock. Thirdly, the quality of *A. saligna* as a forage is moderate to poor. Finally, whilst much of the phenotypic variation in the species is explained in terms of the variants, there is still considerable phenotypic variation within the variants. The role that genetic and environmental variation plays in this phenotypic variation is unclear. In conclusion, from an agronomic standpoint *A. saligna* appears to have good crop potential, owing to its ease of establishment, fast growth rates and tolerance of harsh environmental conditions. It is for these reasons that the species is utilized heavily outside Australia. Nonetheless, there are a number of obstacles to its further use. Although the high genetic diversity in the species, and variability in economically important traits, suggests it may be possible to use selection and breeding to address some of these problems.

Future directions

Provenance trials of *A. saligna* will be required to determine the level of genetic variation in economically important traits such as woody quality, feed quality and biomass productivity. This will clarify the potential for breeding to improve these traits. Experiments to evaluate the potential of different agronomic methods for improving productivity will also be required. From existing literature there are a number of areas that appear to show potential for improving the productivity of *A. saligna.* The species appears to be responsive to additional water (El-Lakany 1987), experiments to quantify the effects of addition water will be valuable. There is little information regarding appropriate silvicultural techniques for *A. saligna*. Although one study has shown that plants pruned at the correct height, at the appropriate times, can produce twice as much regrowth biomass as plants cut differently (Bratti *et al.* 1998). Investigations of pruning and harvesting effects on growth and coppicing may be valuable. Trials testing the effects of mycorrhizal and rhizobial inoculation of *A. saligna* have found dry weight of plants can be around double that of uninoculated plants, depending on soil conditions and the inoculant strain (Hatimi 1999; Jasper *et al.* 1989). The potential for using root-symbiont inoculation to improve yields should be evaluated. Specific trials to test the response of *A. saligna* to fertilizer have not been undertaken, but response to fertilizer in the aforementioned studies was also tested and *A. saligna* was found to respond well to nitrogen and phosphorous applications. The potential for increasing biomass production using fertilizers should be examined. The interaction between root symbionts and fertilizers should also be evaluated.

Development Species

Acacia decurrens

General

Acacia decurrens has the potential to be cultivated on valley floors in regions that receive a minimum of 500 mm annual rainfall. Barbour (2000) found that this species performed better than *A. mearnsii* on drier sites in WA trials suggesting that *A. decurrens* may be the preferred species for development in regions fringing current forestry plantation (550-650 mm annual mean rainfall). Ongoing trials need to include consideration of a range of provenances of both species to provide supporting performance data. Maslin and McDonald (2004) considered this species

Acacia decurrens near Parr Conservation Area in NSW

The distribution and bioclimatic map of *Acacia saligna*.

in the Acacia Search project where it was ranked highly as a potential phase crop and much of the information presented here is from that publication.

Taxonomy and distribution

The species is a member of the section Botrycephalae that includes arborescent acacia species with bipinnate adult foliage. It is endemic to NSW occurring on the coast and tableland from the Hunter Valley to the ACT cutting out at the eastern fringe roughly at the 650 mm annual mean rainfall isohyet and growing on clay and clay loam soils over shale.

Biological features

Acacia decurrens is an erect tree to 15 m, commonly with a single almost straight main stem and a shallow lateral root system. Bark is dark grey to black and smooth but may become fissured. It is widely naturalised and a weed risk in some circumstances. *A. decurrens* is relatively short-lived and declining in vigour after 10-15 years. It has moderate frost tolerance. It shows weak suckering and coppice capacity. The species is easily propagated by seed after breaking hard seededness. It flowers from July to December and seeds can be collected from November to February.

Cultivation

The species has been represented in several trials in Australia and overseas. At Canberra on sites with annual mean rainfall of 630 mm and 824 mm the mean heights range from 6.1-6.4 m and dbh ranges from 9.2-9.6 cm at 5.2 years with negligible differences for the best two provenances (Goulburn and Mittagong) (Searle *et al.* 1998). Only marginal differences were noted between sites. At age 5.2 yr plants at a trial program over three sites in WA (947, 650, 650 mm annual mean rainfall) Barbour (2000) ranked *A. decurrens* second to *A. mearnsii*. *A. decurrens* outperformed at the drier site (650 mm rainfall and highest annual evaporation). Both these species outperformed *A. dealbata* that was considered as a possible crop species on observation of its adaptability in SA. Similarly at a trial of 15 *Acacia* species at two sites in Victoria with a mean annual rainfall of 700 mm *A. decurrens* was amongst the best performing species. At age 34 months the mean height of *A. decurrens* was 2.5-4.8 m while mean diameters ranged from 64-78 cm (Bird *et al.* 1998)

Crop potential

Acacia decurrens has potential as a pulp species that could produce high quality paper. It is most suitable for the 550-650 mm annual rainfall zone of the FloraSearch study area and lends itself to establishment to direct seeding as a phase crop situation. It has been used for tannin production but is of lower quality than *A. mearnsii*. It is known as a producer of gum which has been utilised as a substitute for *A. senegal*. Not known as a fodder species although mention was made of the need to protect young plants from herbivores at establishment suggesting that the foliage is highly palatable in the juvenile phase at least. Analysis of the feed value of adult material shows a moderate protein level but tannin content may be a problem. The plant does not coppice so in situ grazing is not possible but there may be potential for the leaf in a feedlot situation.

Acacia lasiocalyx

Taxonomy and distribution

Acacia lasiocalyx is in the family Mimosaceae, in the Juliflorae section of Acacia. It is widely distributed in south-western Western Australia from around Eneabba and near Kalgoorlie, south to near Bremer Bay and Mt Heywood (northeast of Esperance). It grows in sand, gravely sand, loamy sand, clayey sand and loam, commonly on slopes of granitic hills. While most common around granite outcrops, it also occurs on sandplains and on laterite, in mallee woodland, mallee heath and open heath. (Maslin 2001). *Acacia conniana* is very closely related, and occurs south of the SE distribution of *A. lasiocalyx*. Maslin and McDonald (2004) suggest that this species may be suited for growing in South Coast (WA) areas. It has shown good survival and growth in the Western Australia Search Project trial plantings, especially in deep sandy soils, even in northern agricultural areas.

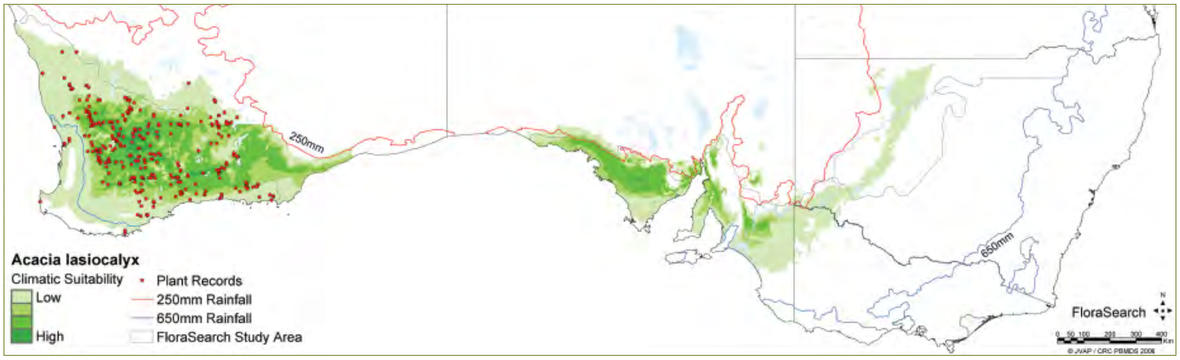
Young *Acacia lasiocalyx* at Dowerin, WA

Biological features

Acacia lasiocalyx is normally a shrub or small tree, but it can reach 15m tall around granite rocks. In this situation it often forms dense colonies with a tree habit, the main trunk more erect and straight than those of plants occurring elsewhere (Maslin 2001). Bark of the main trunks of mature plants is dark and rough, often with longitudinal fissuring. Above this the bark of branches is usually smooth, and often peeling. The branches and bark of younger plants is often pruinose. The phyllodes of *Acacia lasiocalyx* contain high concentrations of cyanogenic glycoside, but seem to lack the endogenous enzyme needed to hydrolyse this into hydrogen cyanide (Maslin and McDonald 2004). It flowers from July to October and seed can be collected from November to January.

Cultivation

Acacia lasiocalyx produces good seed crops that are easy to collect, unless the trees are particularly tall. It is well suited to containerised seedling production in nurseries. Field trials have exhibited impressive early growth. It is a relatively good performer on shallow



The distribution and bioclimatic map of *Acacia lasiocalyx*.

soil profiles. Suckering has not been observed in this species. *Acacia lasiocalyx* can also be established using direct seeding methods. In a field trial at Narrogin in Western Australia, 12.6% of sown seeds established as seedlings 12 months after sowing (CALM 2006).

Crop potential

There is little production data for *Acacia lasiocalyx*; however, it has been included in a number of field trials planted in Western Australia between 2000 and 2003. Maslin and McDonald (2004) suggest *Acacia lasiocalyx* has good prospects as a crop plant for high volume wood production, based on a preliminary assessment of growth rate, plant size and timber density and colour. These observations have been supported by data collected through the Search Project. Coring data for the Search Project determined the species to have a basic density range of 593 kg/m^3 to 912 kg/m^3. Product development work was conducted on material with a density of 648 kg/m^3, and this work showed *Acacia lasiocalyx* was worthy of further study as a feedstock for paper making. It had excellent pulp yield, freeness and density properties, a very good tear index and good bleaching properties (Olsen *et al.* 2004).

Search tests on biomass ash that looked at initiation of fouling deposits during biomass/coal combustion concluded that the combustion of *Acacia lasiocalyx* causes a minor increase in corrosion of mild steel at 800°C above that caused by air alone. *Acacia lasiocalyx* ash produces a minor amount of fouling deposit by condensation at 400°C on a steel surface, with the dominant elements in the deposit being potassium and chlorine. Tests on stainless steel showed corrosion to be negligible at 400°C (Olsen *et al.* 2004).

Trees grow straight and branch free, indicating potential worth as small poles. Straight form is amenable to mechanical harvesting (Maslin and McDonald 2004). Although borderline with several characters for particleboard and MDF, the sample for the Search Project research was based on limited sample selection, and provenance variation may exist to improve these data. *Acacia lasiocalyx* is under trial by Greening Western Australia as a host species for sandalwood.

Although the species is not widely known in cultivation, outside limited use in farm revegetation projects and trials such as this and those planted for the Search Project, there are no records of the plant becoming weedy within its range in Western Australia.

Acacia mearnsii

General

A. mearnsii was ranked by Acacia Search (Maslin and McDonald 2004) as having a high commercial potential (Category 2) as a phase crop. This species is widely cultivated overseas although very little in Australia, and there is a considerable body of information on its development as a forestry crop. It performs best with annual rainfall exceeding 700 mm but is considered to have potential in the FloraSearch study area where rainfall exceeds 550 mm. It was considered worthy of including as a FloraSearch development species as it is very productive and has excellent product specifications for wood products and tannin. In addition the 550-650 mm part of the study area includes some significant high risk salinity areas in the Upper South East of SA, Western Victoria and the Western Slopes of NSW and the RIPA suggests that expansion of forestry products options is favoured in this zone. Provenances from higher rainfall areas are

Acacia mearnsii in a creekline near Armidale, NSW

The distribution and bioclimatic map of *Acacia mearnsii.*

known to be vulnerable to drought but provenances from the lower rainfall zone are thought worthwhile of trialing. *A mearnsii* is naturally widely distributed and extends to 500 mm annual rainfall providing a broad diversity and opportunity for selection of germplasm suited to a drier climate. Maslin and McDonald (2004) considered this species in detail as part of the Acacia Search project and much of the information presented here is from that publication.

Taxonomy and distribution

The species belongs to the section Botrycephalae, characterised by having bipinnate foliage. It occurs in southeast Australia extending from near Sydney southwards along the coast and tableland to Victoria, Tasmania and west to near Naracoorte, SA. It occurs naturally across a range of mean annual rainfall of 450-1600 mm. It is widely naturalised in other regions in southern Australia and overseas in South Africa, New Zealand and Europe. It is an important weed species in South Africa.

Biological features

Acacia mearnsii is a large spreading shrub or tree to typically 5-10 m. In open growing situations plants are spreading while in forest environs they are upright with single stems. It has a shallow root system and grows on a wide range of situations but performs best in sites with favourable soil water conditions. It is a fast growing species that colonises after fire but is short lived (10-20 years). It seeds prolifically but does not sucker or coppice and is sensitive to drought, wind and frost of less than -5 degrees centigrade. It flowers from October to December with seedpods from December to January.

Cultivation

Acacia mearnsii or black wattle is widely cultivated in several countries including Brazil, China, Indonesia and South Africa and there is a large body of information on the silvicultural management (CAB International 2000). In trials of 12 bipinnate species in WA (Barbour 2000) *A. mearnsii* was the best performer in wood and tannin production. The best provenances for stem wood volume across all three sites at 5.5 years in the WA trial were Wattle Circle, Victoria and Tarpeena, South Australia. In trials of 16 Acacia species at a site in Western Victoria with 700 mm mean annual rainfall *A. mearnsii* was the most productive species in terms of mean stem volume (Bird *et al* 1998). Typical yield in South Africa with high rainfall at 10-11 years are 21 t/ha bark and 112 t/ha of wood (air dried) and on appropriate sites with fertilisation a mean annual increment (MAI) over 7-10 years of 15-25 cubic metres/ha of wood is expected. Significant variation within and between provenances has been noted in several trials in Australia and overseas.

Crop potential

A. mearnsii has potential as a phase crop in the 550-650 mm mean annual rainfall zone to produce feedstock for wood products and tannin. *A mearnsii* has been utilised in a variety of uses including timber, fuelwood and wood products such as pulp and paper and hardboard (Masonite). South Africa uses it in pulp manufacture and exports woodchip to Japan for Kraft pulp manufacture. The basic density is around 530-608 kg/m^3 (Fang *et al.* 1994, Hillis 1997) although Acacia Search and FloraSearch testing gave results above 750 kg/m^3 indicating that considerable variability in density may occur due to age and conditions under which plants were grown. Kraft pulp yield in excess of 50% are expected.

The bark of *A. mearnsii* is the best source of tannin in the world with yields of 36-44% possible. South Africa, Kenya and Tanzania have industries producing tannin for export for use in leather tanning and as an adhesive in particleboard manufacture. The leaves have a high fodder content but tannin levels are likely to be an impediment for utilisation as a sole feed source.

Acacia retinodes

General

Acacia Search (Maslin and McDonald 2004) considered the four variants of *Acacia retinodes* in detail. Much of the information that follows was taken from that report. The "typical variant" was ranked highly by Acacia Search as a prospective crop species (Category 1-2), less so for the "swamp" and "uncifolia" variants (Category 2) and Category 2-3 for the "Normanville" variant. The main focus of FloraSearch investigation is on the swamp and typical variants of the variety *retinodes*. The swamp variant is of interest with indications of greater growth rates and better product testing results although these may be influenced by the wetter growing conditions. The typical variant has a higher wood density and low pulp yield making it unsuitable for wood products but will be considered for biomass with a fodder by-product.

Taxonomy and distribution

Taxonomy of the species used here recognises four variants and is based the work of Maslin (2001) and on as-yet unpublished research by M. O'Leary (Adelaide Herbarium). Specimens referable to *A. retinodes* can be accommodated within the following four taxa, var. *retinodes* comprising the "typical" and "swamp" variants, *A. retinodes* var. *uncifolia* and a variant of uncertain taxonomic status from near Normanville, SA. Taxa are geographically separated, except for a few places in South Australia where their ranges abut, for example, Kangaroo Island where var. *retinodes* "swamp" and var. *uncifolia* occur, but do not hybridise (Maslin and McDonald 2004).

A. retinodes var. *retinodes* "Typical"

A. retinodes var. *retinodes* "Swamp"

A. retinodes var. *"uncifolia"*

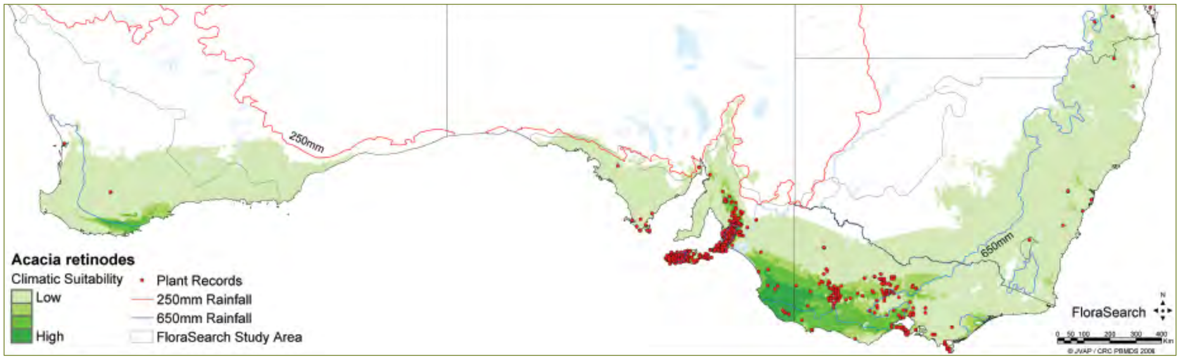
A. retinodes var. *retinodes* "Normanville"

The typical variant occurs in the Mt Lofty Ranges, SA. The swamp variant occurs in wetter areas in the Adelaide Hills eastward to Melbourne, growing on seasonally waterlogged or perpetually wet soil in swamps and along watercourses. *A. retinodes* var. *uncifolia* has a discontinuous distribution in coastal areas of southeastern Australia where it occurs on the southern Eyre Peninsula, Kangaroo Island and the Fleurieu Peninsula, SA, Geelong to Wilson's Promontory in Victoria and King and Flinders Islands, Tasmania. The Normanville variant is restricted to a very small area near Normanville on the Fleurieu Peninsula, SA.

Biological features

The typical variant is typically a single trunk 5-6 m high but sometimes branched from ground level, branches erect and to about 15-20 cm diameter. It grows in loams or clay loams and on rocky hillsides or plains. It is a hardy, frost tolerant species that appears to be moderately long-lived (30-40 years). It has a moderately fast growth rate but not as rapid as var. *retinodes* "swamp". It has a moderate root suckering ability and will coppice but not vigorously.

The swamp variant is a tree commonly 5-6 m tall, single-stemmed or sometimes dividing near ground level. Its main stems are straight and 10-30 cm dbh. It is considered to be capable of very fast growth rate with a life span of 10-20 years. Frost sensitivity of the swamp variant can be variable. It does not sucker and has minimal coppicing ability.



The distribution and bioclimatic map of *Acacia retinodes*.

The uncifolia variant is a shrub or tree 5-10 m high, single-stemmed to much-branched from low down and to 15 cm or more dbh. Its bark is smooth but becoming longitudinally fissured on main trunks of older plants. It is fast growing and is probably frost-sensitive (Martin O'Leary, pers. comm.) There is variation between provenances in suckering ability. The Tasmanian var. *uncifolia* suckers and resprouts following fires, while SA plants have not been seen to either sucker or coppice (Martin O'Leary, pers. comm.).

The Normanville variant is a tree to 6-10 m tall with spreading crown, single-stemmed or branching near ground level, main stems sub-straight and to 24-30 cm dbh. Its growth rate is unknown but is likely to be at least moderately fast. This taxon does not sucker but has some coppicing ability. Gum is exuded from the stems. It is probably a relatively long-lived taxon.

Cultivation

This species is not known to have been included in previous agroforestry trials. The swamp variant is very fast growing in suitable environments reaching 3 m in two years in the Adelaide Hills with a trunk of 10-15 cm dbh. It is outperforming the typical variant in the Murray Bridge trial site at 1.5 years after establishment. The swamp variant has been widely cultivated for ornamental purposes.

Crop potential

A. retinodes is suitable as a phase crop for production of wood products or biomass with the leaf valuable as a fodder supplement. Some of the variants and provenances may be capable of coppicing strongly enough for use as coppice belt species but this requires further investigation in planned trials. Wood pulp values for the swamp variant are in the range for a commercial species. The bark may be a source of tannins and yield gum although more testing is required. The annual rainfall zone 500-650 mm is expected to be most suitable for the swamp and typical variants but the swamp variant may be vulnerable to drought.

Foliage is grazed for most variants and has a high protein value, the low capacity to coppice precludes it from in situ grazing but a fodder co-product from wood production could be considered. Although var. *uncifolia* may produce reasonable quantities of woody biomass its shrubby habit would make harvest more difficult. The seeds of this species are considered by Maslin *et al.* (1998) as having potential as a source of human food.

Anthocercis littorea

Taxonomy and distribution

Anthocercis littorea is in the Solanaceae family, in the subfamily Cestroideae, and the tribe Anthocercideae. It has a coastal and sub-coastal distribution in Western Australia, from near Shark Bay in the north, to east of Esperance. It is most common in the region from Perth to Geraldton.

Coring *Anthocercis littorea* at Arrowsmith, WA

The distribution and bioclimatic map of *Anthocercis littorea.*

Biological features

Anthocercis littorea is short lived species, normally erect with many small branches from the main stem. It can occasionally have small prickles on the branches, but is not spiny like some of the other *Anthocercis* species. It is a fast growing plant, and can reach three metres or more tall. Occurrence is usually on calcareous sands, often with conspicuous limestone outcropping. It is a colonising species, common after fire or disturbance (Purdie *et al.* 1982). The plant suffers a high rate of infestation by the gall midge *Asphondylia anthocercidis*, which deforms the fruit and reduces the production of viable seed. Infected fruit can greatly outnumber non-infested fruit (Kolesik *et al.* 1997).

There are a wide range of tropane alkaloids present in *Anthocercis littorea*, not unlike those found in the genera *Datura* and *Solandra*, with the principal alkaloids being atropine and hyoscyamine (Evans and Treagust 1973). Atropine is a monocyclic alkaloid, a white solid with melting point 118°C with the molecular formula $C_{17}H_{23}O_3N$. It is a highly toxic material, which causes fatalities when ingested in even moderate quantities. It is used in medicine as a muscle relaxant and finds application as an anti-spasmodic which may be used as a pre-treatment before abdominal surgery and optometry to dilate the pupils, where it relaxes the muscles of the eye (Kennedy 2006). It is also used to relieve pain caused by swelling and inflammation of the eye (Medline Plus 2006). It is absorbed from the gastro-intestinal tract, and is excreted in the urine (Pinto Pereiro 1996). The plant is suspected of poisoning stock, although the foliage does not appear to be palatable (Gardner and Bennetts 1956), and the fruits have poisoned children in Western Australia (SGAP 2006, Purdie *et al.* 1982).

Cultivation

Flower and seed production continues over an extended period of time. This characteristic makes collection of large quantities of seed difficult, but increases the window for collection of small amounts for trial work. The species germinates readily in the nursery, and transplants to the field satisfactorily. While not apparently affecting the growth rate of the plant, the presence of the gall midge means the opportunity for seed collection is reduced.

Crop potential

There is a dearth of biomass production data for *Anthocercis littorea* under cultivation. However, there is evidence that the biomass has a high moisture content. A single 20-month-old plant sampled from a field trial at Corrigen, Western Australia, had a moisture content of 68% of total above ground biomass (CALM 2006).

