An Australian Government Initiative

Joint Venture Agroforestry Program

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Developing Species for Woody Biomass Crops in Lower Rainfall Southern Australia

FLORASEARCH 3A

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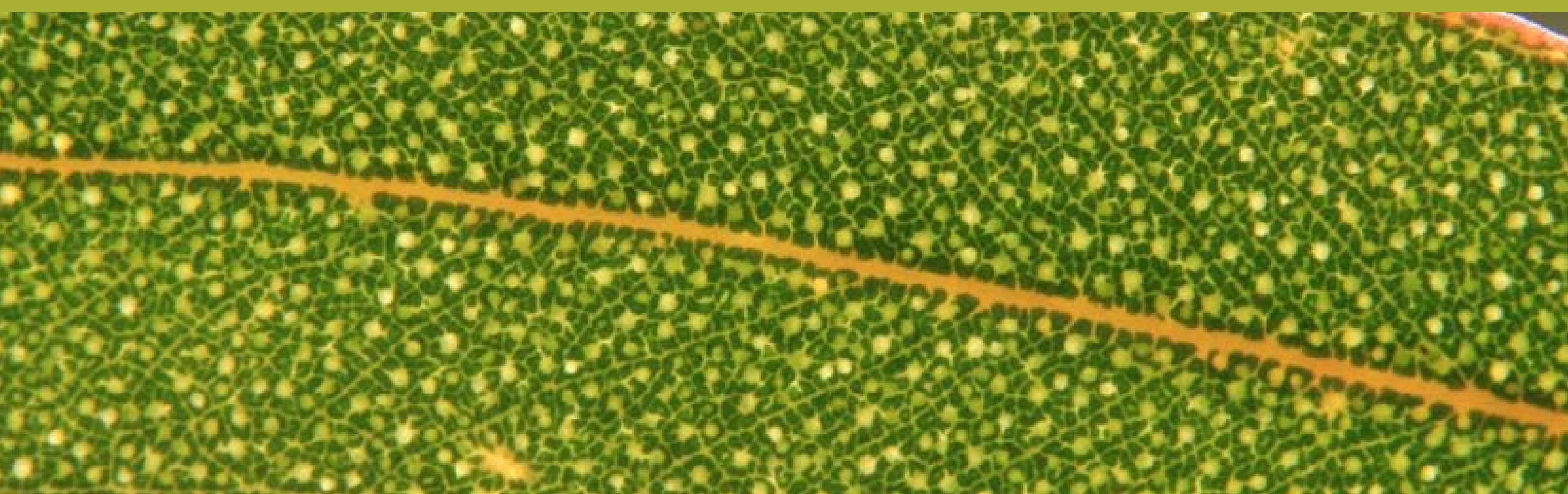

An Australian Government Initiative

Developing Species for Woody Biomass Crops in Lower Rainfall Southern Australia

FloraSearch 3a

by Trevor J. Hobbs, Michael Bennell and John Bartle (eds)

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Researcher Contact Details

Trevor J. Hobbs
SA Dept. of Water, Land & Biodiversity Conservation,
Waite Road, Urrbrae SA 5064
Phone: 08 8303 9766 Fax: 08 8303 9555
Email: hobbs.trevor@saugov.sa.gov.au

Michael Bennell
SA Dept. of Water, Land & Biodiversity Conservation,
Waite Road, Urrbrae SA 5064
Phone: 08 8303 9674 Fax: 08 8303 9555
Email: bennell.mike@saugov.sa.gov.au

John Bartle
WA Dept. of Environment and Conservation
Locked Bag 104 Bentley Delivery Centre WA 6983
Phone: 08 9334 0321 Fax: 08 9334 0367
Email: john.bartle@dec.wa.gov.au

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

RIRDC Contact Details

Rural Industries Research and Development Corporation
Level 2, 15 National Circuit
BARTON ACT 2600

PO Box 4776
KINGSTON ACT 2604

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

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Foreword

The removal of native vegetation and development of annual farming systems in the agricultural districts of southern Australia has had widespread environmental impacts including dryland salinity, salinisation of waterways and soil erosion. Restoration of deep-rooted perennial vegetation can make a significant contribution to correcting this problem but it needs to be on a large scale to control salinity. The recognition of carbon emissions as an important issue has added to the potential importance of perennial woody crops by offering opportunities for mitigation of emissions and adaptation to changing conditions. Woody perennial systems can accumulate and store significant quantities of carbon in both living plant biomass and soil profiles and provide offsets as an alternative feedstock for energy and transport fuel production. Consequently, the development of a mosaic of land uses including tree crops driven by large-scale industrial markets, agricultural systems utilising annual and perennial herbaceous crops, and biodiversity resources has an important role to play in Australian landscapes and sustainability of agricultural systems and rural communities.

FloraSearch, which was initiated in 2002, systematically advances our knowledge of the prospects for native plants in the development of commercially viable woody crops for southern Australia's agricultural regions. The project focuses on selecting and developing new woody crop species to supply feedstock for large-scale markets, including wood products, renewable energy, carbon sequestration and fodder. It investigates performance of these species in southern Australian farming regions and is developing new production systems to meet future industry requirements for biomass products. The project also evaluates the economic and spatial feasibility of these new crops and industries across southern Australia.

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 (LWA), and Forest and Wood Products Research and Development Corporation[1] (FWPRDC). **The Murray-Darling Basin Commission (MDBC) also contributed to this project**. The R&D Corporations are funded principally by the Australian Government. **State and Australian Governments contribute funds to the MDBC**.

Significant financial and in-kind contributions were also made by project partners in the Future Farm Industries Cooperative Research Centre: SA Department of Water, Land and Biodiversity Conservation; WA Department of Environment and Conservation; CSIRO Forest Biosciences; NSW Department of Primary Industries; and Department of Primary Industries Victoria.

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

Most of RIRDC's publications are available for viewing, downloading or purchasing online at www.rirdc.gov.au. Purchases can also be made by phoning 1300 634 313.

Peter O'Brien
Managing Director
Rural Industries Research and Development Corporation

[1] Now: Forest & Wood Products Australia (FWPA)

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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, Bruce Munday, Mike Ewing, Kevin Goss, Daniel Huxtable, Craig Neumann, David McKenna, Wayne O'Sullivan, Richard Mazanec, Brendan George, Malem McLeod, George Freischmidt, Alan Humpries, Daniel Real, Hayley Norman, Jason Emms, Steve Hughes, Dean Revell, Graeme Olsen, Don Cooper, Peter Georgaras, Des Stackpole, Isla Grundy, Olivia Kemp, Peter Jessop, Peter Grayling, Peter Butler, Andrew Fisher and Joe Landsberg. The high quality of field surveys, trial site management, databases, administrative support would not have been possible without the support of Merv Tucker, Gary Brennan, Julie Dean, Andrew and Trina Leah, Ligita Bligzna, and a cast of many casual and contract field assistants.

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Finally we recognise and thank the numerous farmers and landholders across southern Australia for their support and assistance in establishing new trial sites and access to private farm forestry plantings, woodlots and revegetation sites.

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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 broadscale commercial woody biomass crops in the lower rainfall regions of southern Australia. It provides detailed information on species performance through evaluations of several FloraSearch field trials that commenced in 2004, 2005 and 2006, and is further bolstered by data collated from other existing trials and new surveys. We also report on new research investigating several issues of woody crop agronomy and management practices and their influence on woody crop production.

Results from research on woody crop productivity, in combination with new market opportunities (e.g. CO_2 sequestration and bioenergy), has led to the emergence of new species for development and a revision of lists of high priority species for future development and domestication. In this report we highlight two species for domestication, Koojong Wattle (*Acacia saligna*) and Old Man Saltbush (*Atriplex nummularia*), and outline proposed breeding and plant improvement strategies towards their domestication as woody biomass crops. We also include preliminary evaluations of the performance in new plant improvement trials established in 2006.

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 for new woody crop industry selections 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 over-arching 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, improved resilience of agricultural systems in response to climatic variability, and forming the foundation of new, large-scale rural industries. The FloraSearch Stage 3 series of reports builds on earlier FloraSearch research that commenced in 2002 and identified a range of prospective species and industries suited to development as new woody crops. The current work provides a greater focus on species suited for further development and has refined methodologies that can be used to interrogate the feasibility of new woody crop industries at a range of scales. The research is supported by the Joint Venture Agroforestry Program and the Future Farm Industries Cooperative Research Centre and operates out of 2 key nodes based within SA and WA state government departments.

FloraSearch Stage 3 presents the findings of the latest phase of this research and is reported in 3 volumes:

- **FloraSearch 3a - Developing species for woody biomass crops** (this report, Hobbs *et al.* 2009a);
- **FloraSearch 3b - Domestication potential of high priority species (*Acacia saligna, Atriplex nummularia* and *Eucalyptus rudis*) for woody biomass crops** (Hobbs *et al.* 2009b); and
- **FloraSearch 3c - Regional industry potential for woody biomass crops** (Hobbs 2009b).