Olsen *et al.* (2004) showed *Anthocercis littorea* was worthy of further study as a feedstock for paper making. Bleaching properties are excellent, pulp yield, density and tensile strength are rated as very good, and freeness was rated as good. *Anthocercis littorea* was also recommended for further trials 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. Tests on biomass ash that looked at initiation of fouling deposits during biomass/coal combustion concluded that the combustion of *Anthocercis littorea* causes a minor increase in corrosion of mild steel at 800°C above that caused by air alone. Ash from the plant produces a moderate amount of fouling, deposited by condensation at 400°C on a steel surface, with the dominant elements in the deposit being potassium, chlorine and sodium. Minor corrosion of stainless steel at 400°C could be detected.

Casuarina obesa

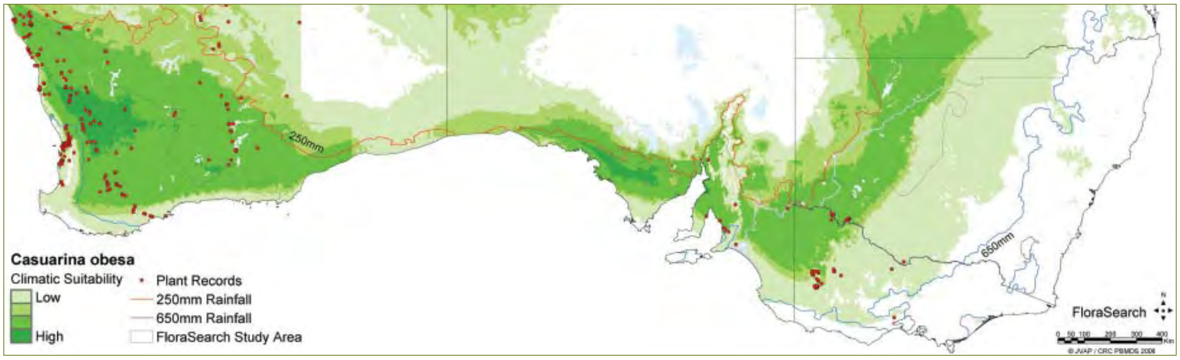
General

Casuarina obesa is a multi-purpose, salt and waterlogging tolerant species capable of producing forestry and other products from low value land (Boxshall, pers. comm.). The species can tolerate poor drainage, saline soils, frosts, exposed sites, and to a degree, drought. However, tough sites exhibiting all of the above features will restrict growth and hence commercial opportunities (Emmott 2006). It is suited to multiple product development, including, high grade appearance timber, craft wood, treated fence posts, community asset protection values, carbon sequestration, fuelwood, biofuels, and industrial product feedstock. Although the species has a reputation for being slow growing when compared to other forestry species, its growth must be seen in context of the situation where it often naturally occurs and is planted, which is on sites that are not available to other species.

Interest is being shown in the Great Southern Region of Western Australia for the development of a *Casuarina obesa* industry. A *Casuarina obesa* working group has been formed, which is a coalition of community groups, development agencies, private and government forestry and research organisations, nursery proprietors, farmers and aboriginal groups (Plantations 2020 2006). The group has bought together significant expertise and resources, and additional cooperative participation in the development of the potential of this species would be welcomed (Bill Hollingworth, pers. comm.).

The Great Southern Region has an estimated one million hectares of salt affected or "at risk" land, much of which is suited to species such as this, either as plantation or as a complement to a saline grazing system with salt tolerant perennial pastures. Pasture grows better under *Casuarina obesa* than it does

Natural stand of *Casuarina obesa*, north of Dowerin, WA, and pruned plantation *Casuarina obesa* at Mt Barker (photos Tim Emmott)



The distribution and bioclimatic map of *Casuarina obesa*.

under eucalypts. This may be due to increased sunlight available through the canopy, less root competition, and nodulation with *Frankia* bacterium. *Frankia* colonises *Casuarina* and *Allocasuarina* roots and can fix atmospheric nitrogen in the soil (Emmott 2006).

Taxonomy and distribution

Casuarina obesa is a small tree that grows widely in southern Western Australia, with limited occurrence in central South Australia, north-western Victoria and south-western New South Wales, although this latter occurrence may now be extinct.

Biological features

Casuarina obesa grows to 14 metres (Midgley 1981, cited in White 2001) with a dominant stem for much of its height when growing in closed stands. Generally, *Casuarina obesa* trees have an erect trunk with erect, but sometimes spreading, branches. The bark is thick, fissured and darkish grey in colour. The trunk is commonly fluted at the base. Form of the *Casuarina obesa* is unreliable, but significant provenance and individual accession differences exist (Hollingworth, pers. comm. 2006). Suckering populations and individuals have been observed, although this is not common. On favourable sites the species has a life span of more than 60 years. The species is nitrogen-fixing and seed can be collected from October to November.

Casuarina obesa naturally occurs in semi-arid areas with a minimum rainfall of 125 mm (50 percentile is 250-500 mm) (Doran and Hall 1983, cited in Safstrom *et al.* 2002). It grows around the margins of salt lakes, along saline creeks and rivers throughout the Wheatbelt and Goldfields of WA. It is found on sand plains, flats, depositional areas of waterways and flood plains, gently undulating land and, occasionally, on the slopes of low hills (Emmott 2006; Safstrom *et al.* 2002). It is usually associated with drainage lines, floodways, river systems, edges of salt lakes and seasonally inundated freshwater depressions. It has been recorded growing in a range of soil types including saline loams, red and yellow earthy sands, calcareous and sandy earths, and grey cracking clays (Emmott 2006).

Optimal growth will occur on moist clays and loams lower in the landscape where average rainfall is 400 mm and above. The species will survive and grow well in areas receiving 350 mm of rainfall per annum where the trees have access to groundwater (Emmott 2006). It is tolerant of waterlogging and will survive in sites that are permanently waterlogged, however growth and survival will be effected in areas that are frequently inundated with saline water (Emmott 2006). *Casuarina obesa* reportedly has moderate drought tolerance, although establishment notwithstanding, this is less likely than waterlogging to be an issue for most sites targeted for this species.

Casuarina obesa can tolerate highly saline conditions and will grow in soil with electrical conductivities (ECe) of greater than 1600 mS/m (equivalent to an EM38 reading of greater than 200 mS/m); however reduced growth can be expected between 800 and 1600 mS/m. In salt concentrations of greater than 800 mS/m (ECe), long term survival is reduced, and establishment and growth of seedlings is also reduced

(Emmott 2006). The pH tolerance of the species is 6-8.5 (Safstrom *et al.* 2002).

The species is vulnerable to grazing damage from native and introduced animals and susceptible to damage by plague locust and psyllids. The twenty-eight parrot (*Barnardius zonarius*) can damage tree form, a problem especially if being grown for timber. *Casuarina obesa* has potential to invade areas outside its natural distribution (Emmott 2006).

Cultivation

In southern Western Australia, *Casuarina obesa* has a long history of use as a revegetation species for nature conservation and resource protection outcomes. It is well known and highly regarded by farmers for ease of establishment, as an amenity plant in difficult situations. Although well established as a utility species, serious development for farm forestry has only been considered recently. The species grows easily from seed both in the nursery and in direct seeding. It transplants with ease, and shows good survival. It is vulnerable as a young plant to grazing by native animals and stock, and insects.

Crop potential

Casuarina obesa displays good agronomic characteristics. It is easily propagated from seed, which is suited to nursery or direct seeding. The species is adaptable to most soils from sands to clays within its natural rainfall zone, and shows good waterlogging and salinity tolerances, which give it significant advantage over other woody species in the Wheatbelt region of Western Australia. Whilst form of the *Casuarina obesa* is unreliable, significant provenance and individual accession differences do exist (Hollingworth, pers. comm.). Suckering populations and individuals have been observed, although this is not common. There is a dearth of biomass production data for this species. Growth rates have been observed to be relatively high on saline sites. The species has short generation times and dioecism, and is suited to rapid genetic deployment (Liz Barbour, cited in Safstrom *et al.* 2002). *Casuarina obesa* is generally abundant where it grows, and usually carries good seed crops, which are retained on the plant for some time, allowing ready selection of material for tree breeding (White 2001).

The market potential for a *Casuarina obesa* industry, producing multiple products (as opposed to a single product industry) appears to be strong (Safstrom *et al.* 2002). The timber has a moderately fine and even texture with conspicuous medullary rays. It is described as being straw to creamy-brown in colour, but some variation has been noted that may relate to provenance, and allow scope for value adding selective breeding. The coordinator of the Dwellingup School of Wood, indicated that light coloured native timbers were not readily available and that imports from the Eastern States were necessary to satisfy demand (M. Harris, pers. comm. 1999, cited in White 2001). The timber is stable and easy to work. It accepts gluing, with good sawing, sanding and planing properties, according to a Department of Conservation and Land Management report (Siemon and Pitcher 1994).

Casuarina obesa has potential as a timber species for fine wood production, and selected trees are expected to achieve a millable size after 20-25 years. Silvicultural practices appropriate for the species are well detailed in White (2001). Shorter rotations may be possible, determined by site and processing requirements. The development of a Lignor plant in the Great Southern Region of WA may open the opportunity for the processing of smaller material (Hollingworth pers. comm.). Search Project showed *Casuarina obesa* to have reasonable prospects for use as a particleboard (tabled below, compared with the industry standard of radiata pine) (Olsen *et al.* 2004). This data was collected from material from a single provenance, and variation can be expected to occur over a species with a range as extensive and varied as this one.

Species	Whole Panel Density (kg/m^3)	Flexural Strength MOR (MPa)	Flexural Modulus MOE (MPa)	Internal Bond Strength (kPa)	Thick-ness Swell (%)
Casuarina obesa	739 (31)	13.35 (2.77)	2460 (112)	354 (88)	6.3 (0.4)
Pinus radiata	733 (11)	16.89 (1.37)	2816 (332)	950 (35)	4.6 (0.3)

Codonocarpus cotinifolius

General

This plant is distinctive in the environment, growing very rapidly after fires to tower above all other plants on the site. When the timber or leaves are cut they exhibit a distinctive mustard-like smell. The plant yields 1-methylpropyl isothiocyanate, an irritant "mustard oil", which is stored in the plant as its glucoside, namely glucocochlearin (Kjaer 1960, Kjaer and Malver 1979). Codonocarpine, a polymine alkaloid, has been isolated from *Codonocarpus* (Carrington *et al.* 1998; Seigler 1998). Bindon (1996) reports that roots or leaves are chewed or made into a tea for use as a narcotic. The leaves have been used to relieve dental pain, and powdered roots and leaves, when mixed with *Acacia cuthbertsonii* are rubbed on aching limbs or teeth.

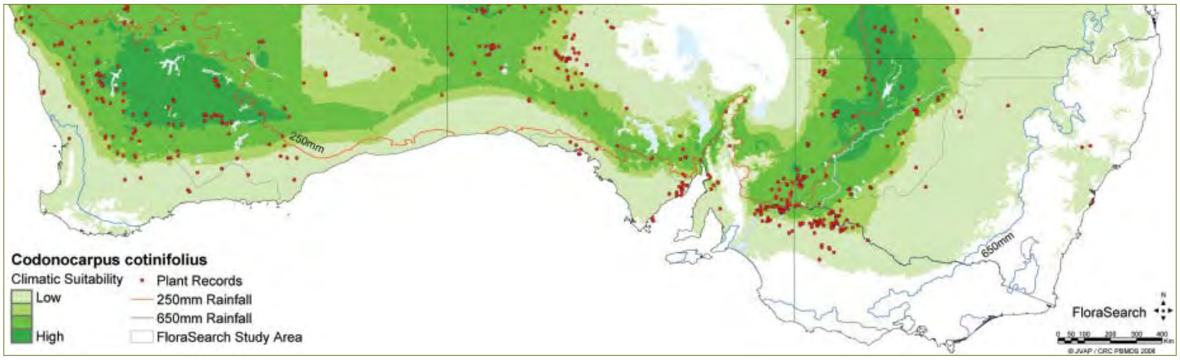
Taking a wood core sample from *Codonocarpus cotinifolius*, Chiddarcooping, WA.

Grubs found in the roots and lower trunk form an important part of the diet of Aboriginal people in central Australia (Latz 1995), but Bindon (1996), reports they are eaten only after being eviscerated, to reduce toxicity. The grubs, which tunnel substantial trails through the wood, are easily collected as the wood is soft and easily split. This plant has been reported to be toxic to stock (Gardner and Bennetts 1956).

Taxonomy and distribution

Codonocarpus cotinifolius (syn. *Gyrostemon cotinifolius* Desf.) is in the family Gyrostemonaceae. It is a fireweed, most commonly known as Desert Poplar, but also as Western Bell Fruit, Bellbush, Firebush or Mustard Tree.

The plant grows in red sands and sandy loams of the central wheatbelt of Western Australia, where the best growth is seen in flat areas with loamy soils receiving some run on water. The species extends eastward across the sandplains of the central desert region, and occurs in the arid zones of all mainland states.



The distribution and bioclimatic map of *Codonocarpus cotinifolius*.

Biological features

Codonocarpus cotinifolius is an erect, smooth barked, conical shaped small tree, with very few branches. It reaches up to 9 m in height (Latz 1995), but is usually around 4-5 m tall. The tree is very fast growing, colonising sites after fire. It is short lived, lasting 5-8 years (Latz 1995) and flowers in spring and summer.

Cultivation

Seed production is extremely high. Seed is produced in abundance, even to the point of overweighing the top of plants to the point that they snap off. The seed is easy to collect and clean, and has a dormancy which is readily overcome with heat treatment. Seedlings are difficult to manage in the nursery, as they develop as a flat rosette much greater in size than the average cell of a nursery tray. Transplantation of seedlings to the field has proven to be difficult, with almost zero survival in Search Project trial plots to date. Further work may need to look at techniques for direct seeding this species.

Crop potential

Rapid growth, consistently erect form, low branching tendency, low density wood (378 kg/m^3), and impressive biomass accumulation make this an attractive prospect for further development. This is tempered by the high water content of the wood (65%) and the problems with seedling production. Selected for particleboard fabrication for the Search Project, *Codonocarpus cotinifolius* gave results very similar in performance to the pine control. The conformability of wood particles was generally poor in panels made from most species in the Search project, with species investigated commonly producing panels of an "open" core construction. They showed excellent properties of density and conformability of the wood (the ability to be compressed into a shape and to retain that shape) (Olsen *et al.* 2004).

The Search report showed *Codonocarpus cotinifolius* was also worthy of further study as a feedstock for paper making, having very good freeness properties, and good pulp yield and bleaching properties. Density, tear index and tensile strength properties were all considered poor (Olsen *et al.* 2004).

Eucalyptus aromaphloia ssp. *sabulosa*

Taxonomy and distribution

Eucalyptus aromaphloia ssp. *sabulosa* belongs in Eucalyptus subgenus Symphyomyrtus section Maidenaria subsection Triangulares. Common names are Western Scented Bark or Scent Bark. It occurs in Victoria from the Serra and Victoria ranges of the Grampians west to Little Desert and Cavendish (Brooker and Kleinig 1999). Populations occur in sandy soils (*sabulosa* derived from the Latin for "of the sand") and are usually small and scattered. Despite this sporadic distribution, however, it is common and under no conservation threat (Rule 1996). *E. aromaphloia* ssp. *sabulosa* is one of a group of small rough barked trees from south eastern Australia that have caused some considerable confusion in taxonomy due to some convergence in adult morphology (Brooker and Slee 1996). More marked differentiation is usually obtained by examining seedling morphology (Chappill *et al.* 1986). *E. aromaphloia* ssp. *sabulosa* can be differentiated from the closely related *E. aromaphloia* ssp. *aromaphloia* by having less lustrous adult leaves

Young *Eucalyptus aromaphloia* ssp. *sabulosa* from the Little Desert region of Victoria

The distribution and bioclimatic map of *Eucalyptus aromaphloia* ssp. *sabulosa.*

of a paler, less glaucous colour with much reduced oil gland density. In contrast to the adult leaves, the juvenile leaves of the ssp. *sabulosa* are linear and more lustrous but lack the waxy appearance of those of ssp. *aromaphloia* (Rule 1996). For a comparison to other closely related species see Rule (1996).

Biological features

E. aromaphloia ssp. *sabulosa* is a small to medium tree to 15 m tall. The bark is greyish, persistent, rough and coarse down to the small branches. Flowering occurs in January to April with seven-flowered axillary inflorescences. Fruit is ovoid or sub globular to 0.7cm diameter. Seed is subsequently ready for collection in the following November.

Cultivation

There is little data available on the cultivation of *E. aromaphloia* ssp. *sabulosa*. In its natural range it occurs on sandy soils. We might anticipate that like many of the other small to medium eucalypt species, such as the morphologically similar *E. viminalis* ssp. *cygnetensis,* it will be easy to propagate and be adaptable to a range of landscape types on moist well drained soils.

Crop potential

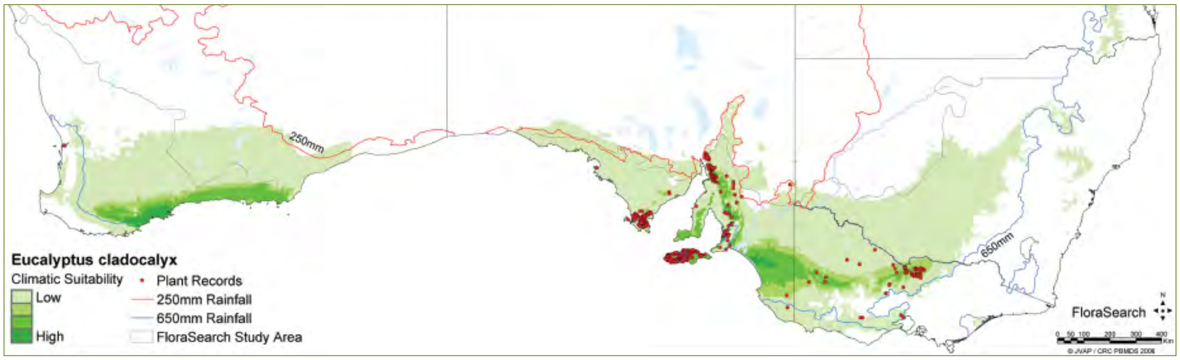
FloraSearch test data shows a low basic density (540 kg/m^3) and a pulp yield of 45.4% (Kappa 18). Testing results suggests that this species is not suitable for making paper but may be suitable as an oil and bioenergy crop. Other uses include gums and honey production.

Eucalyptus cladocalyx

General

E. cladocalyx is a widely planted agroforestry species in southern Australia. It is well adapted to the dryland agricultural regions generally preferring areas of greater than 350 mm rainfall. It is a fast growing species with potential for production for biomass, timber and firewood.


A plantation grown, young *Eucalyptus cladocalyx*



The distribution and bioclimatic map of *Eucalyptus cladocalyx*.

Taxonomy and distribution

E. cladocalyx belongs in Eucalyptus subgenus Symphyomyrtus and is taxonomically isolated in the section Sejunctae by the combination of its unusual inflorescence arrangement, discolourous leaves, absence of pith glands and having bilobed cotyledons. It naturally occurs in a disjunct distribution in SA from lower Eyre Peninsula, Kangaroo Island and the Flinders Range.

Biological features

Sugar gum is a tree to 35 m tall without a lignotuber but having epicormic buds present up the stem. Its bark is smooth, mottled white, yellow, pink, orange, brown, pale grey, dark grey or blue grey), sometimes slightly powdery (Brooker *et al.* 2002). *E. cladocalyx* coppices well with a spreading and competitive root system. It has been the subject of plant improvement programs (Australian Low Rainfall Tree Group) for farm forestry where the marked provenance variation in form and growth has created opportunities for development of superior seed lines. It flowers from January to March and it is best to collect seed from October to May.

Cultivation

E. cladocalyx thrives on a wide variety of soils including gravels, clay loams, sandy loams and sands outside although in Australia it grows poorly on very fine sandy soils. It tolerates shallow soils and a wide pH range including calcareous soils and under irrigation. It is not suitable for wet, saline or waterlogged sites and mature trees can die if excessively waterlogged (Marcar and Crawford 2004). *E. cladocalyx* grows well outside its natural range and prefers a rainfall zone of 400-1010 mm annually across 0-600 m altitude (Jovanovic and Booth 2002). It tolerates light to medium frosts. It is often pollarded at about 1 metre above ground level and the wood used for posts and fuel. Foliage and stems have a low susceptibility to insect attack. Its main insect pests are Christmas Beetle, Gumtree scale, leaf beetle and sawfly (Marcar and Crawford 2004). Sapwood is susceptible to Lyctus borers (Bird 2000).

Crop potential

Wood uses include solid timber for use as posts, poles, general construction, railway sleepers, farm timber and firewood. Noted to have a hard, heavy timber of good strength and durability with green density values 1200 kg/m^3, air dry 1100 kg/m^3 (Washusen 1995). Typical wood from young trees has a lower air-dry density 850 kg/m^3 with FloraSearch measuring basic density at 753 kg/m^3. Pulp yield is high at 49.6% Kappa 18 but a basic density above 700 kg/m^3 would normally preclude its use when judged by the current industry standards. Recent surveys in the Tintinara SA region has discovered low density variants of this species with basic density values of consistently less than 620kg/m^3, making it a potential pulpwood species. Sugar gums adaptability and fast growth in low rainfall regions makes this a preferred species for biomass production.

Eucalyptus globulus ssp. *bicostata*

General

Eucalyptus globulus is a fast growing species that is important for the plantation industry in southern Australia and overseas because of its ability to coppice on short rotation and its favourable pulp qualities.

A relic population of *Eucalyptus globulus* ssp. *bicostata* grows in the lower rainfall region of the southern Flinders Ranges, SA

Taxonomy and distribution

Eucalyptus globulus ssp. *bicostata* belongs to the subgenus Symphyomyrtus section Maidenaria subsection Euryotae. Common names are Southern blue gum, blue gum, Eurabbie, and Victorian blue gum (Brooker *et al.* 2002). It is one of four recognised subspecies of *E. globulus* based on capsule morphology (others being *globulus, pseudoglobulus* and *maidenii*) occurring in geographically distinct regions of southeastern Australia. However, intergrade populations are common between the subspecies (Jordan *et al.* 1993). *Eucalyptus globulus* ssp. *bicostata* occurs primarily on the northern slopes of the montane regions of northeastern Victoria and southern NSW, with isolated populations to the north near Carrai State Forest in NSW. There is also a single disjunct population at Mount Bryan in SA (Brooker and Kleinig 1999). All subspecies occur in areas of 600-1400 mm of annual rainfall.

Biological features

Eucalyptus globulus ssp. *bicostata* is a medium to large forest tree growing to 45m. Bark is generally smooth white or greyish and is shed in long strips. There is often an accumulation of persistent partially shed rough bark at the base. Flowering occurs from September to January and the inflorescences are axillary and 3-flowered. Fruits are sessile and generally globular to 2cm diameter (Brooker and Kleinig 1999). Seed is ready for collection from July to March but may be available throughout the year.

The distribution and bioclimatic map of *Eucalyptus globulus* ssp. *bicostata*.

Cultivation

Eucalyptus globulus subspecies have been widely adapted for cultivation in Australia and around the world in places such as China, Brazil and Portugal and there is a large body of information relating to its cultivation and management. Briefly, seeds germinate readily in the nursery where they are grown for 3-4 months in tube stock before being ready for planting (Skolmen and Ledig 1990). Following planting it is necessary to manage weeds for the first two years until the trees become more established.