Aims/objectives

The aims of FloraSearch Stage 3 are to:

- Assess the agronomic suitability of development species for cultivation in the wheat/sheep belt including adaptability and productive potential;
- Evaluate species with merit for progression as commercial crops (development species) and initiate a process for the domestication and improvement of plant species with greatest potential (focus species); and
- Refine and adapt new industry evaluation methods, spatial analysis tools, and to conduct scoping feasibility studies for new large-scale industries based on products from woody perennial production systems.

The specific aim of research described here is the continued development of perennial plant 'building blocks' for woody crop systems of the future. A key objective is to start filling gaps in plant performance knowledge through field trials of prospective and targeted species, further data collection of growth attributes, and refinement of allometric and growth modelling of key species. This leads to a review of the focus species to provide a consensus on the continuing process of selection and development of woody germplasm on the national scale. Species selected for ongoing development are the subject of newly instigated plant improvement and breeding programs.

Methods used

This work is based on extensive analysis of FloraSearch field trials initiated in 2004, 2005 and 2006, several new agronomic investigations, enhanced field survey methodologies from new biometric and allometric studies, and field surveys of farmer woodlots and other trial sites. It is also a product extensive database collations, literature reviews, new analyses and consultations with numerous plant and farm forestry researchers, taxonomists and rural industry practitioners.

Regional research teams evaluated this data in order to make final selections of priority or focus species suitable on a regional basis, to be carried into ongoing development work and plant improvement. Koojong Wattle (*Acacia saligna*) and Old Man Saltbush (*Atriplex nummularia*) were selected as the first subjects for plant improvement through extensive germplasm collections, establishment of progeny trials and the development of plant improvement strategies.

Extensive germplasm collections and family progeny trials of Old Man Saltbush and Koojong Wattle, across different sites, will enable examination of the level of genetic variation among populations and its influence on productivity and other critical characteristics under a range of environmental conditions. These family progeny trials over 6 sites include 28 provenances, 528 families and 73,008 individuals of Old Man Saltbush and 20 provenances, 398 families and 28,008 individuals of Koojong Wattle. Preliminary data (1 year old) includes survival rates for these two species across a range of sites and morphological characteristics and edible biomass for Old Man Saltbush at two sites.

Results/key findings

Our research identifies several high priority species for future research, development and domestication as new woody biomass crops in lower rainfall regions of southern Australia. The highest priority species for domestication include Koojong Wattle (*Acacia saligna*), Old Man Saltbush (*Atriplex nummularia*) and Blue Mallee (*Eucalyptus polybractea*). Other strong candidates are Sugar Gum (*E. cladocalyx*), Flat-topped Yate (*E. occidentalis*), Flooded Gum (*E. rudis*), Mallee Box (*E. porosa*), Smooth-barked York Gum (*E. loxophleba* ssp. *lissophloia*) and Rough-barked Manna Gum (*E. viminalis* ssp. *cygnetensis*). These species, and several less well-known potential candidates, may gain further momentum from our current research and trials on provenance variations within this group of species. We have adopted a systematic approach to plant improvement for future woody biomass crop species which has already been initiated for Koojong Wattle and Old Man Saltbush. Many of the domestication candidates have strong potential to contribute to the future sustainability of dryland farming systems in Australia.

To provide new information on the suitability and growth of species targeted for the lower rainfall regions (<650mm mean annual rainfall), a wide range of germplasm has been gathered for a series of field trials across South Australia, Western Australia, New South Wales and Victoria. This work started with a broad range of species for planting in 2004 and 2005, and continued with more focussed selections of germplasm for provenance and some family evaluations planted in 2006. Sites across a range of soil types and climatic zones allow preliminary investigations of genotype by environment (GxE) interactions in growth and desired product traits of species.

New allometric models were developed which will enable more reliable and rapid assessments of primary productivity of plantations of low rainfall woody crops. Reliable assessments of standing biomass of known age plantations were used to determine annual productivity rates, with the most productive species selected for use in new biomass industries or carbon sequestration plantings. Regional predictions of biomass production using geographic information system technologies, observed species productivity rates, and regional productivity models, were integrated with other spatial data to determine the commercial viability of proposed industries.

More detailed species research and development on Old Man Saltbush (*Atriplex nummularia*), Koojong Wattle (*Acacia saligna*) and Flooded Gum (*Eucalyptus rudis*) has provided short reviews of the current knowledge base for each species (see FloraSearch 3b for more detailed work) and further data collection of growth attributes, refinement of allometric and growth modelling of key species, and development of plant improvement strategies.

Implications for relevant stakeholders

This research provides a solid base for development of several Australian species for woody crop production in the lower rainfall regions of southern Australia. It is work that is strongly supported by the Future Farm Industries Cooperative Research Centre, Joint Venture Agroforestry Program, several state government departments, farm forestry researchers and several industry groups. We are developing new research and development opportunities by engaging further support of research and development corporations and new industry partners in Australia. The successful development of these new crop species can greatly diversify and improve agricultural landuse in many parts of southern Australia.

Recommendations

Further investment in research is required to progress the development of these species and associated industries in Australia. Plant selection, trials, agronomic experimentation and breeding outcomes, will improve woody crop performance and profitability in agricultural lands. Several species have immediate potential for expansion, such as Old Man Saltbush (*Atriplex nummularia*) and Blue Mallee (*Eucalyptus polybractea*) due to existing or infant industries in Australia. Others require only minimal enhancement to suit expansions of existing wood fibre industries, or to service rapidly emerging industries such as CO_2 sequestration and bioenergy. Examples include Sugar Gum (*Eucalyptus cladocalyx),* Flat-top Yate (*E. occidentalis*) and Koojong Wattle (*Acacia saligna*).

Within the currently highlighted species, future work should strongly focus on more detailed studies of provenance and family variations in productivity and yields to enhance plant improvement processes, bring forth new candidates for domestication and develop superior planting stock for farmers. Our revision of high priority species and industries for development supports the need for further research and understanding of several additional species. The highest priorities current lie with Sugar Gum, Flat-top Yate and Blue Mallee and their use in bioenergy, integrated wood processing industries and carbon sequestration.

The potential of forage production from woody species has been highlighted during the FloraSearch project and strengthened through our spatial and economic evaluations of fodder shrub systems. Synergies with other research within the Future Farm Industries CRC and CSIRO Livestock Industries, have contributed to development of the Enrich project where these fodder shrub species and production systems are being explored further.

Further agronomic and crop management research is also required to optimise productivity rates and sustainability of the new crops. This should aim to improve plant production systems, water harvesting plantation designs, harvesting methods and production chains to meet emerging markets and underpin adoption of these new woody crops.

Spatial variation in landscape productivity of both existing annual crops and new woody crops must be evaluated so that regional and whole-of-farm profitability can be optimised for agricultural landscapes facing the challenges of variable climates, uncertain markets and evolving policy directions. Economic evaluation of new crop opportunities also requires reliable estimates of productivity (harvestable yield and carbon accumulation) and detailed spatial information on economic returns from existing enterprises.

We will need to explore and evaluate the potential and optimum spatial arrangement of a range of innovative woody crop systems suited to the dryland cereal cropping and livestock grazing regions of southern Australia in regard to climate change policies. The decision metrics will be economic analyses at the farm level for different rainfall zones, based on a rigorous scientific analysis of key factors and processes that influence the productive and carbon sequestration potential of our farming landscapes (e.g. climate, soils, water use and species selection). From this we can develop new farming systems that are most profitable and sustainable in the longer term.

The FloraSearch research team and its evolution within the Future Farm Industries Cooperative Research Centre, and beyond, will continue to develop the prospects of broadscale commercially-viable, adaptable and sustainable woody crop species and production systems that benefit a diverse array of Australian landscapes, industries, communities and our natural environment.

1. Introduction

Michael Bennell1,2, John Bartle2,3 and Trevor J. Hobbs1,2

[1] Department of Water, Land and Biodiversity Conservation, Urrbrae SA 5064
[2] Future Farm Industries Cooperative Research Centre, Crawley WA 6009
[3] Department of Environment and Conservation, Bentley WA 6983

Overview

The clearing of native vegetation systems for agricultural use has altered the natural hydrology, soils and ecology of many landscapes in southern Australia. These changes have led to the emergence of many natural resource management issues, including increased rates of landscape salinisation, reduced groundwater and stream quality, soil erosion, depleted environmental carbon stores and the loss of biodiversity. The targeted reestablishment of woody perennial plants in the 250-650mm winter dominated rainfall zone (Fig. 1) could help alleviate the scale of these detrimental effects (Bartle *et al.* 2007). To do this on the scale required, woody perennials must be economically viable and must either provide a commercial alternative to, or complement, current land uses (Bennell *et al.* 2008, Stirzaker *et al.* 2002). More recently the recognition of carbon emissions and the consequences of climate change have emerged as a critical world and national issue. This has led to great public interest in the emerging opportunity to re-establish woody perennial plants into our agricultural landscapes to both sequester carbon dioxide and adapt to a changing environment.