The species grows in the wetter regions above 600 mm annually so may show some potential for adaptation to the wetter regions of the FloraSearch study area. Previous trials in areas of 500-600 mm of rainfall in the south east of SA found that ssp. *globulus* had significantly better growth than ssp. *bicostata* at 14 months post planting (Bush 1999). There is evidence however, that seedlings of ssp. *bicostata* are more drought tolerant than those of ssp. *globulus,* and therefore may have better suitability to lower rainfall areas in the longer term (Wang *et al.* 1998).

Early results from FloraSearch trial sites suggest that there is some susceptibility of seedlings to frosts. Seedlings of ssp. *bicostata* can be cold hardened in the nursery so that they have a greater resistance to temperatures as low as -7°C, although provenance variation can be significant for this trait (Moraga *et al.* 2006). Other issues include the potential for insect attack, which can be significant and impact on growth (Floyd and Foley 2001).

Crop potential

FloraSearch test data shows a basic density of 656 kg/m^3 and a pulp yield of 46.7% (at Kappa 18) suggesting a potential for wood processing as pulp fibre and particleboard. These figures support those of Hicks and Clark (2001), who found basic densities of 575 kg/m^3 and pulp yields of between 47.0% and 49.4% across the different provenances tested. Paper quality testing places *E. globulus* ssp. *bicostata* at the mid range of quality compared to species such as *E. smithi,* and *E. nitens* (Hicks and Clark 2001). It is a fast growing species that coppices readily.

Oil content was found to be high at 5.6% dm. Dunlop *et al.* (2003) analysed the oil content of all four subspecies of *E. globulus* and found that ssp. *bicostata* had the lowest mean oil content (1.5% dm vs. 2.1% dm for ssp. *maidenii*) but the highest proportion of 1,8-cineole at 60%. Substantial oil harvesting occurs from this species in China, Spain and Portugal.

Eucalyptus loxophleba ssp. *lissophloia*

Taxonomy and distribution

One of four subspecies of *Eucalyptus loxophleba,* along with E. *loxophleba* ssp. *loxophleba, E. loxophleba* ssp. *gratiae* (treated as a separate species by some authors), and *E. loxophleba* ssp. *supralaevis*. *Eucalyptus loxophleba* ssp. *lissophloia* and *E. loxophleba* ssp. *gratiae* normally occur as mallees, and their growth and performance are comparable. The remaining two subspecies normally occur as tree forms, although they do form lignotubers.

They belong to Eucalyptus subgenus Symphyomyrtus section Bisectae subsection Glandulosae, because the cotyledons are bisected, buds have an operculum scar and the branchlets have oil glands in the pith (Brooker *et al.* 2002).

Eucalyptus loxophleba ssp. *lissophloia* is a smooth-barked mallee of the eastern wheatbelt and the goldfields, extending from Bencubbin and Merredin east as far

Alleys of *Eucalyptus loxophleba* ssp. *lissophloia*a planted on farmland at Kalannie, WA

Eucalyptus loxophleba ssp. *lissophloia* coppice following trial harvesting

as Karonie (Cardunia Rocks), Coonana, and almost to Balladonia and to Peak Charles. It often occurs in wet depressions (Brooker *et al.* 2002) or in association with granite outcrops, especially in the eastern part of its range.

Biological features

Eucalyptus loxophleba ssp. *lissophloia* is a mallee, to 8 m tall. It is smooth barked, although rarely with a short stocking of rough bark up to 0.5 m (1.0 m). The bark of the young stems is usually glaucous. The presence of a lignotuber allows for a strong recovery in the plant following repeated harvest of above ground biomass. It flowers from August to December and seed is best collected from February to March.

Cultivation

The mallee is easily grown in nursery, and transplants to the field readily. It shows strong growth, frequently out performing most other species on mixed species trial sites. It is adaptable to a range of conditions including sandy and clayey sites, making it a versatile species for revegetation work.

Crop potential

Eucalyptus loxophleba ssp. *lissophloia* and *E. loxophleba* ssp. *gratiae* should be considered synonymous in discussion about use at this stage. Their growth performance, site preferences, timber and oil characteristics show little difference.

In Western Australia, the Department of Environment and Conservation has initiated a breeding program for the species, focusing on improving vigour and leaf oil yield. Assessment of belt plantings in the 300-500 mm annual rainfall zone suggest that above ground biomass yields of 4-12 green tonnes/ha/year are attainable (CALM 2006).

Assessment for paper production for the Search Project found that *Eucalyptus loxophleba* ssp. *lissophloia* had very good pulp yield, bleaching properties and density, but poor tear index, tensile index and freeness (Olsen *et al.* 2004).

Search tests on biomass ash that looked at initiation of fouling deposits during biomass/coal combustion concluded that the combustion of *Eucalyptus loxophleba* ssp. *lissophloia* causes a minor increase in corrosion of mild steel at 800°C above that caused by air alone. Ash from the plant produces a minor amount of fouling, deposited by condensation at 400°C on a steel surface, with the dominant elements in the deposit being

The distribution and bioclimatic map of *Eucalyptus loxophleba* ssp. *lissophloia*.

potassium and chlorine. Negligible corrosion of stainless steel at 400°C could be detected (Olsen *et al.* 2004).

A CSIRO report discussed the potential for MDF manufacture using a range of species, including *Eucalyptus loxophleba* ssp. *lissophloia.* Bark removal is a problem with small trees, but is necessary to achieve good quality. The boards had higher density than current commercial boards, and internal bond strengths were lower than required (Olsen *et al.* 2004).

Eucalyptus occidentalis

General

Eucalyptus occidentalis is a widely cultivated species in southern Australia and overseas, known to be productive, highly adaptable and with potential for wood products.

***Eucalyptus occidentalis* in a wind break near Tintinara, SA**

Taxonomy and distribution

Eucalyptus occidentalis belongs in Eucalyptus subgenus Symphyomyrtus section Bisectae subsection Glandulosae because the buds have an operculum scar, cotyledons are bisected and branchlets have oil glands in the pith (Brooker *et al.* 2002). A tree or mallee endemic to Western Australia, of widespread distribution south and south-east of Perth, it is usually found in wet, fresh-water depressions, but sometimes around salt lakes, from the southern wheatbelt and subcoastal areas north-west of Albany east to Cape Arid National Park and to the north of Mt Ragged.

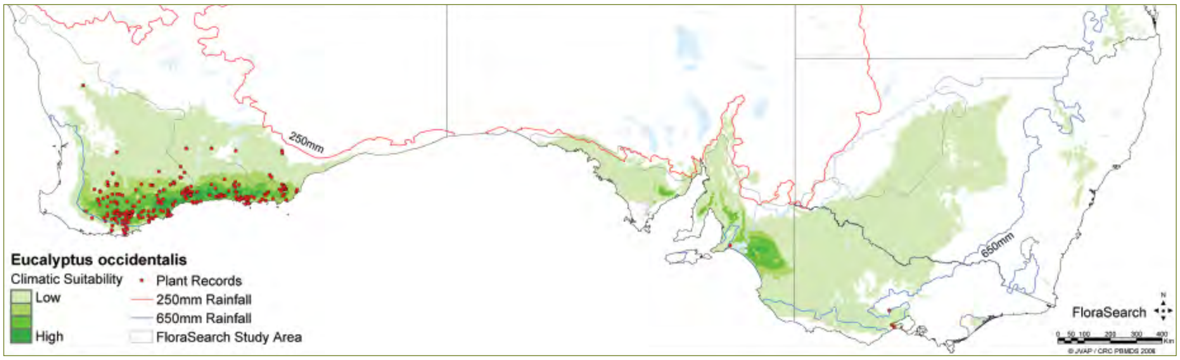
Biological features

E. occidentalis is tree to 20 m tall, rarely a mallee and forms a lignotuber (Brooker *et al.* 2002). Bark is rough over part or all of trunk, sometimes extending to large limbs, black to dark grey, fibrous, fissured and often hard, shedding in broad scruffy strips at its upper limit, smooth above, white to pale grey or pale grey-brown, sometimes powdery.

Within its natural distribution *E. occidentalis* is a distinctive species because of its habitat, habit and bark. In addition seedling or coppice growth is often present and is conspicuous with dull blue-green broad ovate leaves. *E. occidentalis* is useful in cultivation in waterlogged sites and some provenances are salt-tolerant (Brooker *et al.* 2002). It flowers from April to May and seed is best collected from September through to April.

Cultivation

It is known to tolerate and grow in a wide range of soils including alkaline, saline and waterlogged sites (Bird 2000). The species is also frost and drought tolerant (Marcar *et al.* 1995) but susceptible to insect attack (Marcar and Crawford 2004). The preferred rainfall range is generally 355-1000 mm mean annual rainfall. The species has been grown successfully in several countries. It has been the subject of trials on saline and non-saline sites in southern Australia and there is a considerable body of performance data at



The distribution and bioclimatic map of *Eucalyptus occidentalis*.

a variety of locations and for several provenances. The opportunity for plant improvement has been recognised by the Australian Low Rainfall Tree Improvement Group and the Forest Products Commission has established a provenance trial in WA. Marcar and Crawford (2004) report *E. occidentalis* as a reasonably fast growing eucalypt, probably as a result of genetic improvement that has occurred in the last 10 years. Reasonable growth rates of 10.5-16.5 m^3/yr stemwood volume (at age 35 years) were reported in Victoria (Bird 2000) but with variable form requiring significant form pruning to produce sawlogs. FloraSearch evaluation of young plantings (6-7 years) report plant stemwood volume of up to 20 m^3/yr (when normalised to a 500 mm annual mean rainfall).

Crop potential

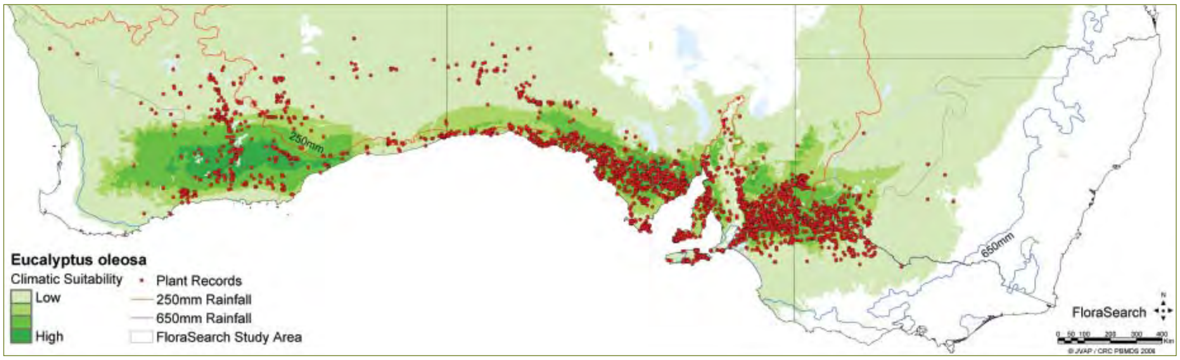
E. occidentalis is reported as a potential timber species for solid timber including posts, poles and firewood. Air-dry density is 850-900 kg/m^3 (basic density ~780 kg/m^3) and for younger trees less than 600 kg/m^3 (basic density ~590 kg/m^3) (Marcar and Crawford 2004). FloraSearch data confirms this evaluation of basic density for younger plantings and pulp yields of approximately 50% (Kappa 18) are also reported suggesting this species as being suitable for pulp and paper and MDF/Fibreboard products. The leaf is reported to contain 0.95% oil with aromadendren (or aromadendrol), pinene, cineol, and sesquiterpenes. The bark is reported to contain 35-52% tannin (Duke 1983).

Eucalyptus oleosa

General

Eucalyptus oleosa has the potential to be cultivated for biomass production on a range of soil types including shallow calcareous soils, sands, sandy loams and clays, in regions that receive a between 200 and 350 mm annual rainfall. Ongoing trials need to include all four subspecies and a range of provenances to provide performance data. Ongoing work is also required if

Eucalyptus oleosa is a moderately fast growing mallee species suited to lower rainfall regions



The distribution and bioclimatic map of *Eucalyptus oleosa*.

this species is to be seriously considered for eucalyptus oil production as an adjunct to any biomass industry.

Taxonomy and distribution

Eucalyptus oleosa is a member of series Subulatae subseries Spirales and includes tree and mallee types distributed from Lake Barlee in Western Australia, along the Great Australian Bight and into north-western Victoria and south-western NSW. The taxonomy of *Eucalyptus oleosa* has provided difficulties for researchers for some time. Its wide distribution and variation in form within subspecies has even seen some subspecies attached to the closely related *Eucalyptus longicornis*. For the purposes of this study the 2006 revision by Nicolle and Whalen was adopted and recognises four subspecies of *Eucalyptus oleosa;* ssp. *oleosa, ampliata, corvina* and *cylindroidea.*

Eucalyptus oleosa ssp. *oleosa* is distinguished from the other ssp. by having larger, moderately spaced seedling leaves around a five-sided stem and includes those individuals once labelled ssp. *repleta*. Ssp. *oleosa* has the widest distribution of the subspecies extending east from Lake Barlee and the Western Australian Goldfields to north-western Victoria and south-western NSW.

Eucalyptus oleosa ssp. *ampliata* has similar seedling leaves to ssp. *oleosa* but they are more widely spaced and become alternating relatively early. The subspecies *victima* and *wylieana* are now included within *Eucalyptus oleosa* ssp. *ampliata.* Ssp. *ampliata* is found in coastal regions from Israelite Bay in Western Australia to the Eyre, Yorke and Fleurieu Peninsulas and Kangaroo Island in South Australia.

Both *Eucalyptus oleosa* ssp. *corvina* and *Eucalyptus oleosa* ssp. *cylindroidea* have very small, crowded seedling leaves around a seven-sided stem. However the buds of ssp. *cylindroidea* are much larger than those of the other subspecies, with ssp. *corvina* having moderately small buds and fruit. Both *Eucalyptus oleosa* ssp. *corvina* and *Eucalyptus oleosa* ssp. *cylindroidea* are confined to Western Australia, ssp. *corvina* to an area around Ravensthorpe and ssp. *cylindroidea* to the Esperance sand plains.

Biological features

Eucalyptus oleosa is a tree or mallee to 8m tall with the exceptions being ssp. *ampliata* that rarely exceeds 4 m and ssp. *oleosa* that can sometimes obtain 10 m. All form lignotubers and coppice readily. All but ssp. *ampliata* have rough grey-brown bark on lower stems giving way to smooth variable coloured bark above. Ssp. *ampliata*'s bark is usually smooth throughout. *Eucalyptus oleosa* can be found on soils ranging from shallow, slightly acidic sands to calcareous clay loams overlying limestone. This species flowers from December to May and holds its seed year round.

Cultivation

Little specific work has been carried out from a plantation perspective for this species, but it is one that is commonly used in revegetation programs and varies little from other eucalypts when treated in this fashion. Bonney (1997) indicates that *Eucalyptus oleosa* benefits from wider spacing (5 m x 5 m) and initial irrigation when planted as a seedling and can be direct seeded at anytime of year if irrigation water can be provided for establishment.

Crop potential

Eucalyptus oleosa has potential for biomass energy industries at the drier end of the FloraSearch study area where other species may not persist. While FloraSearch found this species to have a low stemwood production rate, its tolerance of dry conditions and a variety of soil types suggests its use in areas of lower land value and rainfall. With a basic density close to 800 kg/m^3 it is well above industry tolerances for pulp products and more suited for fuel production or charcoal. *Eucalyptus oleosa* has oil yields of 4.6% dm recorded indicating some promise in terms of integrated tree processing but results are highly variable across its provenances and subspecies.

Eucalyptus ovata

Taxonomy and distribution

Eucalyptus ovata is a small to medium tree widespread from Kangaroo Island, Mt Lofty Ranges and SE of SA, eastern Tasmania, southern Victoria and the south tablelands of NSW north to Oberon. It belongs to the subgenus Symphyomyrtus. Swamp Gum is usually smooth barked but often with conspicuous basal unshed dead bark. It is related to *E. yarraensis* and *E. brookeriana*. *E. ovata* prefers areas of poor drainage or swamps in its natural range. There are two subspecies, var. *ovata* which is widespread and has no visible oil glands in the adult leaves, and var. *grandiflora* (large flowered compared with var. *ovata*). It has larger buds and fruits and prominent oil glands in the adult leaves. It is restricted to the Mount Gambier-Naracoorte-Portland area (Brooker *et al.* 2002).

Eucalyptus ovata **growing at Nangkita, SA**

Biological features

Eucalyptus ovata occurs along creek banks, in valleys of fine sand over heavy impermeable clays and shallow soils subject to waterlogging. *E. ovata* flowers from March through to January and seed can be collected from September to December.

The distribution and bioclimatic map of *Eucalyptus ovata*.

Cultivation

There are not many reports on the cultivation of this species within Australia. Senelwa and Sims (1998) included *E. ovata* in a trial of short rotation forestry trials for biomass in New Zealand and created tree biomass equations for up to five year old plants. *E. ovata* and *E. brookeriana* were the most vigorous species in a coppice trial in the Palmerston North region of New Zealand (mean annual rainfall not quoted) and was one of the most productive species after five harvest cycles. Amongst other species MAI's of over 16 Oven Dry t/ha/yr were measured in small plots and the species was considered as a candidate for commercial plantings of short rotation coppice forestry schemes (Sims *et al.* 1999). Average stemwood volume measured by FloraSearch and normalised for 500 mm annual rainfall were modest at 2.36 m^3/yr.

Crop potential

E. ovata was not considered to have much value as a timber resource but FloraSearch test data showing a low basic density (504 kg/m^3) for 10 year old plants and a high pulp yield of 49.8% dm (Kappa 18) suggest a potential for wood processing although paper testing did not indicate that high quality paper would be produced from this species. *Eucalyptus ovata* ssp. *ovata* has produced oil yields of 3.9% dm indicating some promise in terms of integrated tree processing in combination with either wood pulp, chip or biomass industries.

Eucalyptus petiolaris

General

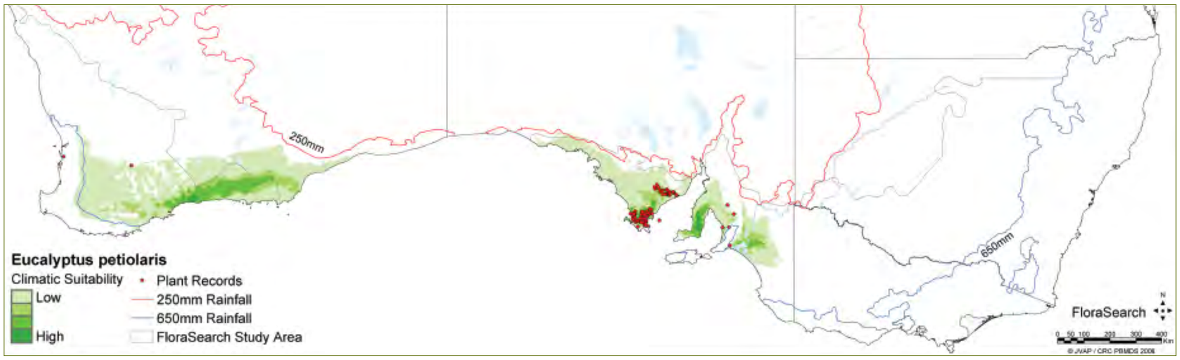
Eucalyptus petiolaris has the potential to be cultivated on valley floors or on open flats near water in regions that receive 300 mm or more annual rainfall. Well known as an amenity plant, *Eucalyptus petiolaris* has potential as feedstock for a variety of industries.

Taxonomy and distribution

In April 1992, K. Rule revised *Eucalyptus leucoxylon* ssp. *petiolaris* to species level on the basis of its differing morphology and geographic isolation from any trees belonging to the *leucoxylon* group. Endemic to South Australia's Eyre Peninsula, two distinct populations exist, one behind Port Lincoln in the Koppio Hills and the other around Cleve and Darke Peak to the north.

Biological features

Small to medium sized trees to 20 m, *Eucalyptus petiolaris* forms a large lignotuber and multi-stemmed individuals are not uncommon. While it bears many similarities with *Eucalyptus leucoxylon*, *Eucalyptus petiolaris* has petiolate juvenile leaves, and its conspicuously ribbed buds each have 6-8 ovular rows rather than the 4-6 of the leucoxylons. The bark is either wholly smooth or rough and fibrous at the base, sometimes extending to the bottom of the larger limbs. *Eucalyptus petiolaris* displays moderate frost tolerance and good coppice capacity from the lignotuber. It is also one of the few



The distribution and bioclimatic map of *Eucalyptus petiolaris*.

Long cultivated for parks and gardens *Eucalyptus petiolaris* is also suited to producing wood fibre products

Eucalypts to display a variety of flower colours, ranging from white, through pink, orange and yellow, to a brilliant red. It flowers from May to September and germplasm is best collected in December and January.

Cultivation

Eucalyptus petiolaris is a widely used species in gardens and parkland situations. It is valued as a horticultural specimen for its copious, showy flowers, which unfortunately are not always the same colour as the source plant. While this species is commonly sold in nurseries as *Eucalyptus leucoxylon* 'rosea', little information is available specifically for this species in a plantation context. It is usually treated similar to *Eucalyptus leucoxylon* and is planted out as seedlings in winter and early spring into weed free sites that have been ripped and flattened out. Row spacings of 3 to 4 m and a plant spacing of 3 m along rows are suggested (Bonney 1997).

Crop potential

With wood densities at the upper limit for pulpwood processing and moderate pulp yields of 42.9% dm (18Kappa) *Eucalyptus petiolaris* could provide feedstock suitable for integrated tree processing, with either biomass industries or pulpwood industries coupled to oil extraction. *Eucalyptus petiolaris* has a reasonable oil yield of 2.1% dm. This species is a reasonably fast grower and would be suitable well beyond the current limits of forestry for the production of wood chip and fibre products or biomass industries.

Eucalyptus polybractea

General

Eucalyptus polybractea, blue mallee, has been harvested from natural stands for eucalyptus oil production since the 1890s. Industry expansion based on this and other species is planned, particularly in low rainfall agroforestry projects in WA were mitigation of salinity problems is a huge challenge.

Eucalyptus polybractea has a long history of use in oil mallee systems

The distribution and bioclimatic map of *Eucalyptus polybractea*.

Taxonomy and distribution

E. polybractea belongs in Eucalyptus subgenus Symphomyrtus section Adnataria (the boxes). Within Adnataria, *E. polybractea* belongs to a subgroup, series Buxales subseries Continales. Most species in this group are from eastern Australia and include several mallees including *E. viridis, E. froggattii, E. odorata* and *E. porosa*. It occurs in two main areas, central western NSW in the Wyalong area and Victoria NW of Bendigo. Some reported outlier populations in Mt Lofty and the Flinders Ranges of SA have more lately being identified as *E. odorata* (Dean Nicolle pers. comm.).

Biological features

E. polybractea is a mallee to 8 m tall forming a lignotuber and has a fast growth rate. It is an adaptable species reported to grow well on a range of soil conditions. Flowering is from March to June and seed can be collected year round.