While natural resources management (NRM) benefits have been a public motivation for revegetation in all its forms, this benefit is often only realised in the long term. For private landowners, a rational analysis of the immediate NRM benefits of revegetation on landscape productivity and health will seldom support any significant investment in revegetation. To provide public, and longer-term, natural resource management benefits from revegetation requires public investments and support to develop of commercially viable woody crops that are both attractive to farmers and have a complementary role in agricultural systems and broader environmental services (Bartle 1991, Bartle and Shea 2002, Pannell 2008).

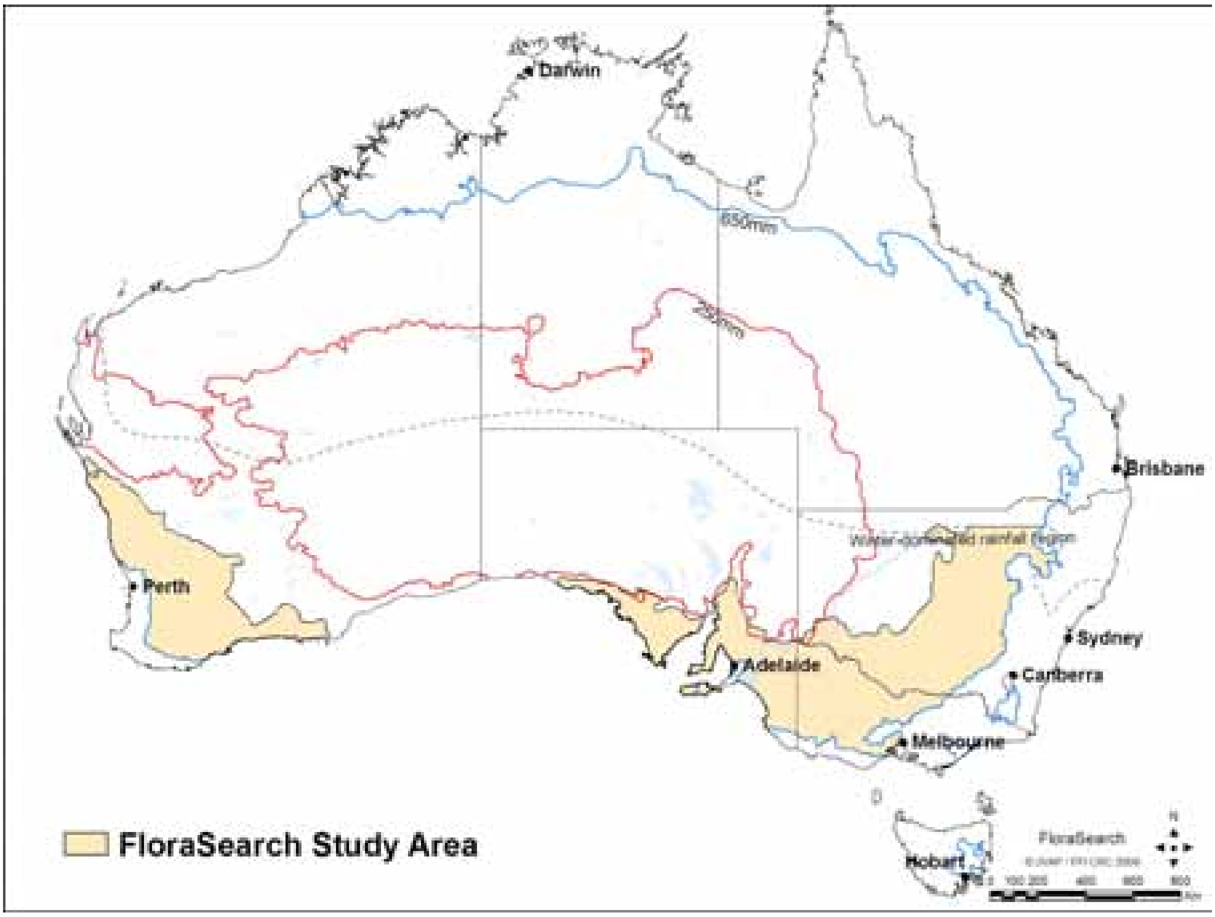
Commercial sawlog and pulpwood forestry in southern Australia is mainly limited to higher rainfall regions (650 - 1000mm mean annual rainfall). These industries are typically based on long-cycle rotations (>20 years) to grow large diameter logs which are transported to centralised processing facilities (Zorzetto and Chudleigh 1999). In medium to lower rainfall regions sawlog harvest cycles are even longer (Harwood *et al.* 2005) due to reduced water availability and slower growth rates. Recent rainfall trends and climate change predictions suggest that these long-cycle systems are likely to become progressively less viable in these regions.