Cultivation

Studies of the species show a high degree on variability in oil yield (1-16% dry leaf weight) and vigour while quality as indicated by cineole content was consistently high between 80 and 92% (Slee 1999). Milthorpe (1994) conducted a trail on the effect of time of harvest, fertiliser and irrigation on dry matter and oil production of blue mallee at Condobolin, NSW over three years. After the first year annual dry matter and oil production for the dryland plots ranged from 3.1-7.0 t/ha and from 117 to 230 kg/ha respectively. A limited and inconsistent response to fertiliser was recorded. Milthorpe (1994) also recommended that a selection program be undertaken to increase the oil yield.

Eucalyptus porosa

General

Eucalyptus porosa has the potential to be cultivated on shallow stony or sandy soils where other forestry species might not persist. It can be found growing in regions that receive as little as 200 mm annual rainfall but is generally grown in the 350-650 mm rainfall range. As a multi-purpose tree it can provide feedstock for a variety of industrial purposes and has the potential to be used in places where both conventional forestry and farming would not value highly.

Taxonomy and distribution

A member of the Eucalyptus subgenus Symphyomyrtus section Adnataria (the boxes), *Eucalyptus porosa* is found from the Gawler Rangers and Eyre Peninsular in SA to north western Victoria and south western NSW, with isolated occurrences in NSW as far east as Euabalong in the central-west of that state. The subspecies *Eucalyptus porosa* ssp. *devestiva* appears to be restricted to the Upper South East region of SA. *Eucalyptus porosa* often occurs on stony hill slopes with shallow soils, on shallow calcareous soils over limestone and brown earths with limestone.

Eucalyptus porosa is a highly adaptable oil mallee with good wood fibre qualities

Biological features

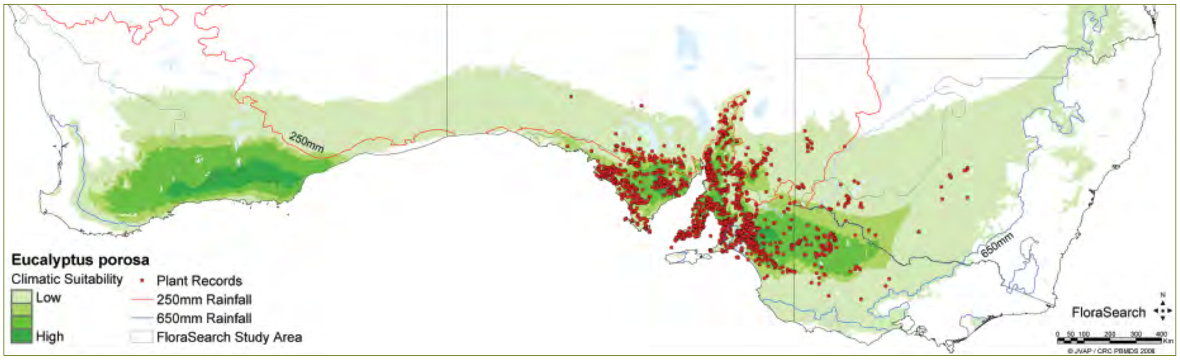
Eucalyptus porosa is generally a small rough barked tree or mallee to 12 m tall. The exception to this is the subspecies *Eucalyptus porosa* ssp. *devestiva* that is wholly smooth barked. On most individuals the rough box bark persists on the trunk and larger branches and is dark grey to grey-brown in colour. This species forms a lignotuber and is known to coppice. It flowers from May to November and germplasm is best collected prior to flowering in May.

Cultivation

Eucalyptus porosa can be established by direct seeding into ripped and levelled rows but it is important to keep the rows free of competition for the first three years. If sown in good conditions in winter the emerging saplings don't require watering or fertiliser. A row spacing of 4 to 5m is suggested (Bonney 1997). With the same preparations seedlings can be planted out in early spring at a spacing of 3m along the rows if good soil moisture is available.

Crop potential

Eucalyptus porosa has potential as a multi-purpose species with good pulpwood qualities and reasonable oil yields (2.1% dm). With suitable wood density, a pulp yield of 49.9% dm (18Kappa) and a good paper score, *Eucalyptus porosa* can provide feedstock suitable for paper manufacturing. This species is best suited for use in areas of moderately low rainfall and on sites with poor shallow soils. It can provide feedstock for integrated tree processing for either biomass industries or pulpwood industries, coupled with oil extraction. Its modest growth rate probably precludes it from better-watered sites or sites with deeper soils.



The distribution and bioclimatic map of *Eucalyptus porosa*.

Eucalyptus rudis

General

Eucalyptus rudis has very good waterlogging, soil and salinity tolerances for a eucalypt, making it suited to much of the "at risk" land of the western wheatbelt, reducing the opportunity cost for planting land.

Eucalyptus rudis is subject to attack from a number of insect pests, notably leaf miners (*Perthida* sp) and psyllids (*Creiis periculosa*) (Clay and Majer 2001). Almost all trees show evidence of significant levels of insect herbivory, and the rate and extent to which they recover varies. Research done to date suggests that the trees can sustain reasonable levels of defoliation without excessively compromising their growth, but sustained attack, in combination with environmental stress (salinity and waterlogging) can be fatal, and site selection for revegetation work will be important to minimise impact.

Eucalyptus rudis ssp.*rudis,* Uannup Creek, WA.

Taxonomy and distribution

Eucalyptus rudis belongs to Eucalyptus subgenus Symphyomyrtus section Exsertaria (the red gums) because the buds have two opercula, ovules are in 6(8) rows, seeds are ± cuboid, cotyledons are oblong-reniform, adult leaves are concolorous and the buds have a shallow hypanthium and a conical operculum (Brooker *et al.* 2002). There are two subspecies of *E. rudis*, the other being *Eucalyptus rudis* ssp. *cratyantha,* which is distinguished by its larger buds and fruit (Brooker and Hopper 1993). Its restricted distribution and status as a priority taxa have excluded it from this work to date.

Brooker *et al.* (2002) consider that *E. rudis* grades into *E. camaldulensis* in the north and north-east of the *E. rudis* distribution, based largely on the description of seed coat and colour. The occurrence of trees with intermediate characteristics is extensive, around the northern and north eastern part of the distribution, from York to Dongara. There is very little *E. camaldulensis* adjoining this zone, and such "intermediates" may indicate a relictual distribution of these species. Further work on this species would require a closer

The distribution and bioclimatic map of *Eucalyptus rudis*.

examination of this variation, as some provenances do not appear to be stable in the seedlings they produce, which may represent the difference between hybrid and intergrade populations.

Eucalyptus rudis hybridises with a range of other eucalypts. FloraBase lists hybrids with *E. camaldulensis, E. drummondii, E. gomphocephala, E. loxophleba, E. occidentalis* and *E. wandoo* (Western Australian Herbarium 2006).

Biological features

Eucalyptus rudis is a tree up to 25 m tall, with rough, fibrous, grey bark, usually over all of the trunks and major branches, becoming tessellated on older trunks. Bark of branches is smooth and creamy or grey coloured. Towards the north and north eastern part of the range the trunks commonly have a low bark stocking, and in rare cases they are entirely smooth. The tree is lignotuberous, and has a good ability to recover from harvest. It flowers from July to November and seeds are best sought from January to April.

Eucalyptus rudis occurs on creek lines, valley floors and flood plains. Although generally low in the landscape, it can occur on upper slopes, where it is associated with rock bars or dykes to provide additional moisture. It is usually on sandy or silty duplex soils over tight fine grained clays. Increasing salinity and waterlogging in the agricultural region is putting this species under pressure across much of its natural distribution.

Cultivation

Seed germinates readily, and seedlings grow rapidly in the nursery and after transplantation to the field. Natural populations seed readily and regeneration can usually be established simply by controlling weeds adjacent to established trees.

Crop potential

There is little production data for this species.

Work carried out for the Search Project to investigate paper making properties showed young *Eucalyptus rudis* to have very good pulp yield, and bleaching and freeness properties. Density, tear index and tensile strength properties were poor (Olsen *et al.* 2004).

Search Project tests on biomass ash that looked at initiation of fouling deposits during biomass/coal combustion concluded that the combustion of *Eucalyptus rudis* causes a minor increase in corrosion of mild steel at 800°C above that caused by air alone. *Eucalyptus rudis* ash produces a minor amount of fouling deposit by condensation at 400°C on a steel surface, with the dominant elements in the deposit being potassium and chlorine. Tests on stainless steel showed corrosion to be negligible at 400°C (Olsen *et al.* 2004).

Eucalyptus rudis was among a group of low density species (density range 468-494 kg/m^3) recommended for revisiting for MDF production in the Search Report, with a view to quantifying fines content and fibre furnish geometry. Timber testing by the Forest Products Commission showed the timber of mature trees (considered a *E. rudis-E. camaldulensis* intergrade) to have dense (1005 kg/m^3) timber suitable for value adding for furniture, flooring and building uses (Murphy and Beel 2001).

Future work would need to quantify the impact of insect predation. This is not as straight forward as one might assume, as the trees have the ability to re-allocate resources to compensate for defoliation, e.g. a fifty percent defoliation does not mean a similar reduction in growth. This situation changes if there is severe attack in consecutive years where the trees do not have time to recover. Trial work protecting some trees with systemic insecticide may be a consideration.

Limited trials are now in place in WA testing the heritability of natural resistance of trees. Collections of seedlings grown from individual trees showing some degree of resistance to insects have been planted out and will be assessed to see if there is any difference in seedlots. This work can be expanded across the range of the species.

Eucalyptus viminalis ssp. *cygnetensis*

General

Eucalyptus viminalis ssp. *cygnetensis* has the potential to be cultivated on a variety of sandy and clay loam soils in lower rainfall regions abutting the edge of current forestry areas and down to the 450 mm rainfall zone. As a multi-purpose tree it can provide feedstock for a variety of industrial purposes and has the potential to be used in areas too dry for conventional forestry species.

Eucalyptus viminalis ssp. *cygnetensis* plantation in SA

Taxonomy and distribution

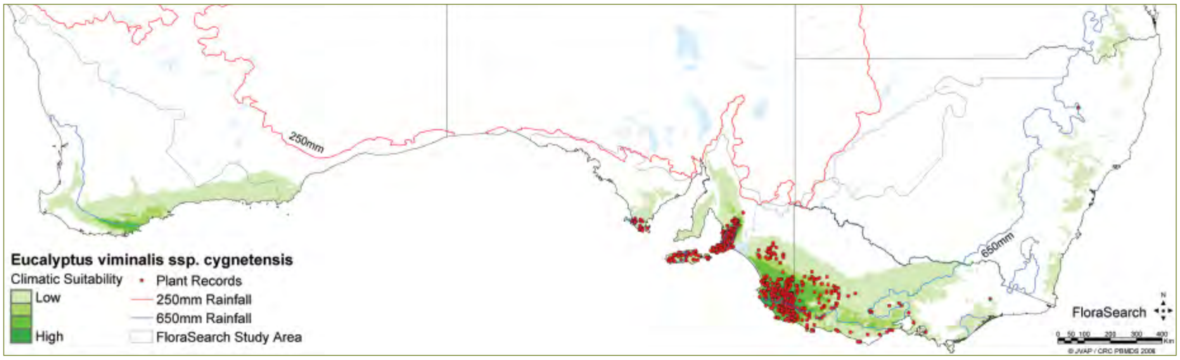
E. viminalis is a small to tall tree widespread in the higher rainfall area of SE Australia from southern Eyre Peninsula, Kangaroo Island and SE of SA, Victoria, Tasmania and eastern NSW. It belongs to the subgenus Symphyomyrtus section Maidenaria. It is related to *E. rubida* and *E. dalrympleana.* There are four subspecies: ssp. *viminalis* which can be a tall tree to 90 m in Tasmania and occurs in wet areas of NSW, Victoria, Tasmania and SA in the central part of the Mt Lofty Ranges; ssp. *cygnetensis* having rough bark to larger limbs and occurring from the Grampians to Mt Gambier, Pt Lincoln and Mt Lofty Ranges; ssp. *hentyensis* occurring in Tasmania; and ssp. *pryoriana* which is a small tree endemic to Victoria on infertile coastal sand (Brooker *et al.* 2002).

Biological features

Eucalyptus viminalis ssp. *cygnetensis* flowers from February to April and seed needs to be collected in December. In open situations this subspecies turns into a large rambling, heavily limbed tree to 30 m. In a forest situation however, it is more erect.

Cultivation

This species grows over a wide range of landscape types preferring moist well drained soils. *E. viminalis* is being planted in subtropical areas of Brazil to supply feedstock for paper manufacture (Bellei *et al.* 1992). It has also been included in high density trials of short rotation coppice tree species for woody biomass in NZ. *E. viminalis* was productive and had high survival



The distribution and bioclimatic map of *Eucalyptus viminalis* ssp. *cygnetensis* .

after two harvest cycles at three year intervals. Production figures were high, up to 39.7 tdm/ha/yr exceeding *Salix*, Poplar, *Acacia mearnsii, E. camaldulensis* and *E. nitens* amongst others at a site in Palmerston North that receives and annual mean rainfall of 1000 mm (Sims *et al.* 2001).

Crop potential

This species has the potential for a range of wood and biomass products with a basic density of less than 600 kg/m^3 and a pulp yield exceeding 45% dm (Kappa 18) recorded. It also has an oil yield of 3.4% dm recorded indicating some promise in terms of integrated tree processing in combination with either wood pulp, chip or biomass industries.

Taxandria juniperina

Taxonomy and distribution

Taxandria juniperina is in the family Myrtaceae. The genus *Taxandria* was separated recently from the *Agonis* genus, and is the resurrection of an earlier classification that separated the two groups on flower structure (J. Wheeler, pers. comm.). The species is restricted to the southwest region of WA, from Bunbury to Albany. Its best development is around the Warren River, where it reaches impressive dimensions and has been used as a sawn timber species in the past. The plant is commonly known as Wattie, or Warren River Cedar.

Biological features

Taxandria juniperina is an erect tree or shrub, growing to 27 m high (Western Australian Herbarium 2006). It grows in grey or pale sand, clay loam, peat, gravel, and laterite. It is restricted to water gaining sites, even in the wettest part of its distribution.

Cultivation

Seed is easy to collect and extract, as it is retained on the plant for some time. The height of many of the trees represents a major obsticle, however. Seed germinates readily, and grows satisfactorily in the nursery.

Taxandria juniperina, Mt Barker, WA, a location at the drier end of the range of the species, where the plant exhibits a multi stemmed, bushier form

The distribution and bioclimatic map of *Taxandria juniperina*.

Crop potential

There is a dearth of biomass production data for *Taxandria juniperina*. Observations of young plants in trial plantings suggest that it may struggle if taken out of its natural range into drier environments.

Taxandria juniperina performed extremely well in a number of areas of product testing research for the Search Project. In looking at potential feedstocks for papermaking based on yield, paper properties and bleachability, *Taxandria juniperina* was found to be the most promising species. It was considered to have excellent properties for bleaching, freeness and density, an excellent pulp yield, and very good ratings for tear index and tensile index (Olsen *et al.* 2004).

Of the species successfully converted into panels for MDF and particleboard production, *Taxandria juniperina* was considered worthy of further trials to optimise production by investigating a range of production variables. In the case of MDF, optimising process variables to reduce the "fines" content would have high priority (Olsen *et al.* 2004).

A number of fuel-related parameters were analysed for Search Project. These included the level of ash, level of moisture, and the gross calorific value. *Taxandria juniperina* had a surprisingly high gross calorific value, (23.1 MJ/kg, against an average value range for biomass of 19 to 20.5 MJ/kg). The reasons for this are unclear, but the result is good, and it may warrant further investigation (Olsen *et al.* 2004).

Search tests on biomass ash that looked at initiation of fouling deposits during biomass/coal combustion concluded that the combustion of *Taxandria juniperina* causes a minor increase in corrosion of mild steel at 800°C above that caused by air alone. Ash from the plant produces a minor amount of fouling, deposited by condensation at 400°C on a steel surface, with the dominant elements in the deposit being potassium and chloride. Negligible corrosion of stainless steel at 400°C could be detected (Olsen *et al.* 2004).

Taxandria juniperina was also assessed as a sawn timber in Search Project tests. Recovery of select grade timber from the logs was poor, due to high incidence of borer damage, and seasoning checks. In the final analysis *Taxandria juniperina* was rated as a good medium density timber with excellent gluing properties, but there was concern about the incidence of borer holes in the timber (Olsen *et al.* 2004).

Viminaria juncea

General

This species is noted for its rapid growth and has performed well at CRC trial sites in the first year. Pulp and paper results from the WA population were modest but a SA sample has tested more positively with a pulp yield of 50.3% dm.

Taxonomy and distribution

Viminaria juncea is a single species in Australia only. It is fairly common, having an extensive distribution on poorly drained soils, especially in coastal regions of southern Australian mainland states.

Biological features

V. juncea is a shrub or small tree with a single trunk to 6 metres. When maintained as a tree it is upright

***Viminaria juncea* growing in SA**

Viminaria juncea closeup of foliage

with a slender trunk with a dark fibrous bark. It has slender phyllodes up to 25 cm that are smooth, flexible and fresh green with leaves reduced to scales and flowers with yellow sprays in late spring-early summer. It has rapid growth and is adaptable to a range of growing conditions and although often occurring in swampy areas is not confined to these areas and can tolerate moderate summer drought conditions. It is known to produce cluster roots, aiding adaptability to low fertility soils.

Cultivation

Information on the productivity of this species is limited and it does not appear to have been included in past trials. It has performed well in the first two years at Murray Bridge as part of the CRC FTWG project but is somewhat prone to drought and frost conditions and is therefore more suited to a higher rainfall region (>500 mm).

Crop potential

This species has potential as a phase crop for wood products in the 450-650 mm mean annual rainfall portion of the study area. The results of wood testing are variable but it has a high value of pulp 50.3% dm (SA samples) and basic density of less than 500 kg/m^3. The WA Search project also selected *Viminaria* for further investigation based on its wood fibre qualities. The foliage has a modest fodder value and its palatability is unknown.

The distribution and bioclimatic map of *Viminaria juncea*.

5. Regional industry potential analysis

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 based on short rotation woody crops in the FloraSearch region. It evaluates potential plantation productivity and industry product yields, economically optimum harvest intervals of woody crops, and landholder annual equivalent return (AER) from each industry type and location. RIPA allows spatial and economic comparisons between existing agricultural systems, new industries based on existing infrastructure, and hypothetical explorations of new investments in infrastructure or highly prospective industry types. The methodology of the RIPA is detailed in the FloraSearch Phase 1 report (Bennell *et al.* 2008) and should be read prior to reviewing the current outputs. The following section is based on that methodology but has been expanded to include Western Australian data, additional economic models and improved spatial models of woody crop productivity. Current models include updated information (2006 prices) on production costs and delivered feedstock values and refined estimates of product yields for each industry type and location.

In brief, the RIPA consists of a series of models predicting potential spatial distributions of individual species based on bioclimatic relationships, spatial plantation productivities and yields of biomass components, point-based economic models of optimised annual equivalent returns from short cycle woody perennial woody crops, and transportation network models for each industry type. Finally, the RIPA integrates point-based economic models with spatial information to predict agroforestry equivalents to annual returns using ArcGIS 9.1 geographic information system software (ESRI 2005). The integrated RIPA model is not scale dependant – the analyses presented here are at a one kilometre resolution due to the size of the study area. Other potential biomass industry studies in the Upper South East SA (Hobbs *et al.* 2006) have used the RIPA methodology and models at a scale of one hectare where high resolution data is available for landuses, infrastructure, vegetation and soil mapping.

Infrastructure and Other Drivers

We have documented and mapped existing infrastructure which may be utilised for each potential industry type (e.g. roads, processing plants, ports, etc.). Existing facilities for FloraSearch related industries are presented in Figure 18 and Figure 19. Figure 18 shows current wood fibre processing facilities in southern Australia including pulp mills, medium density fibreboard mills, particleboard mills and sawmills. Figure 19 shows ports for the export of woodchips and other processed products, existing solid fuel electricity generation plants, feedlots and stock feed manufacturing facilities and the Narrogin integrated wood processing plant. Lands other than those used for annual cropping and livestock pasture have been excluded from analysis.

Other than landholder economic returns there are two significant drivers for developing woody perennial crops in southern Australia. They include reducing the threat of dryland salinity and saline discharges into rivers (Figure 20) through the use of perennial wood crops, and the recognised demand for renewable energy sources (ABARE 2005b, Biofuels Taskforce 2005) and localised electricity generation facilities for populations that are some distance from existing major power generation plants (Enecon 2001, 2002). Figure 21 illustrates the spatial distribution of regional electrical energy demands based on populations that are poorly serviced by existing large scale power generation plants in southern Australia. These locations represent potential opportunities for investments in renewable electricity generation facilities.

Regional Plantation Productivity

The first step in the productivity modelling process was to determine which agroforestry, fodder shrub or other woody biomass industry is to be evaluated. Species are then selected that match the product specifications of that industry type (e.g. from laboratory pulp yields test for pulpwood species). Bioclimatic models predict the regional suitability of the species chosen. Observations of plantation productivities from field trials and agroforestry plots have then been correlated with BiosEquil productivity indices (Raupach *et al.* 2001) and then these relationships were used to predicted growth rates and yields across the study area. This allows the most appropriate (industry product specifications), productive and climatically suited species to be selected for each dryland location in southern Australia. The optimised species selections (or species group) and their productivity predictions are then used for economic analyses for each industry type across southern Australia.

The pulp and fibre species group include *Eucalyptus occidentalis* for southern mid-rainfall regions, *E. globulus* for higher rainfall regions, *E. rudis* for northern WA and *E. porosa* for low rainfall regions (Figure 22). The bioenergy species group includes *Eucalyptus cladocalyx* in mid-higher rainfall zones, and *E. camaldulensis* for mid-low rainfall zones (Figure 23). The oil mallee species group include *Eucalyptus polybractea* in southern mid-higher rainfall regions, *E. loxophleba* ssp. *lissophloia* for western mid-low rainfall zones, and *E. oleosa* and *E. porosa* for mid-low rainfall eastern Australia (Figure 24). The Acacia pulp and fodder group include widely adapted *Acacia saligna* and *Acacia retinodes* (Figure 25). The fodder species group currently includes mid-low rainfall adapted *Atriplex nummularia* (Figure 26). The carbon sequestration woodlot species group includes bioenergy and fibre species groups (Figure 27).

Spatial productivity models have been applied for each industry species group for the wheat-sheep zone of southern Australia. Model outputs include parts of neighbouring higher rainfall regions. However, our productivity models have not been calibrated for higher rainfall regions (e.g. >700 mm) and greater caution is required in interpreting productivity predictions and economic results for these higher rainfall areas.

Regional Industry Analysis 2006

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 during 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.

Investment analysis

Discounted Cash Flow 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:

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

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 livestock industries in the region, we have explored the expected AERs 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.

Spatial economic analyses

The RIPA incorporates all plantation establishment and maintenance costs for each biomass industry group of species. Planting densities are set at 1000 plants per hectare for all biomass industry species groups except for the Saltbush Fodder Species group which uses 2000 shrubs per hectare. Establishment costs are based on those reported by Bennell *et al.* (2008) for broadacre biomass industries and Bulman *et al.* (2002) and Mt Lofty Ranges Private Forestry (2006) for farm forestry woodlots in the Adelaide Hills. For this study we have used an establishment cost of $740/ha for trees and mallees and $850/ha for fodder shrubs for flat, simple and sandy landscapes. Average annual maintenance costs have been set at $10/ha/year to include occasional and sporadic activities such as firebreak control, supplementary fertilisers and follow-up weed and pest control.

Harvest cost varies depending on each industry type and the degree of biomass sorting and product quality controls. For wood fibre, bioenergy and oil mallee costs are based on continuous flow in-field biomass chipping technologies described by Enecon Pty Ltd (2001) or in-field log chippers used in existing Tasmanian blue gum (*Eucalyptus globulus*) industries (Timbercorp 2006). Off-farm fodder harvest costs are based on forage harvesters. A summary of establishment, harvest and transport costs are presented in Table 20.

In our analyses coppicing species have a 30% increase in the biomass productivity rate compared to the initial seedling growth rate following the first (and subsequent) harvests. This increase is due to coppicing plants having effectively more stems per hectare and established energy investments stored in root biomass. For unharvested carbon sequestration biomass crops of woodlots we have incorporated an estimate of below ground biomass +15% as a proportion of above ground biomass.

Freight costs are a significant contributor to the economics of biomass commodity industries, especially for producers of high volume/relatively low value products that need to be transported to distant mills and processing plants (Bennell *et al.* 2008). Transport costs are dependant on vehicle travel speeds and are variable in their proportion of running costs and driver salaries. To increase the accuracy of spatial economic models we detailed different road types and surfaces and applied a +20% cost to unsealed roads and a +40% cost for farm track and paddocks. Transport paths and associated freight costs have been mapped and evaluated between each square kilometre of land potentially available for new woody biomass industries and each existing processing facility.

The RIPA economics module then combines information on plantation productivities, changes in plantation product component yields (i.e. biomass fractions) with plant age, establishment costs, maintenance costs, harvest costs and delivered feedstock values (see Table 20 and Table 21). It then conducts sensitivity analyses to determine economically optimal harvest cycles for each industry type. Spatial economics models are constructed for each industry type and applied to spatial surfaces of plantation productivities for each industry species group and road transport costs (where applicable) for every hectare of land potentially available to revegetation industries in the region. Cash flows over the first 20 years of each production system (under a financial discount rate of 7%) are converted to Annual Equivalent Returns (AER $/ha/year) which may then be compared with annual returns from existing agricultural industries. Figure 28 to Figure 40 illustrate the spatial distribution of likely landholder returns for a number of existing and potential industries in southern Australia.

Regional Industry Evaluations

Overall, many new biomass industries can bring substantial financial returns to many districts in the wheat-sheep zone of southern Australia depending on farmer access to existing and potential markets or corporate/government/cooperative investment in new infrastructure. Immediate access can be gained to livestock fodder which is reflected in existing farm diversification in the region. Low to medium rainfall pulpwood industries for export or delivery to the existing pulp mills are feasible in many areas and are likely to create the greatest return per hectare in many districts. Delivery of feedstock to the particleboard mills is only viable close to existing mills due to relatively low feedstock values and modest transportation costs. Prospective bioenergy and oil mallee systems (Integrated Tree Processing) could provide substantial returns in many regions but these require a reasonable investment in new infrastructure to be viable. In-field mallee harvesting and distillation of eucalyptus oil could also provide significant returns in landscapes suited to oil mallee species with minimal investments in infrastructure.

Carbon sequestration in above-ground and root biomass of unharvested woodlots using low planting density (1000 plants per hectare) and high-cost establishment techniques (tubestock plantings used in our analysis cf. cheaper direct seeding) provide modest returns for farmers at present without co-investment from governments. These potential returns are currently subject to highly volatile carbon dioxide equivalent market prices and a lack of current firm markets in Australia. It must be noted that revegetation efforts using local native habitat species are usually less productive and economically viable than the woodlot species group shown here (Hobbs *et al.* 2006). In the future, if the average standing plant and root biomass of harvested woody crops was included in carbon dioxide sequestration trading it could provide additional income streams to extractive agroforestry enterprises in the region.

Table 20. Primary production, freight costs and discount rate used in regional industry potential analysis.

	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]
Freight costs - includes truck return trip ($/t/km)	0.115 for sealed roads / 0.138 for unsealed roads / 0.161 for farm tracks and paddocks				
Discount rate	7%				

[#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.

Table 21. Estimated 2006 delivered feedstock values by industry type used in regional industry potential analysis.

Industry and Commodity Type	Delivery Location	Likely delivered value [$/freshweight tonne]
Export pulp - woodchip	Port	90
Australian pulp - woodchip	Mill	85
Australian MDF - woodchip	Mill	65
Australian particleboard - woodchip	Mill	43
Electricity generation - whole plant biomass	Powerplant	28
Eucalyptus bulk oil - leaf	Mobile Processing Plant	80
Eucalyptus essential oil - leaf	Mobile Processing Plant	210
Integrated wood processing - whole plant biomass	Processing Plant	36
Carbon Sequestration - unharvested woodlot	In situ	20
Fodder - Saltbush leaf (Autumn)	In situ/Paddock/Mill	65
Fodder - Saltbush leaf (Spring)	In situ/Paddock/Mill	45

Figure 18. Existing wood fibre manufacturing facilities in southern Australia.

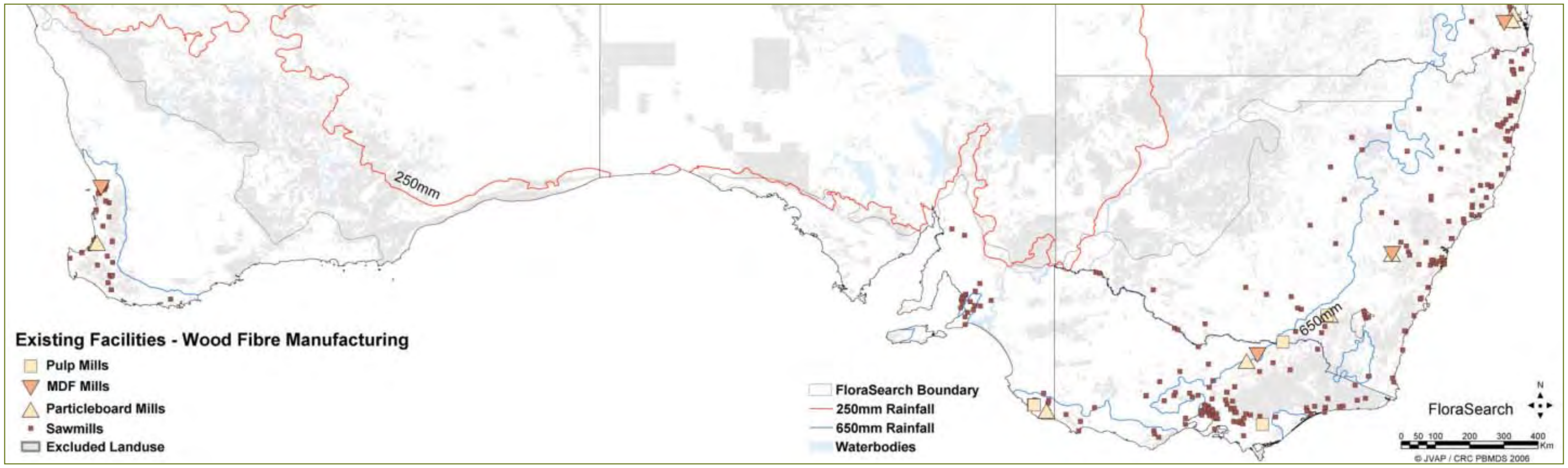


Figure 19. Existing non wood fibre manufacturing, processing or port facilities in southern Australia.

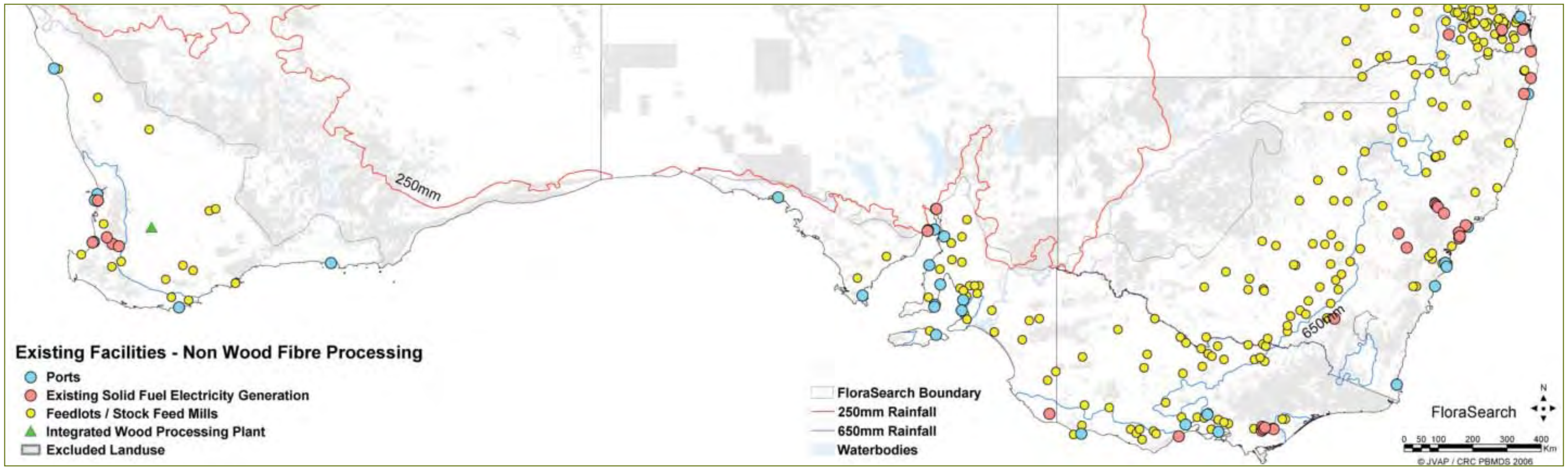


Figure 20. Salinity risk in 2050 from dryland salinity and discharges to river from saline groundwater flows.

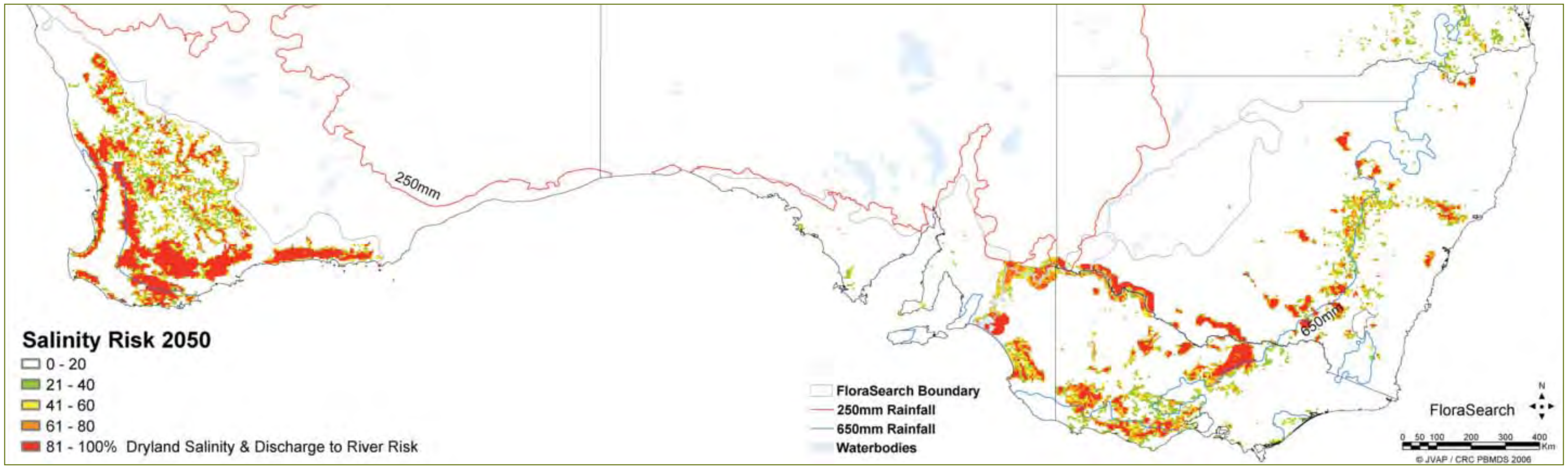


Figure 21. Electricity demand versus supply distance from existing 20MW generating facilities in southern Australia.

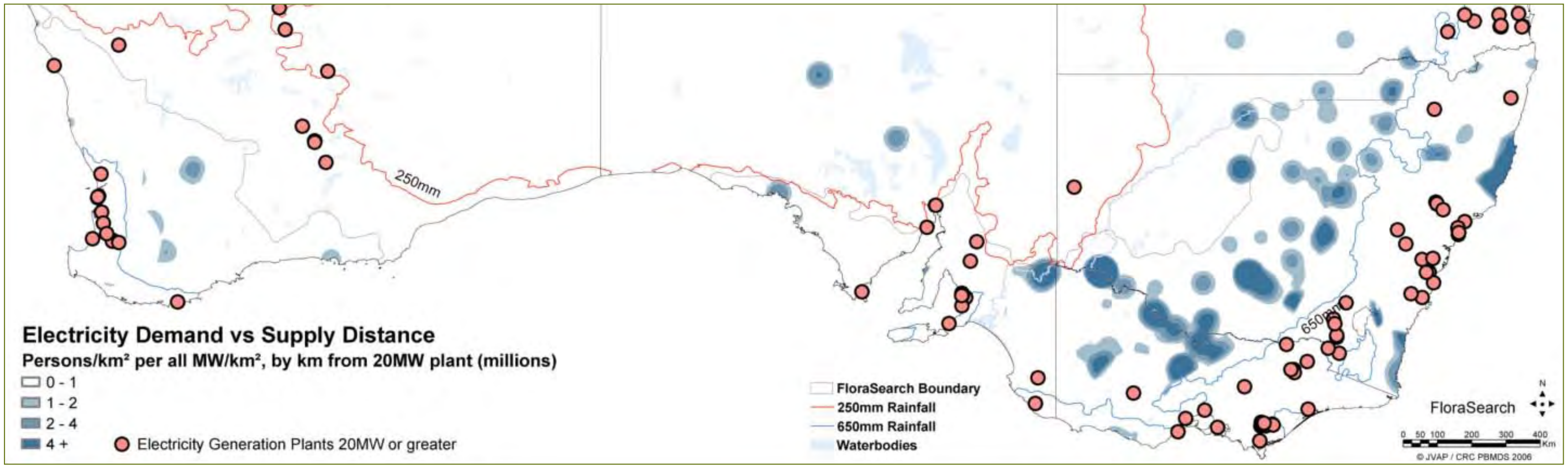


Figure 22. Productivity of climatically suitable pulp and fibre species in southern Australia.

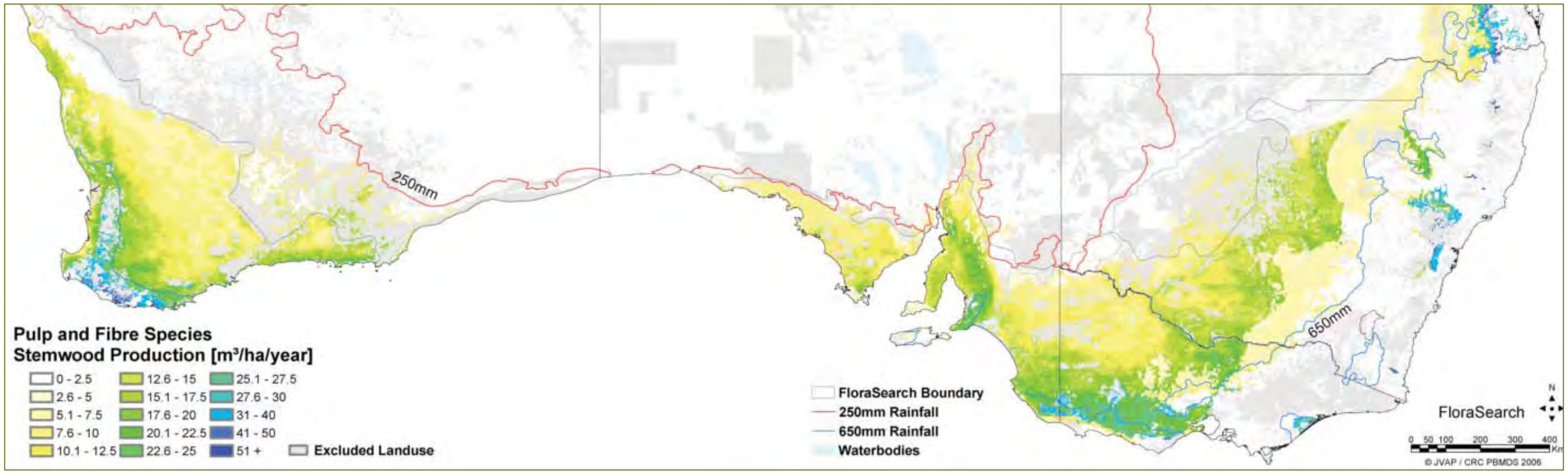


Figure 23. Productivity of climatically suitable bioenergy species in southern Australia.

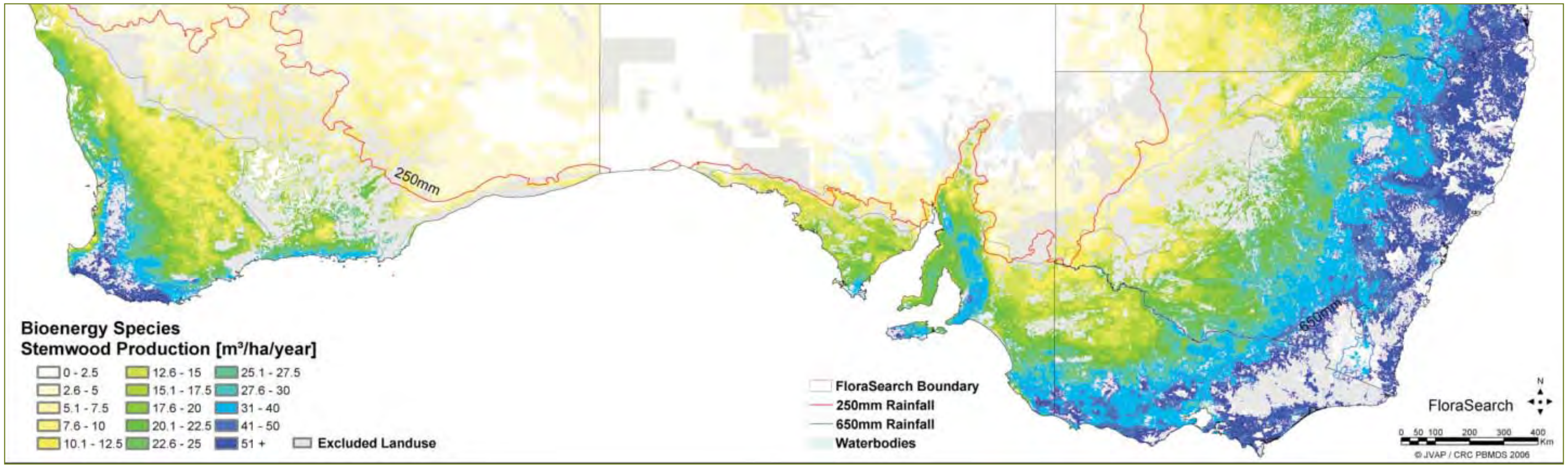


Figure 24. Productivity of climatically suitable oil mallee species in southern Australia.

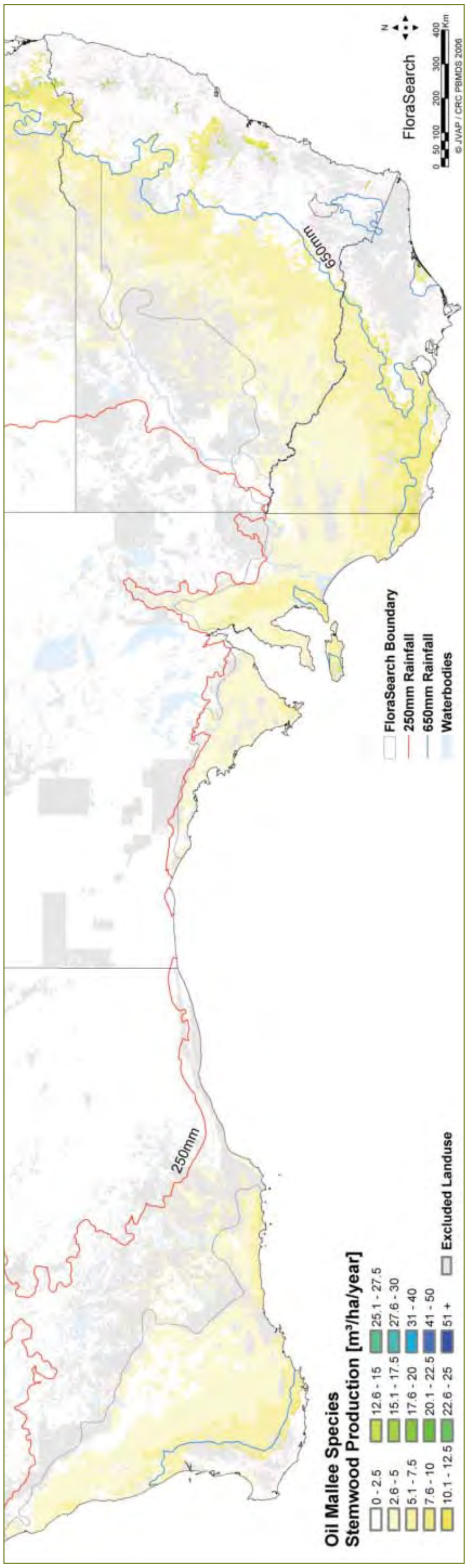


Figure 25. Productivity of climatically suitable Acacia pulp and fodder species in southern Australia.

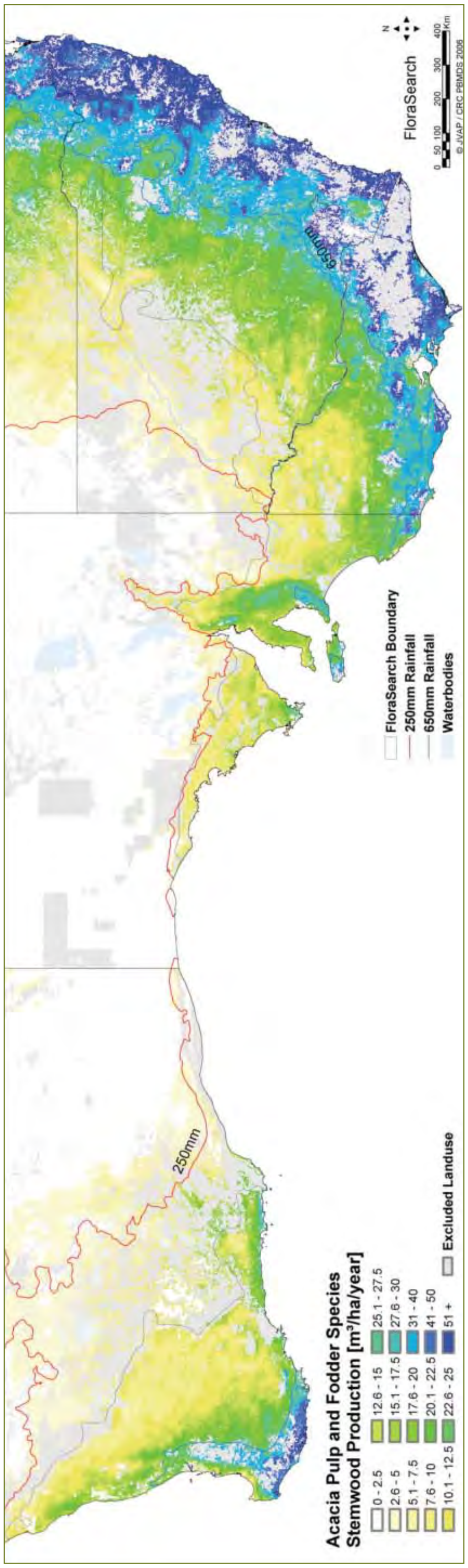


Figure 26. Productivity of climatically suitable saltbush fodder species in southern Australia.