To develop an alternative to long cycle species a significant investment has been made in developing short cycle native species as woody crop options in lower rainfall regions. Investigations into the use of oil-bearing mallee species for woody crops indicate significant potential for development of these new crops in the wheatbelt regions of Australia (Bartle and Shea 2002, Bartle *et al.* 2007). In the 1990's extensive research and development work on 'oil mallee' species commenced in Western Australia and was oriented towards the development of new industries based on commercial integrated wood processing systems yielding Eucalyptus oils, charcoal and bioenergy (Bartle and Shea 2002, Enecon 2001). An expanded focus of this work and diversification of potential industries led to the development of 'WA Search' (Olsen *et al.* 2004) and later the 'FloraSearch Stage 1' (Bennell *et al.* 2008) projects to systematically screen other Australian native flora for their potential as new woody crops. With the support of the Cooperative Research Centre (CRC) for Plant-based Management of Dryland Salinity and the Joint Venture Agroforestry Program (JVAP) these two project teams joined forces in 2004 under the banner of the 'FloraSearch Stage 2' project to further progress woody crop research and development across southern Australia. Building on the strengths and results of this alliance of researchers the work was further supported by the CRC (now Future Farm Industries CRC) and JVAP in 2006 as 'FloraSearch Stage 3'.

The FloraSearch project has made significant advances in developing novel crop options for the dryland agricultural region of southern Australia (Fig. 1). It integrates sciencific advances in the biology of native plant species with agriculture and economics to demonstrate that woody crops have potential within the wheat/sheep regions. It begins the process of generating confidence that the best available information on biomass production for a range products including carbon, bioenergy, extractives, fodder and wood products is available to landowners and businesses with aspirations in this area. New woody crop research and development, evolving out of FloraSearch ideas and information, will progress from within the Future Farm Industries Cooperative Research Centre and guide future woody biomass crop and industry development.

Fig. 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, winter-dominated rainfall areas, and the 650mm annual rainfall isohyet.



Background

Key drivers for the development of new woody crops

While the mitigation of dryland salinity using commercially-viable perrenial plants was the primary NRM driver for our early work on developing new woody crops, the issue of climate change has recently added extra impetus. Woody crops can sequester carbon and create long-lived carbon pools in the form of soil carbon and plant biomass, both above and below ground. Furthermore, harvested biomass is a renewable resource, suitable for use as an industrial or bioenergy feedstock, which in economies with emissions control, will not be subject to any carbon emissions penalty. The potential sale of sequestered carbon and the potential enhanced demand for emissions-free renewable feedstocks could provide an early extra revenue source for woody crops. This revenue accrues progressively improving the cash flow and profitability of woody crops. From the growers perspective carbon benefits might greatly exceed NRM benefits as a driver for adoption.

Hence woody production systems can yield multiple benefits for landowners including economic diversification from new products (harvested biomass, carbon sequestration) together with social and environmental outcomes. Adaptable woody species selected through the species survey described in Stage 1 and 2 of the FloraSearch project (Bennell *et al.* 2008, Hobbs and Bennell 2008, Hobbs 2008a, Hobbs *et al.* 2008c) provide robust and reliable crop options in landscapes with variable soils and climates. The integration of perennial plants into our farming systems provides productive opportunities to buffer seasonal and annual variations in rainfall that cannot be reliably utilised by annual crops alone. By increasing the mix of functional plant types in the productive landscape we can improve risk management and long-term economic sustainability. Landscape and farm-scale benefits include decreasing recharge and thus the threat of salinisation, reducing wind erosion, and providing shelter for stock. Reforestation is also a means of restoring catchment water quality, the protection of land from salinity and erosion, the enhancement of remnant biodiversity, and opportunities for rural development.

Farm forestry industries for lower rainfall regions

The competitiveness of conventional long cycle forestry is quite sharply confined by rainfall. There is potential to extend conventional forestry into lower rainfall regions, especially with some modification in site selection, species selection and planting design, but the long production cycle of these crops restricts their profitability to wetter areas peripheral to the main wheatbelt regions. In this region options based on species more tolerant of lower rainfall such as Sugar Gum are gaining some traction but scale is limited. Consequently, FloraSearch has focused on short production cycle woody crops that current economic analyses indicate could be viable across the wheatbelt. These would utilise new agroforestry systems and include short-cycle woody crops based on belts or blocks of coppice and phase crops. These crops will produce a large-scale commodity product having a low value per unit weight product and this has directed FloraSearch towards highly productive agroforestry systems and large-scale industrial approaches to product harvest and handling.