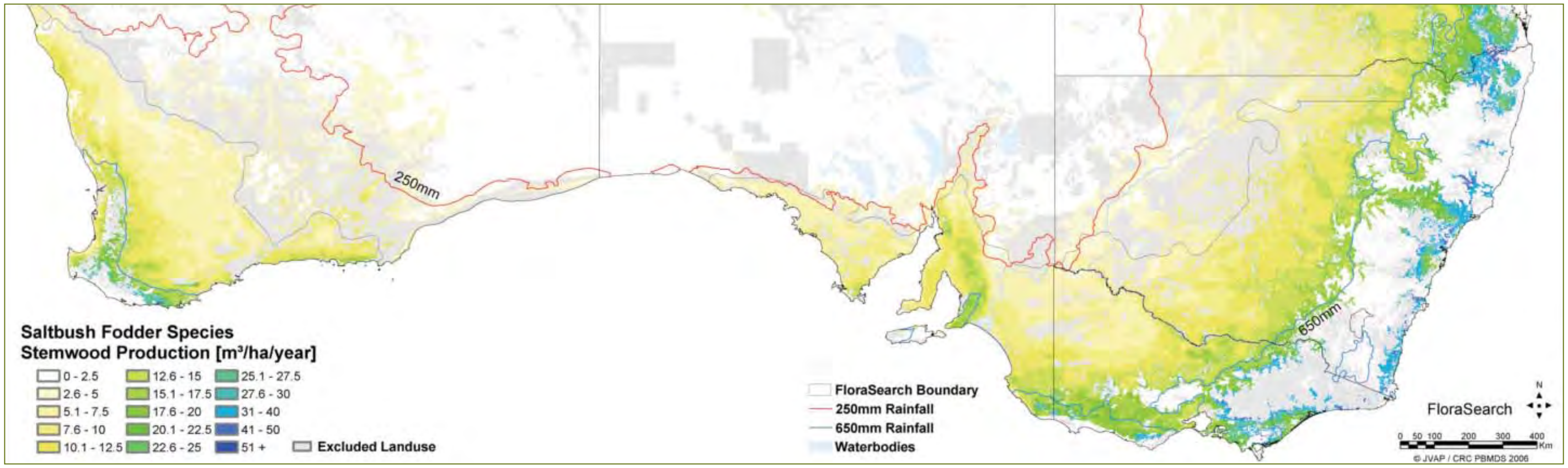


Figure 27. Productivity of climatically suitable carbon sequestration woodlot species in southern Australia.

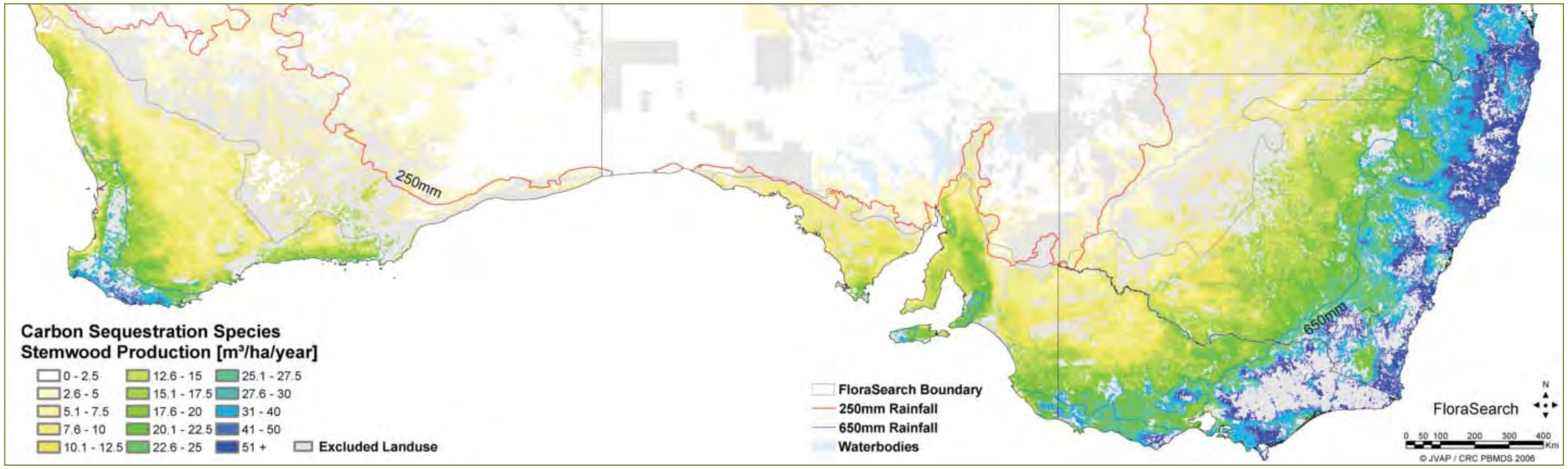


Figure 28 - Estimated primary producer returns from Export Pulpwood Only scenario to existing facilities.

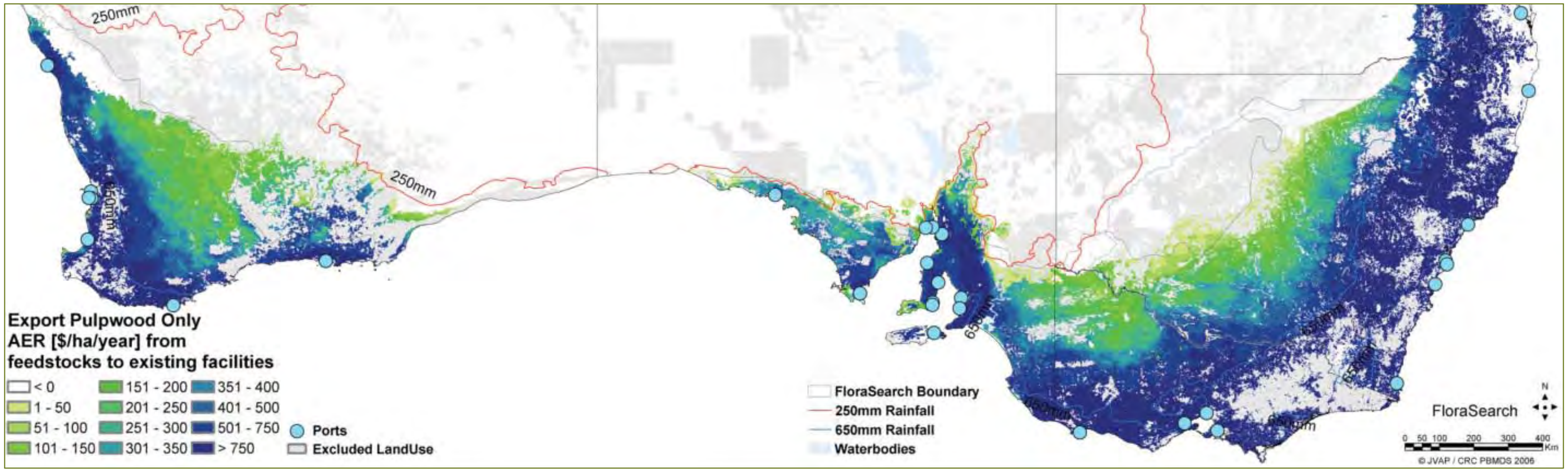


Figure 29. Estimated primary producer returns from Australian Pulpwood Only scenario to existing facilities.

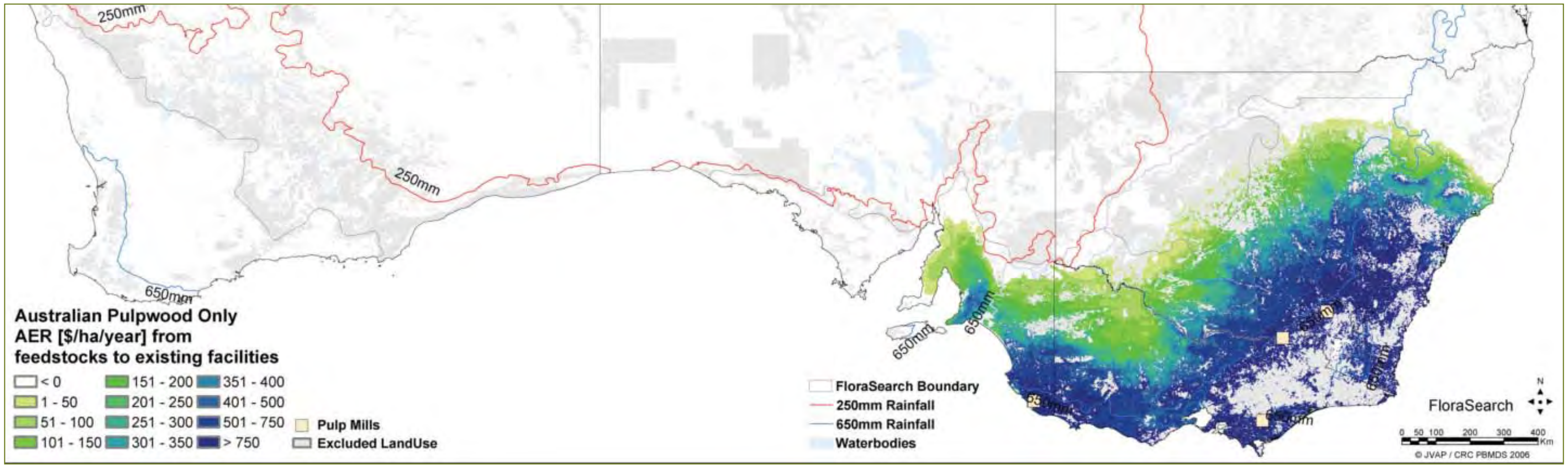


Figure 30. Estimated primary producer returns from Medium Density Fibreboard Only scenario to existing facilities.

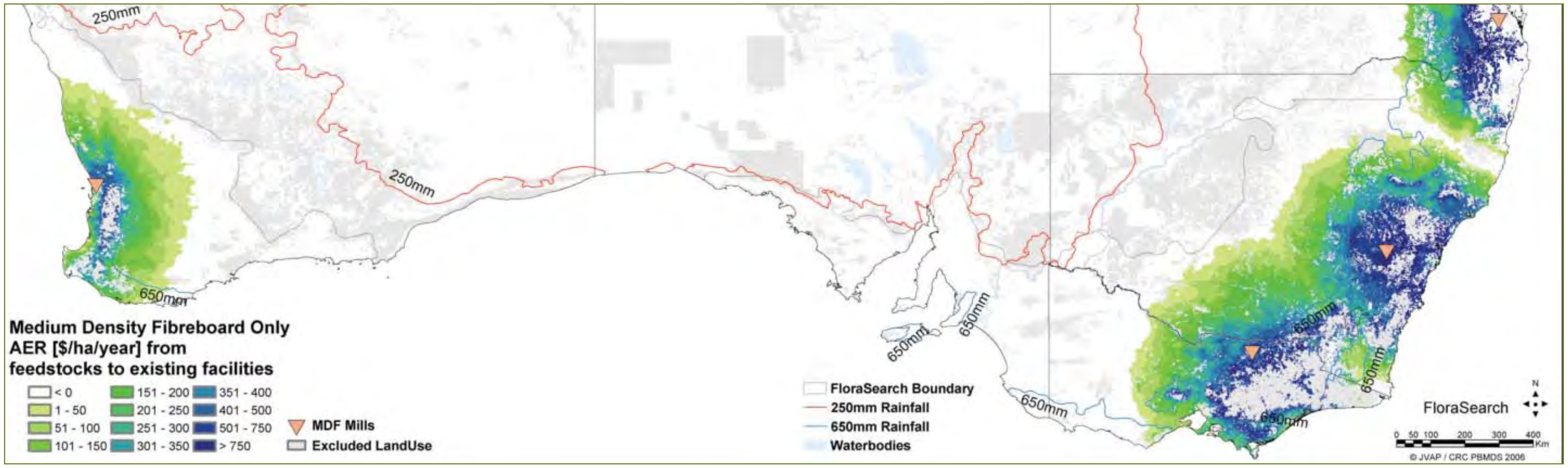


Figure 31. Estimated primary producer returns from Particleboard Only scenario to existing facilities.

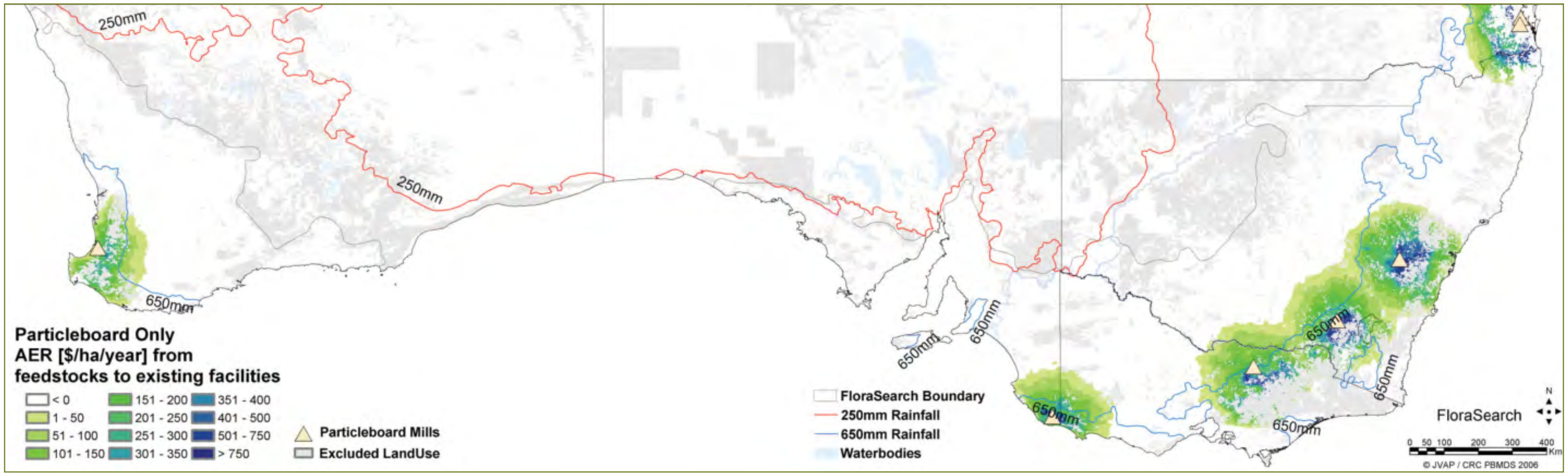


Figure 32. Estimated primary producer returns from Bioenergy Only scenario to existing facilities.

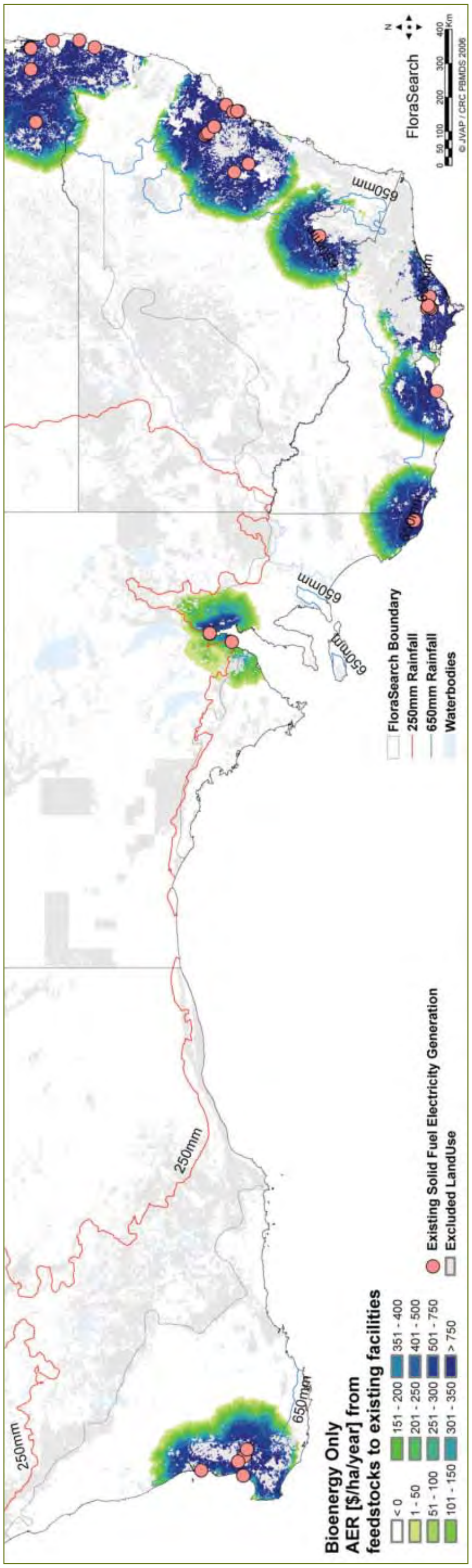


Figure 33. Estimated primary producer returns from Eucalyptus Oil Only @$3.00/kg scenario to existing facilities.

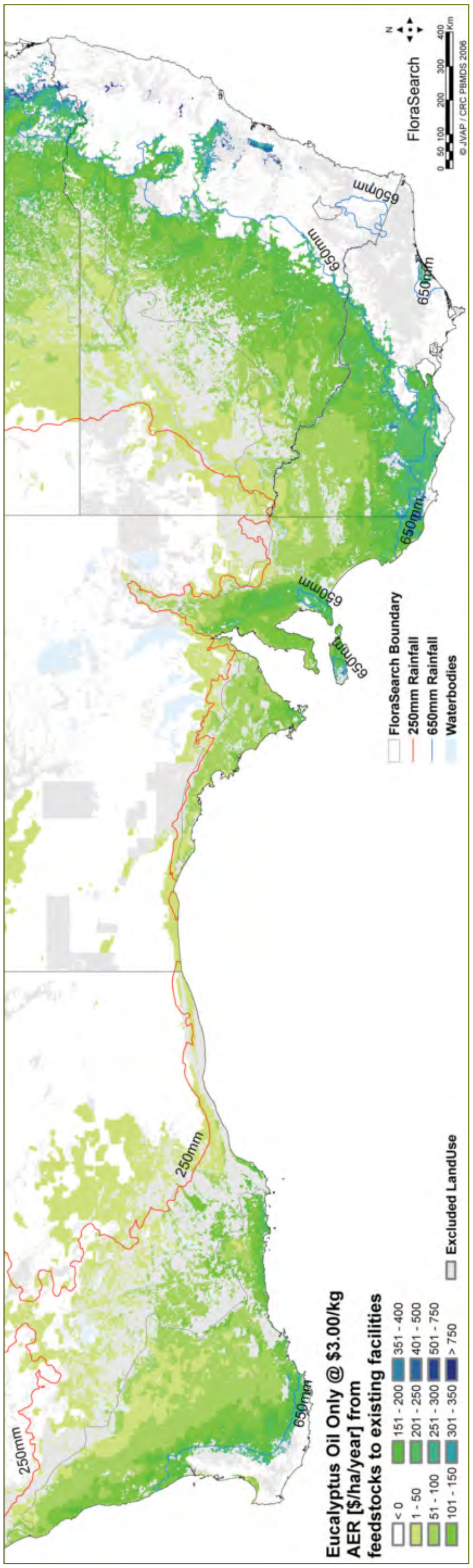


Figure 34. Estimated primary producer returns from Eucalyptus Oil Only @$7.50/kg scenario to existing facilities.

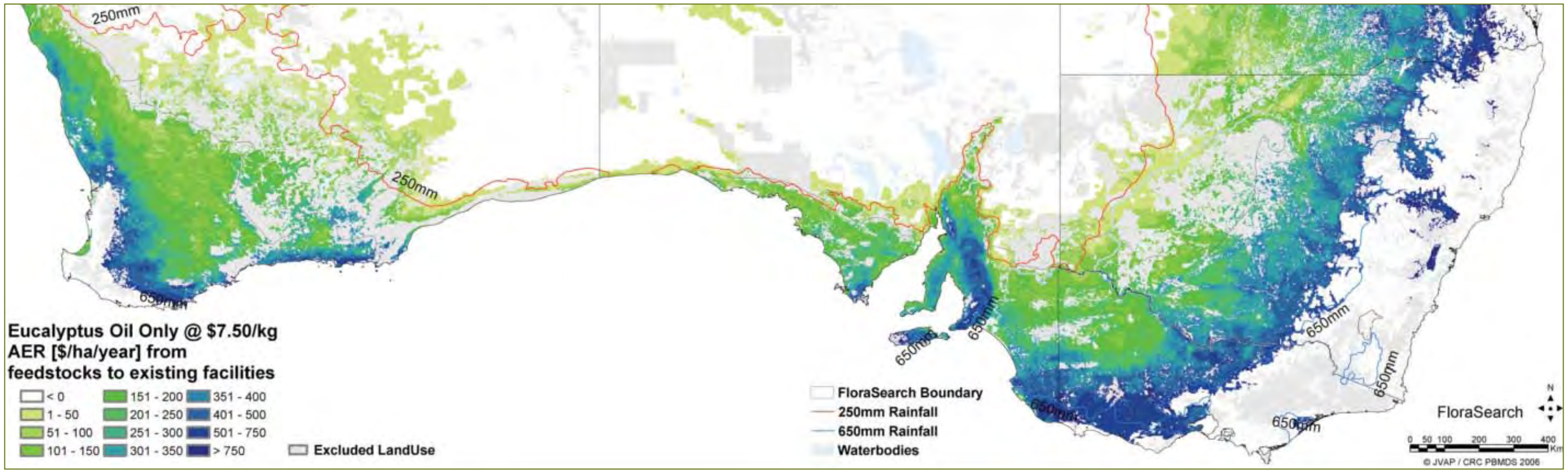


Figure 35. Estimated primary producer returns from Eucalyptus Oil and Bioenergy scenario to existing facilities.

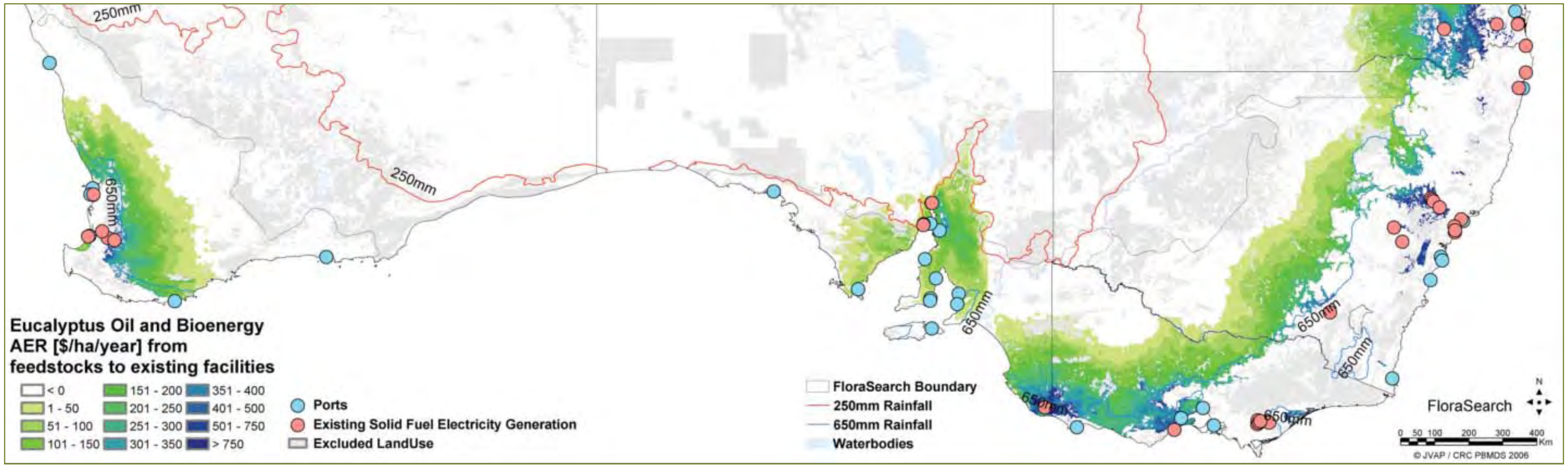


Figure 36. Estimated primary producer returns from Integrated Wood Processing scenario to existing facilities.

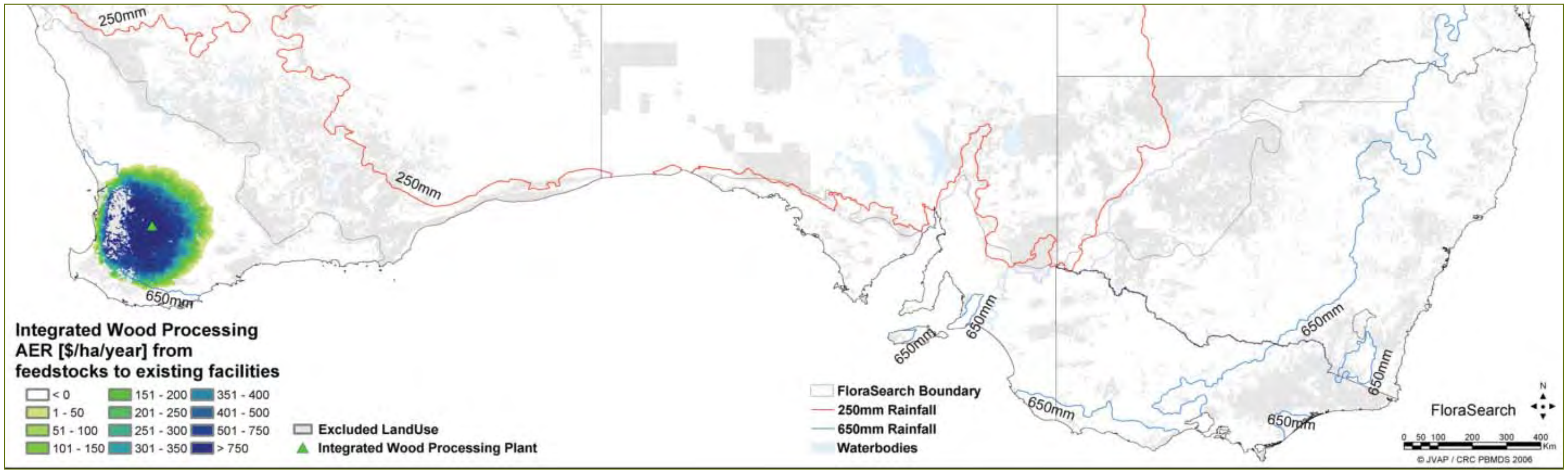


Figure 37. Estimated primary producer returns from Carbon Sequestration (unharvested woodlot @ A$20/t CO_2 equivalent) scenario.

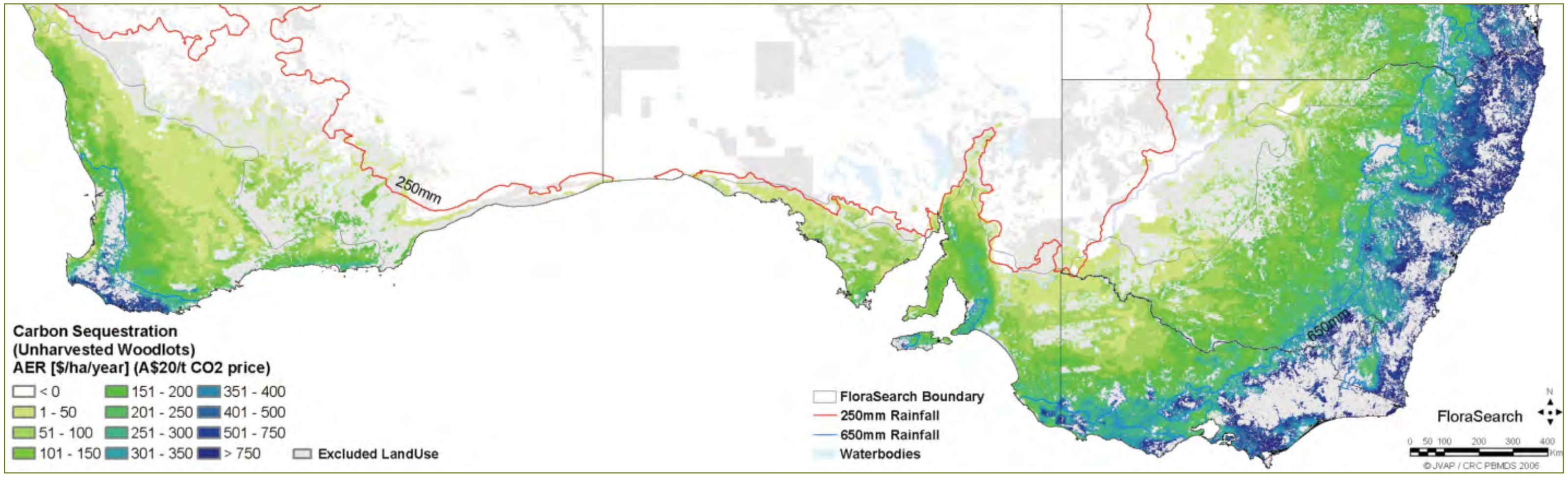


Figure 38. Estimated primary producer returns from In situ Farm Fodder Only (Spring saltbush) scenario.

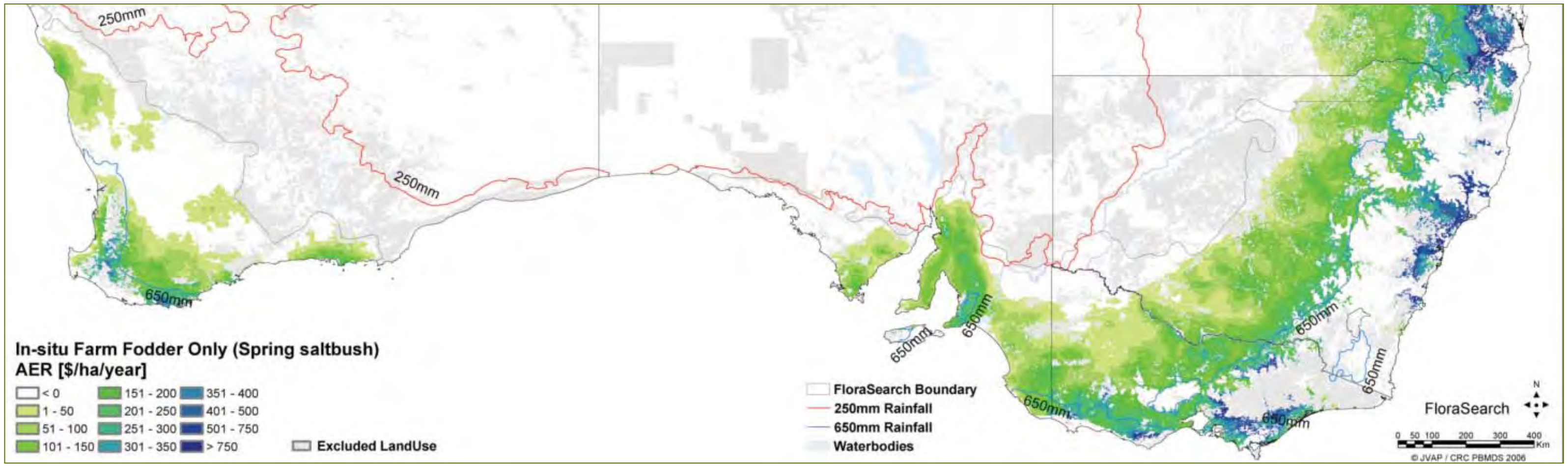


Figure 39. Estimated primary producer returns from In situ Farm Fodder Only (Autumn saltbush) scenario.

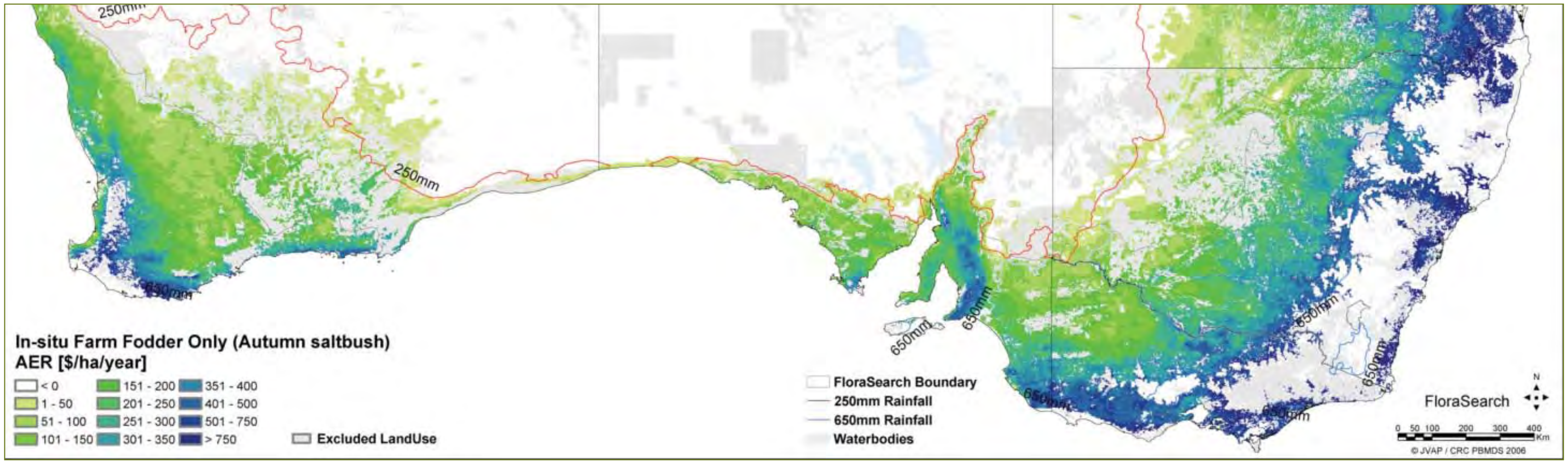
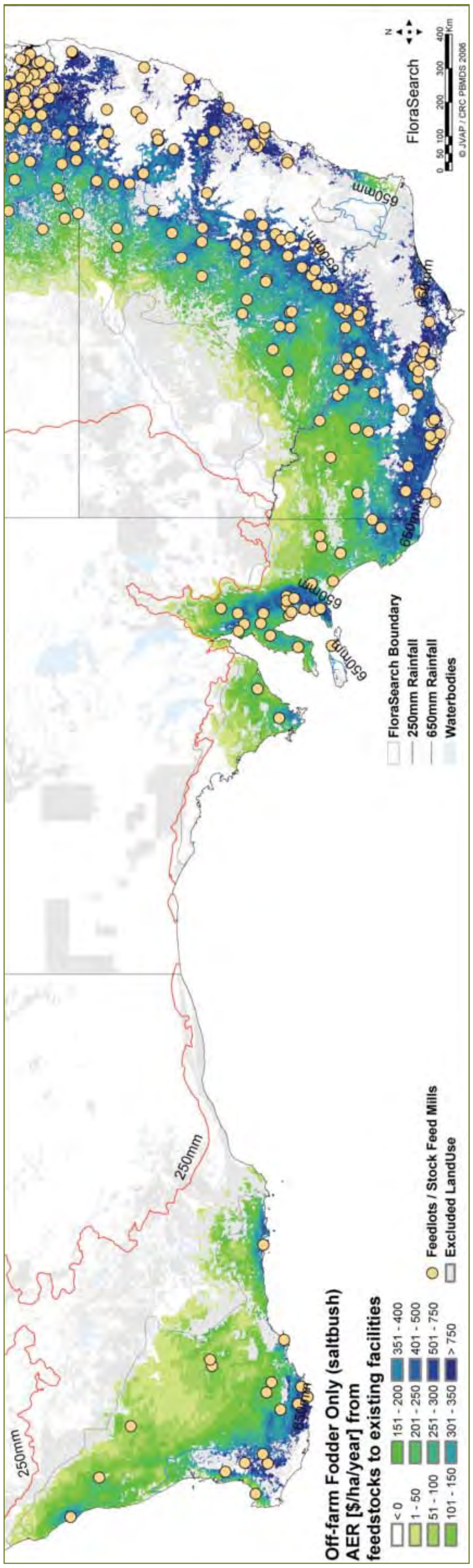
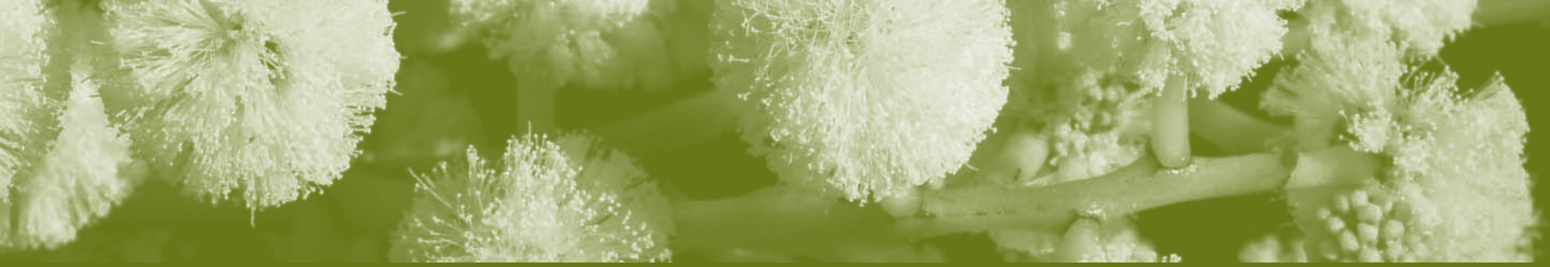


Figure 40. Estimated primary producer returns from Off-farm Fodder Only (Autumn saltbush) scenario.





6. Conclusion and Future Directions

Products and Markets

Wood products (pulp and paper, fibreboard and particle board) remain a high priority woody biomass industry with continued high level policy comment on the huge net import of wood fibre products into Australian in the order of $ 2 billion annually, major new infrastructure developments (pulp mills) proposed for the southeast of SA and western Victoria, and concerns by some sectors of the forest products industry about future short fall in feedstock availability.

Australia currently consumes around 5500 Petajoules (1 PJ = 10^{15} joules) of energy ever year across its industrial, mining, agricultural, commercial and residential sectors. The trend and price of energy is continuing to increase. In Australia, electricity generation is predominantly based on black and brown coal deposits. Opportunities exist for greater use of woody biomass to generate electricity either as a coal replacement (or blend) in existing solid fuel plants or a co-product in a Narrogin style integrated wood processing facility. World oil prices have escalated from around US$25 per barrel in 2001 to over US$60 per barrel in 2006 (EIA 2006) and initially, predictions were that the current high price was only a short term prospect. Currently there are no clear indicators to suggest that oil will return to around US$35 per barrel as was often prophesised in 2004.

The Biofuels Taskforce (2005) has recently reported to the Prime Minister on status, potential and issues of biofuels development and adoption in Australia. This report states a target of 350ML of biofuels by 2010 and draws upon ABARE analyses of the viability of ethanol and biodiesel in the current policy and market environment. They report that biofuels are currently competitive and will remain so until around 2015 when current government excise assistance is reduced. They recommend that the potential of lignocellulosic feedstocks for ethanol production be thoroughly assessed before any major commitment is made to other ethanol feedstocks and production opportunities. Technological developments in North America and Europe in the production of ethanol from wood through lignocellulosic processes is raising the profile of biomass as an important source of transport fuel within a 10-20 year time frame for large scale adoption.

The metallurgical industry faces increasing pressure to reduce emissions of greenhouse gases from the production of metals. The substitution of fossil carbon by renewable carbon from biomass has the potential to radically reduce the net carbon emissions from metallurgical processes. The high reactivity and low sulphur content of charcoal makes it an attractive metallurgical reductant. The extent of substitution that is technically possible depends on the process.

It may also be possible to substitute charcoal for coal in other processes such as synthetic rutile production in rotary kilns where high reactivity is beneficial and the strength of the carbon is less critical. This opens up a large potential range of markets for wood carbons as reductants.

Oldman saltbush and the exotic Tagasaste or Lucerne Tree (*Chamaecytisus* spp.) have been widely used as a southern Australian fodder shrub crop the last decade. Early research on Oldman Saltbush on saline affected landscapes has painted a poor picture of its nutritional status (Lefroy 2002) largely due to high salt loads in the foliage from these environments. However, the salt load in the foliage is much less significant on non-saline affected sites. Further, Oldman Saltbush provides a valuable green feed resource during summer and autumn, when other typically annual fodder species are desiccated. This seasonally increases the value of the saltbush fodder crop to a level similar to that of lucerne pastures or hay. Interest in developing fodder shrubs species continues to grow and is currently reflected in the funding and research support for the current Enrich and FloraSearch projects.

Climate change is emerging as a significant issue for federal and state governments and this has increased the relevance and opportunities for the research goals of FloraSearch. Carbon sequestration can now be considered as a product in it own right. The opportunities for renewable energy from biomass are expanding. There is also a growing realisation that agricultural production systems of the future need to account for the risk of increased climate variability. Robust and productive perennial plant species can make an important contribution to the resilience of future farming systems.

Species Evaluations

The southeast node of FloraSearch has continued to focus on the evaluation of native species suitable for the eastern agricultural regions, while the WA node has refined selections made following evaluation undertaken in the preceding Search Project. The testing program continued to focus on basic wood density, pulp yield, paper making properties and fodder nutrient value. At the time of this report there are still some results from testing laboratories that have not been received and will need to be incorporated in the next phase with the possible result of additional species being added to lists of development species. The ranking of prospective species will be an ongoing process as the level of knowledge on particular species increases over time and it becomes apparent that their potential for domestication increases or decreases.

Recent surveys and product testing have revealed several significant advances in product yields and industrial suitability for some germplasm collections. Examples of this include the improved oil mallee selections where oil yields have doubled in the last few years for *Eucalyptus polybractea* and *E. horistes*. Recent evaluations of *Eucalyptus cladocalyx* have discovered variants with lower wood densities that allow this species (with demonstrated high pulp yields) to be utilised for paper making when previously the wood was too dense to be used in conventional pulp mills. Selections of *Eucalyptus globulus* spp. *bicostata* from low rainfall regions (<400 mm annual rainfall) provide germplasm that can be utilised by the existing Tasmanian blue gum plantation industries in lower rainfall regions where current industry selections fail.

Concurrent with the testing program there has been a significant effort on improving the knowledge of the productive potential of the development species. Measurements at FloraSearch trial sites in SA, NSW, Victoria and WA at one year are providing data on ease of establishment, levels of survival and growth rates. Early trends are apparent and it is clear that one species (*Codonocarpus cotinifolius*) ranked highly on growth rate and product suitability has significant problems with establishment (close to total failure at several locations over two years) and this species has now been demoted in priority. Project partners have undertaken collection of tree performance data from existing trial sites and farm forestry demonstration sites. This ongoing work includes the collection and collation of existing data (eg TreDat), re-measurement of trial sites, and harvesting of high priority species to allow the development of allometric relations linking easy to measure parameters (diameter at breast height, tree height) to total biomass.

A list of development species has been identified for each region (east and west). From this list two focus species have been selected for intense domestication activities. The focus species are *Atriplex nummularia* (Oldman Saltbush) with potential as a fodder species across southern Australia, and *Acacia saligna* as a wood and fodder species in WA only (there are significant weed risks in eastern Australia). *Eucalyptus loxophleba* ssp. *lissophloia* is also being considered by the WA node for elevation to a focus species based on its potential as an oil mallee species. Some the highest priority species (not in a priority order) from the eastern node include; *Acacia decurrens, Acacia mearnsii, Acacia retinodes* var. *retinodes, Eucalyptus cladocalyx, E. globulus* spp. *bicostata, E. occidentalis, E. ovata, E. polybractea, E. viminalis* ssp. *cygnetensis* and *Viminaria juncea*. Western node species include *Acacia lasiocalyx, Anthocercis littorea, Casuarina obesa, Codonocarpus cotinifolius, Eucalyptus rudis* and *E. horistes*. There are some overlapping species with *Codonocarpus cotinifolius* and *Viminaria juncea* occurring in both regions and considered be prospective. Often however, a mix of the unique environmental conditions in each region and environmental risk considerations has resulted in species occurring in a region to be developed and utilised locally.

Regional Industry Potential Analysis

The RIPA combines geographic information system data with economic models to evaluate the potential commercial viability of the woody perennial crop industries described in this report. The RIPA methodology was first described in the FloraSearch Phase 1 report (Bennell *et al.* 2008) using early estimates of productivity and preliminary models to illustrate the concept. This work has progressed and is becoming a sophisticated tool, able to support the systematic regional evaluation of perennial crop options. It incorporates improved species knowledge (e.g. productivity estimates), industry developments, updated costs and returns, a refinement in the modelling process and has now been expanded to include the WA region.

The current analyses presented in this report shows that many short-cycle woody crops and biomass industries are profitable across vast regions of southern Australia. The economic returns of several industry types in the region are even competitive with existing land uses. The current and potential profitability and sustainability of perennial woody crops can provide landholders with alternatives into the future.

Future Directions

The evaluation of species will continue at a reduced level and be focused on evaluating provenance variability and also matching development species to emerging industry types with greatest potential. The assessment of fodder value of selected woody species will continue and be expanded in conjunction with project work on grazing systems based on woody perennials in the Enrich project. We are also liaising on a project to evaluate charcoal use in metal smelting and evaluation of feedstock value for lignocellulosic ethanol may be considered.

The growth of woody crops and yields of products is critical for commercial reality of FloraSearch industries. Work on productivity evaluations will be continued and with additional collections of plant growth the accuracy of biomass productivity and yield models will be improved and economic evaluations more robust.