Engagement with industries that market wood based products and can utilise this new source of feedstock is an important part of the project. The potential markets and products can best be considered in 3 broad categories:

1. Existing larger scale markets that are largely commodity based, e.g. pulp and export wood chip that are well developed and have been operating for a significant period;
2. Existing smaller scale and ‘niche’ markets that are generally developed but operate on a smaller scale; and
3. Emerging markets that are still developing with supply and demand channels not well established (e.g. carbon sequestration and biofuels).

Forestry products are the largest user of woody feedstocks and early FloraSearch market evaluation considered this market to provide the most likely demand. Pulpwood production and composite board products have a huge demand for feedstock currently met from high rainfall forestry operations but opportunities exist to gain access to this market. Farm forestry could supplement existing supplies or provide resources to new mill developments.

Options have recently broadened in scope, with products related to climate change mitigation and adaptation becoming more significant particularly as a significant amount of research and development funding is being invested to bring new technology online.

The principles of producing heat, electricity and transport fuels from woody biomass are well known from early in the twentieth century and have returned to the forefront of industrial research as an alternative to fossil energy supply. Biomass as an alternative feedstock for energy and transport fuel production provides benefits in offsetting carbon release to the environment i.e. it is a renewable energy source and provides a positive multiplier of energy gained in the product over the energy that goes into producing it. Providing greater security for fuel supplies by reducing the dependence on offshore suppliers of raw materials is also considered to be strategically important, particularly in the USA. The availability of clean second-generation transport fuels is still constrained by the need to develop economically competitive industrial scale processes and this is the subject of huge investment, particularly in North America and Europe. It is forecast to be five to ten years before a large-scale industrial plant becomes available for diesel and ethanol production from woody biomass.

Strong entrepreneurial interest, stimulated by the growing commitment to reduced carbon emissions and restructuring of the energy sector, is emerging in large-scale processing of biomass from woody crops grown in the wheat/sheep agricultural regions of southern Australia. Carbon sequestration in farm-forestry based projects, and the substitution of fossil fuel emissions using biomass combustion provide a real and immediate opportunity to reduce net greenhouse gas emissions. Large scale planting of tree crops is already occurring in NSW where there is a legislative framework in place to support carbon cropping. Delivery contracts for carbon will have to be underpinned by solid science and auditable accounting procedures to ensure delivery. At this stage, the carbon sequestration potential of many species and woody crops productions systems are poorly understood. We need to identify the best species and options for dryland farming systems if they are to contribute to future carbon sequestration markets. Introduction of an Australian emissions trading scheme is likely in 2010, and is expected to allow carbon sequestration in trees and possibly agricultural soils, to be counted as an offset against fossil fuel emissions. Similarly, there will be a national renewable energy target of 20% by 2020 that will promote the adoption of alternative energy sources including those sourced from biomass. Recent factors in bioenergy development include: the successful conclusion of Verve Energy’s IWP (Integrated Wood Processing) demonstration in WA; investment by Willmott Forests in second-generation ethanol R&D in NSW and several developers looking in detail at the potential for exporting wood fuel pellets to Eurpoe and Japan.

Biosequestration thus forms a major component in both national and state climate change policies in reducing net greenhouse gas emissions. For landholders, carbon investment provides a very real prospect of financing revegetation to increase farm sustainability (Harper *et al.* 2007; Shea *et al.* 1998). Bioenergy from woody crop residues offer a direct means of reducing carbon dioxide levels and has been pursued in several projects including the Narrogin IWP plant (Enecon 2001) based on mallee residues.

The potential of forage production from woody species has been highlighted during the FloraSearch project. The potential of shrub based forage systems is gaining acceptance as a means of providing options that:

- Provide a feed base made up of a functional mixture of plant species including shrub options that are resilient to prolonged dry periods and provide feed in periods of seasonal shortfall;

- Integrate into a productive livestock enterprise based on current pasture options but are of a sufficient scale to have a positive impact on land management issues, and

- Provide the opportunity to include a plant in a mixed assemblage that provide compounds of medicinal value, or compounds that have favourable effects on gut health through manipulating the microflora and fauna of the digestive tract.

FloraSearch undertook a broad evaluation of native plants for forage value and outstanding species were included in evaluation trials as part of Stage 1 and 2. This work from FloraSearch and other overlapping research in the Future Farm Industries CRC and CSIRO Livestock Industries, this fodder shrub-based research had sufficient merit to win support for funding and development of a separate project (Enrich) where these fodder shrub species and production systems will be explored further. Enrich has the goal of introducing a greater degree of perennial-based feed production together with an increased diversity of plants available to grazing animals. Combining this with a broader approach in plant selection that includes indigenous plant species offers exciting prospects with the potential to provide feed and medicinal outcomes. Many of these potential forage species also have potential medicinal benefits for livestock with broad-spectrum antibacterial or anthelmintic activity.