Economic evaluation and spatial analysis of farm and industry economics will be refined as new data becomes available, such as improved industry and market knowledge flowing from related projects, and improved understanding of the effects of biophysical factors on woody crop productivity, especially water movement and capture. Estimated farm returns from new industries will be compared to current land use options. This component of FloraSearch will have strong links with, and draw on results from, the CRC's New Industry and Marketing project. Utilising the economic and spatial tools described above, a case study of pilot industry development option(s) will be undertaken in conjunction with an industry partner.

Research into the domestication of selected focus and development species will be a central area of work. This includes germplasm collection and establishment of plant improvement trials for focus species. Multiple provenances will be collected for development species and included in the trials to collect field performance data. Feedstock characteristics will be identified that are appropriate targets for improvement by selection of germplasm to ensure product attributes are incorporated into germplasm selection. Future species development evaluations will also include weed and genetic pollution risks assessed in collaboration with related CRC programs and projects

Agronomic experimentation on focus species will be used to develop methods for production of short-cycle phase and coppice crops. Important aspects to be studied include system design, site selection, establishment techniques, the impact of density on productivity, nutrient response, coppice and sucker management, and susceptibility to herbicides, grazing and pests.

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Appendices

Appendix A. Summary of South Australian data used to develop allometric relationships between simple plant observations and their biomass

Source: Hobbs and Bennell 2005.

Table A1. Plant species measured and destructively sampled for biometrics study, including some key plant characteristics (mean values, n=3).

Region / Species	Rainfall [mm]	Age [years]	Height [m]	Crown Width [m]	Lifeform [Tree/Mallee/Shrub]	Foliage Density [%]	Total Green Biomass [kg plant^{-1}]	Proportion Green Biomass by Weight		
								Wood & Bark	Twig & Bark	Leaf, Fine Twig & Bark
Riverland Corridor										
Acacia ligulata	247	8.5	1.80	2.97	S	81	26.30	0.09	0.60	0.31
Acacia oswaldii	253	8.5	1.35	1.72	S	57	7.55	0.10	0.57	0.32
Atriplex nummularia (ungrazed)	251	7.5	1.90	3.20	S	81	28.69	0.14	0.55	0.31
Atriplex nummularia (grazed)	251	7.5	1.17	1.60	S	34	5.29	0.11	0.76	0.13
Callitris gracilis	253	8.5	2.13	1.37	S	76	4.42	0.14	0.41	0.45
Eucalyptus calycogona	261	8.5	2.70	2.53	M	57	26.01	0.29	0.25	0.46
Eucalyptus cyanophylla	261	9.5	2.88	2.53	M	62	35.32	0.29	0.26	0.45
Eucalyptus gracilis	261	6.6	1.77	1.97	M	91	10.65	0.06	0.35	0.59
Eucalyptus largiflorens	261	10.5	3.77	2.57	T	52	32.57	0.54	0.22	0.24
Eucalyptus oleosa	261	10.4	2.93	3.53	M	76	40.35	0.32	0.28	0.40
Eucalyptus porosa	261	9.5	2.37	3.13	M	76	21.29	0.23	0.39	0.38
Eucalyptus socialis	261	10.5	3.30	4.50	M	71	80.40	0.33	0.30	0.37
Lower Murray Corridor										
Acacia oswaldii	340	12.5	2.03	2.90	S	95	44.54	0.19	0.41	0.40
Acacia pycnantha	340	13.5	4.10	3.80	T	43	50.73	0.55	0.28	0.17
Acacia rigens	340	12.5	2.60	2.13	S	100	42.07	0.27	0.35	0.38
Allocasuarina verticillata	340	12.5	5.67	3.27	T	43	80.32	0.64	0.19	0.17
Eucalyptus porosa	340	12.4	5.33	4.40	M	71	98.43	0.54	0.18	0.28
Melaleuca uncinata	340	12.4	1.83	1.70	S	100	17.63	0.12	0.44	0.44

Table A2. Mean wood properties, bark proportions and moisture contents of biomass fractions for plant species sampled for biometrics study.

Region / Species	Basic Density [kg/m³]	Proportion Bark to Stemwood		Proportion Moisture by Weight			
		By Volume	By Weight	Wood & Bark	Wood Only	Twig & Bark	Leaf, Fine Twig & Bark
Riverland Corridor	(n=9)#	(n=9)	(n=9)	(n=3)	(n=9)	(n=3)	(n=3)
Acacia ligulata	840	0.33	0.32	0.36	0.35	0.32	0.55
Acacia oswaldii	869	0.26	0.23	0.35	0.31	0.36	0.46
Atriplex nummularia (ungrazed)	793	0.09	0.05	0.32	0.32	0.28	0.64
Atriplex nummularia (grazed)	762	0.12	0.08	0.33	0.32	0.30	0.69
Callitris gracilis	619	0.23	0.24	0.46	0.44	0.44	0.38
Eucalyptus calycogona	775	0.21	0.23	0.31	0.30	0.33	0.37
Eucalyptus cyanophylla	787	0.37	0.33	0.34	0.34	0.37	0.37
Eucalyptus gracilis	830	0.24	0.26	0.34	0.31	0.39	0.43
Eucalyptus largiflorens	687	0.30	0.28	0.37	0.36	0.40	0.46
Eucalyptus oleosa	793	0.28	0.27	0.35	0.33	0.40	0.38
Eucalyptus porosa	668	0.27	0.26	0.40	0.39	0.44	0.48
Eucalyptus socialis	757	0.27	0.26	0.33	0.32	0.37	0.37
Lower Murray Corridor							
Acacia oswaldii	859	0.17	0.19	0.33	0.32	0.32	0.55
Acacia pycnantha	785	0.20	0.21	0.30	0.27	0.39	0.41
Acacia rigens	776	0.21	0.23	0.37	0.37	0.37	0.49
Allocasuarina verticillata	723	0.24	0.25	0.36	0.36	0.43	0.51
Eucalyptus porosa	663	0.26	0.22	0.41	0.41	0.43	0.49
Melaleuca uncinata	711	0.19	0.21	0.37	0.38	0.36	0.42

(# number of samples per species and location)

Table A3. Relationships between total green biomass, dry biomass and carbon content of plant species measured and destructively sampled for biometrics study (mean values, n=3).

Region / Species	Total Green Biomass [kg plant^{-1}]	Dry Biomass [kg plant^{-1}]				Proportion Dry Biomass to Green Biomass by Weight	Proportion Carbon to Green Biomass by Weight
		Wood & Bark	Twig & Bark	Leaf, Fine Twig & Bark	Total		
Riverland Corridor							
Acacia ligulata	26.30	1.47	10.67	3.74	15.89	0.604	0.302
Acacia oswaldii	7.55	0.50	2.79	1.33	4.62	0.612	0.306
Atriplex nummularia (ungrazed)	28.69	2.75	11.38	3.16	17.29	0.603	0.301
Atriplex nummularia (grazed)	5.29	0.39	2.79	0.21	3.40	0.642	0.321
Callitris gracilis	4.42	0.34	1.00	1.25	2.59	0.585	0.293
Eucalyptus calycogona	26.01	5.20	4.41	7.51	17.11	0.658	0.329
Eucalyptus cyanophylla	35.32	6.60	5.91	9.99	22.51	0.637	0.319
Eucalyptus gracilis	10.65	0.44	2.24	3.58	6.26	0.588	0.294
Eucalyptus largiflorens	32.57	11.03	4.31	4.32	19.66	0.603	0.302
Eucalyptus oleosa	40.35	8.41	6.83	9.91	25.15	0.623	0.312
Eucalyptus porosa	21.29	3.01	4.67	4.16	11.83	0.556	0.278
Eucalyptus socialis	80.40	17.77	15.15	18.61	51.53	0.641	0.320
Lower Murray Corridor							
Acacia oswaldii	44.54	5.78	12.35	7.90	26.02	0.584	0.292
Acacia pycnantha	50.73	19.69	8.54	5.14	33.38	0.658	0.329
Acacia rigens	42.07	7.17	9.19	8.20	24.56	0.584	0.292
Allocasuarina verticillata	80.32	32.98	8.66	6.63	48.27	0.601	0.300
Eucalyptus porosa	98.43	31.24	10.14	14.17	55.55	0.564	0.282
Melaleuca uncinata	17.63	1.38	4.97	4.47	10.81	0.613	0.307

Table A4. Summary of key plant attributes tested for developing allometric models of total green biomass and biomass fractions (mean values, n=3).

Region / Species	Height [m]	Basal Area [cm²]#	Crown Area [m²]	Foliage Density [%]	Stemwood Volume x 1000 [m³]	Green Biomass [kg plant⁻¹] Total	Wood & Bark	Twig & Bark	Wood & Bark + Twig & Bark	Leaf, Fine Twig & Bark
Riverland Corridor										
Acacia ligulata	1.80	62.62	6.92	81	14.09	26.30	2.31	15.73	18.04	8.26
Acacia oswaldii	1.35	22.31	2.58	57	2.11	7.55	0.78	4.34	5.11	2.44
Atriplex nummularia (ungrazed)	1.90	133.31	8.17	81	12.74	28.69	4.06	15.84	19.90	8.79
Atriplex nummularia (grazed)	1.17	37.51	2.06	34	3.28	5.29	0.58	4.02	4.60	0.69
Callitris gracilis	2.13	17.02	1.49	76	3.13	4.42	0.62	1.80	2.42	2.00
Eucalyptus calycogona	2.70	76.02	5.09	57	8.88	26.01	7.58	6.55	14.13	11.88
Eucalyptus cyanophylla	2.88	62.25	5.24	62	9.80	35.32	10.07	9.33	19.41	15.92
Eucalyptus gracilis	1.77	31.41	3.04	91	2.48	10.65	0.66	3.70	4.35	6.30
Eucalyptus largiflorens	3.77	95.45	5.41	52	19.78	32.57	17.45	7.19	24.64	7.94
Eucalyptus oleosa	2.93	85.85	9.91	76	14.13	40.35	12.91	11.34	24.25	16.10
Eucalyptus porosa	2.37	67.55	7.83	76	7.42	21.29	4.98	8.31	13.29	8.00
Eucalyptus socialis	3.30	136.75	16.04	71	25.77	80.40	26.63	24.06	50.69	29.71
Lower Murray Corridor										
Acacia oswaldii	2.03	132.52	6.62	95	23.38	44.54	8.64	18.27	26.91	17.62
Acacia pycnantha	4.10	68.45	11.53	43	16.18	50.73	28.03	14.02	42.04	8.68
Acacia rigens	2.60	92.35	3.68	100	17.25	42.07	11.31	14.61	25.92	16.15
Allocasuarina verticillata	5.67	183.85	8.39	43	54.77	80.32	51.47	15.18	66.65	13.67
Eucalyptus porosa	5.33	218.15	17.87	71	57.57	98.43	52.74	17.80	70.54	27.88
Melaleuca uncinata	1.83	73.41	2.32	100	10.90	17.63	2.19	7.72	9.91	7.72

(# [1] basal area at 0.1m height, [2] 0.2m, [5] 0.5m)

Appendix B. Field Trials of Woody Germplasm Project 2004 plantings

Table B1. Summary of early results from the Field Trial of Woody Germplasm project 2004 plantings.

FTWG Early Results (1 year old)	Survival						Average Height [m]						Max. Individual Height [m]						500mm Rain Equiv.#		
Provenance	SA Murray Bridge	SA Roseworthy	SA Lucindale	Vic Rutherglen	WA Coorow	WA Toolibin	SA Murray Bridge	SA Roseworthy	SA Lucindale	Vic Rutherglen	WA Coorow	WA Toolibin	SA Murray Bridge	SA Roseworthy	SA Lucindale	Vic Rutherglen	WA Coorow	WA Toolibin	Av. Survival	Av. Height	Rank
Acacia aneura [Glendambo]	47%						0.14						0.24						66%	0.19	75
Acacia bartleana [Dandaragan]					90%	64%													91%		15
Acacia deanii ssp. *deanii* [Biloela CS16922]	93%						0.72						1.74						100%	1.01	22
Acacia lasiocalyx [Muntadgin S-AV-22]	54%				64%	91%	0.27												87%	0.38	70
Acacia leucoclada [ATSC]	55%	92%	57%	98%			0.22	0.35	0.17	1.14			0.55	1.35	0.37	2.14			80%	0.48	64
Acacia mearnsii [Bungendore CS18975]	98%						1.01						2.10						100%	1.41	2
Acacia melanoxylon [Mt. Compass]	86%						0.45						0.84						100%	0.64	41
Acacia pycnantha [Kuipto CS19346]	98%	96%	65%	100%			0.40	0.44	0.14	1.00			0.82	0.88	0.50	1.73			88%	0.53	59
Acacia pycnantha [McLaren Flat]	98%						0.63						1.12						100%	0.89	26
Acacia pycnantha [Onka NP]	95%						0.41						0.87						100%	0.57	49
Acacia retinodes var. *retinodes* (hill form) [Bull Creek]	91%			98%			0.61			1.68			1.30			2.60			93%	1.16	16
Acacia retinodes var. *retinodes* (hill form) [Clare/Spalding]	84%	97%	43%				0.55	0.75					1.06	1.46					80%	0.85	38
Acacia retinodes var. *retinodes* (hill form) [Eden Valley]	96%						0.66						1.44						100%	0.92	24
Acacia retinodes var. *retinodes* (swamp form) [BSC]	96%	92%	17%	99%			0.85	0.70	0.85	2.06			2.14	2.33	1.66	3.30			76%	1.17	27
Acacia salicina [Condobolin Milthorpe 01/04]	90%						0.27						0.76						100%	0.38	62
Acacia salicina [Mambray Creek]	88%	92%	46%	99%			0.25	0.38		1.01			0.83	0.78		1.70			83%	0.57	57
Acacia salicina [threshed 87R 2/88]	84%						0.25						0.69						100%	0.36	67
Acacia saligna (coastal form) [Mandurah RSU]	99%				68%	77%	0.91												96%	1.27	3
Acacia saligna (wheatbelt form) [Parkeyerring RSU]	100%	75%	54%	99%	56%	69%	1.05	1.12	0.68	2.21			2.10	2.46	1.78	3.20			82%	1.36	11

FTWG Early Results (1 year old)	Survival						Average Height [m]						Max. Individual Height [m]						500mm Rain Equiv.#		
Provenance	SA Murray Bridge	SA Roseworthy	SA Lucindale	Vic Rutherglen	WA Coorow	WA Toolibin	SA Murray Bridge	SA Roseworthy	SA Lucindale	Vic Rutherglen	WA Coorow	WA Toolibin	SA Murray Bridge	SA Roseworthy	SA Lucindale	Vic Rutherglen	WA Coorow	WA Toolibin	Av. Survival	Av. Height	Rank
Acacia victoriae [Copley CS19334]	91%						0.27						0.49						100%	0.38	63
Agonis flexuosa [Esperance FPC-C99101D]						87%													100%		4
Allocasuarina huegeliana [Beverley NS-22554]					83%	65%													91%		13
Allocasuarina huegeliana [Toolibin NGN]						71%													90%		17
Alyogyne hakeifolia [Salmon Gums NS-18647]						73%													93%		12
Alyogyne huegelii [Yorke Peninsula]	76%			99%			0.37			1.16			0.90			1.50			93%	0.77	36
Atriplex nummularia [Eyres Green]	99%						1.07						1.83						100%	1.49	1
Atriplex nummularia [Yando]	99%	97%	47%	100%	86%	12%	0.74	1.02	0.69	1.08			1.35	1.29	1.21	1.85			75%	0.98	35
Bursaria occidentalis [Mullewa CS16638]					0%														0%		77
Callitris gracilis [Murray Bridge]	90%	98%	34%	98%			0.29	0.35		0.99			0.59	0.82		2.22			80%	0.57	60
Casuarina cunninghamiana ssp. *cunninghamiana* [Coonabarabran CS15001]	68%	98%		100%			0.40	0.65		1.49			0.99	1.15		2.50			94%	0.89	29
Casuarina obesa [Salt Creek]	89%		19%				0.43						1.20						59%	0.61	66
Casuarina obesa [Yornaning N-203781A]					95%	90%													100%		4
Codonocarpus cotinifolius [Goodlands]	0%																		0%		77
Codonocarpus cotinifolius [Youaumi]	0%				0%														0%		77
Dryandra sessilis [Kendenup NS-25020]						41%													52%		42
Eucalyptus baxteri [Willunga]	81%						0.39						0.95						100%	0.55	51
Eucalyptus bridgesiana [Cullerin Range CS20500]	89%	77%	9%	98%			0.61	0.52		1.47			1.06	1.10		2.82			73%	0.93	39
Eucalyptus camaldulensis var. *camaldulensis* [Lake Albacutya CS20561]	94%	98%	27%	99%			0.91	1.28	0.66	2.29			1.90	3.19	1.44	3.65			78%	1.38	18
Eucalyptus chloroclada [Dalby CS17756]	97%						0.43						0.93						100%	0.60	44
Eucalyptus cladocalyx [Wirrabara]	94%	93%	35%	100%			0.71	1.01	0.73	1.83			1.46	2.28	1.38	2.63			80%	1.14	25

FTWG Early Results (1 year old)	Survival						Average Height [m]						Max. Individual Height [m]						500mm Rain Equiv.#		
Provenance	SA Murray Bridge	SA Roseworthy	SA Lucindale	Vic Rutherglen	WA Coorow	WA Toolibin	SA Murray Bridge	SA Roseworthy	SA Lucindale	Vic Rutherglen	WA Coorow	WA Toolibin	SA Murray Bridge	SA Roseworthy	SA Lucindale	Vic Rutherglen	WA Coorow	WA Toolibin	Av. Survival	Av. Height	Rank
Eucalyptus cneorifolia [Kangaroo Island CS20275]	97%	34%	56%	98%			0.49	0.37	0.23	0.85			0.91	0.88	0.36	1.64			71%	0.53	65
Eucalyptus cyanophylla [Alawoona]	94%						0.41						0.74						100%	0.58	48
Eucalyptus globulus ssp. *bicostata* [Mt. Bryan CS19864]	87%	76%	30%	99%			0.40	0.46	0.34	1.10			0.79	0.90	0.56	2.00			78%	0.61	58
Eucalyptus globulus ssp. *bicostata* [Mt. Bryan FS_BB055]	95%	99%	39%	100%			0.41	0.75	0.34	1.19			0.84		0.73	1.80			81%	0.72	47
Eucalyptus globulus ssp. *bicostata* [Wee Jasper CS19283]	63%	99%	22%				0.54	0.75					0.88						70%	0.85	45
Eucalyptus goniocalyx [Mt. Osmond]	87%	80%	19%	100%			0.55	0.51	0.43	1.26			0.99	1.00	1.00	2.50			76%	0.73	50
Eucalyptus incrassata [Finnis]	97%						0.42						0.75						100%	0.59	46
Eucalyptus incrassata [Jabuk]	82%						0.35						0.67						100%	0.49	56
Eucalyptus incrassata [Owen]	92%	92%	47%	91%			0.38	0.55	0.23	0.80			0.77	0.85	0.58	1.75			81%	0.54	61
Eucalyptus leucoxylon ssp. *leucoxylon* [Wirrabara CS20274]	98%						0.61						1.11						100%	0.85	28
Eucalyptus loxophleba ssp. *lissophloia* [Newdegate CLM-11_03-P95]	95%	94%	64%	94%	86%		0.66	0.88	0.32	0.98									89%	0.80	37
Eucalyptus macrorhyncha ssp. *macrorhyncha* [Clare CS20290]	47%						0.26						0.44						66%	0.36	73
Eucalyptus obliqua [Macclesfield]	50%						0.35						0.59						70%	0.48	69
Eucalyptus occidentalis [Bundaleer SO]					90%	77%													99%		9
Eucalyptus occidentalis [Redhill]	91%	91%	45%	99%			0.86	1.04	0.70	1.87			1.99	2.11	1.49	2.57			83%	1.21	23
Eucalyptus ovata [Back Valley]	83%	79%	6%	100%			0.57	0.53	0.67	1.76			1.16	1.10	0.85	2.98			73%	0.91	40
Eucalyptus petiolaris [Ungarra]	98%	83%	47%	99%			0.69	0.67	0.79	1.59			1.48	1.63	1.37	2.40			83%	0.99	30
Eucalyptus polybractea [Collie P93-POL-01.03.A1]	95%	95%	51%	99%	80%	70%	0.48	0.62	0.31	1.17									87%	0.69	43
Eucalyptus porosa [Laura]	96%			99%			0.45			1.25			0.80			2.10			93%	0.86	32
Eucalyptus porosa [Yorke Peninsula]	94%						0.38						0.66						100%	0.53	54

FTWG Early Results (1 year old)	Survival						Average Height [m]						Max. Individual Height [m]						500mm Rain Equiv.#		
Provenance	SA Murray Bridge	SA Roseworthy	SA Lucindale	Vic Rutherglen	WA Coorow	WA Toolibin	SA Murray Bridge	SA Roseworthy	SA Lucindale	Vic Rutherglen	WA Coorow	WA Toolibin	SA Murray Bridge	SA Roseworthy	SA Lucindale	Vic Rutherglen	WA Coorow	WA Toolibin	Av. Survival	Av. Height	Rank
Eucalyptus rubida ssp. *rubida* [Boboyan Forest CS19628]	57%						0.48						0.73						80%	0.67	53
Eucalyptus rudis [Narrogin FPC-N201471A]	74%				93%	81%	0.39												100%	0.55	52
Eucalyptus socialis [Chapman Bore]	93%	71%	74%	98%			0.45	0.43	0.29	1.11			0.76	0.80	0.56	1.90			86%	0.61	55
Eucalyptus viminalis ssp. *cygnetensis* [Williamstown CS16025]	90%	97%	28%	100%			0.63	0.73	0.77	1.87			1.02	1.24	1.45	2.85			79%	1.04	31
Grevillea candelabroides [Geraldton NS-21542]					4%														6%		76
Gyrostemon ramulosus [Arrowsmith WA CALM]					20%														27%		71
Hakea oleifolia [Manjimup FPC-N200195A]					88%	57%													86%		20
Indigofera australis [Scott Creek]	74%			100%			0.45			1.13			0.89			1.84			94%	0.81	34
Jacksonia sternbergiana [Tambellup NS-21837]					78%	58%													87%		19
Lambertia inermis [Esperance NS-21341]						14%													17%		74
Melaleuca preissiana [Manjimup FPC-N16397]					97%	97%													100%		4
Melaleuca uncinata [Finnis]	88%	90%	31%				0.29	0.40					0.59	0.81					77%	0.45	68
Paraserianthes lophantha [Boddington NS-19267]					75%	78%													100%		8
Pittosporum phylliraeoides [Pingrup NS-25093]					44%	57%													66%		33
Senna pleurocarpa [Gutha RS]					59%	72%													85%		21
Taxandria juniperina [Marbelup SP7]					78%	74%													97%		10
Trymalium floribundum [Harvey NS-25093]					21%	10%													21%		72
Viminaria juncea [Harvey NS-25075]					75%	79%													100%		4
Viminaria juncea [Mt. Compass]	90%	91%	14%	100%			1.10	1.25	0.63	2.41			2.41	2.25	1.43	3.10			75%	1.46	14
Average Annual Rainfall [mm]	357	402	519	570	373	394	357	402	519	570	373	394	357	402	519	570	373	394	500	500	500

#Average survival and height based on linearly adjusted value by rainfall at each site to standardise values. Rank based on multiplication of average survival and height at 1 year old.

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