Species evaluation and development

Earlier FloraSearch reports describe the intensive step-by-step process of screening the ~10,000 plant species in the flora of south eastern Australia by a desk audit of documented attributes, a follow up field campaign to collect field data and samples of several hundred selected species, testing for product suitability, and ultimate nomination of a list of development species with high potential for development. This process led to a decision at the conclusion of Stage 2 to undertake more detailed species development of south eastern and south western selections from the earlier Search Project including Old Man Saltbush (*Atriplex nummularia*), Koojong (*Acacia saligna*) and Flooded Gum (*Eucalyptus rudis*). Old Man Saltbush is a standout adaptable species with potential to supply forage as part of grazing systems in many locations across southern Australia including saline and non-saline environments, *Acacia saligna* is a highly productive and adaptable species with the potential to supply woody biomass and forage in WA only due to weed risk in eastern Australia; and *Eucalyptus rudis* is an adaptable productive species suited to WA conditions.

FloraSearch 3 has continued development of an efficient process to provide the perennial plant germplasm ‘building blocks’ for agroforestry systems of the future through field trials of targeted species, further data collection of growth attributes, refinement of allometric and growth modelling of key species, agronomic evaluations and continued evaluation of economic and market potentials. This culminated in a review of the Development and Focus species list and has provided a team consensus on the continuing process of selection and development of woody germplasm on the national scale. Additional species, including Sugar Gum (*Eucalyptus cladocalyx*), Flat-top Yate (*E. occidentalis*) and Blue Mallee (*E. polybractea*), will be the subjects of development in the future.

Woody crop production systems

Future research will provide improved plant production systems and in the future harvest methods to meet emerging markets. However, the question remains as to where to place these new systems in highly variable landscapes and how to optimise returns taking into account the land resource, existing land-uses and new crop options. Economic evaluation of new crop opportunities also requires reliable estimates of productivity (harvestable yield and carbon accumulation in plant biomass and soil profiles) and this will be related to regional and local variation in site conditions and more too – economic analysis needs to include all of the direct tangible costs and benefits discounted to present values over a long enough block of time to see whether large initial costs are exceeded by later revenues. This can be applied to alternative uses for the land in question such that the best option can be selected, thereby dealing with the issue of land opportunity cost. Abadi *et al.* 2005 (JVAP 05-181) developed a scenario analysis called Imagine (Don Cooper did the software) that does this well.

The challenge of optimising landowner returns whilst adopting new crop options is a fundamental issue. Through a better understanding of the optimal productive arrangement of annual and woody crops in a farming enterprise issues of competition with woody crop options can be avoided and reduce opportunity costs to existing landuses. It is crucial to compare economic returns of new systems with those from existing annual crops/pastures so that the most profitable option is applied at any point.

Mallees are being extensively planted into belts through cropping areas particularly in WA. An investigation of the economics of belts in crop systems (Cooper *et al.* 2005) showed that for the mallee crop to break even with conventional annual plant agriculture belt designs would need to efficiently exploit lateral flows of surface and shallow surface water to achieve sufficient yield. However, we must be vigilant of the delicate balance between annual crop leakage of water that benefits neighbouring woody crop belts and the potential reduction in annual crop performance in areas adjacent to belts and windbreaks (Jones and Sudmeyer, 2002; Bennell and Cleugh 2002; Cleugh 2003). Improvements in productivity are thought to be achievable following Salinity CRC research showing that mallees have high water use potential and display a strong yield response to extra water. Several workers have shown that considerable vertical (>10 m) and horizontal depletion (up to 20 m) of soil water in the root zone of mallee belts can occur on a wide range of soils (Harper *et al.* 2008; Sudmeyer and Goodreid 2007). Mallee belts appear to have the capacity to create a substantial sink for surplus water and, if water is available to recharge that sink, to respond with higher water use and greater yield. The water use attributes of mallee are likely to be shared to a substantial degree by other eucalypt tree crops. There appears to be considerable potential to manipulate water sources and sinks to capture extra water to achieve a 20% yield increase. Lateral flows of shallow subsurface water can be captured by belts or on the surface by grade banks and diverted to belts or small block plantings.

Economics and spatial analyses

In looking beyond solid wood products as a market outlet the investigation and development of markets has become a critical part of FloraSearch and related projects, and the need to analyse the scale and potential of existing and new industries that could utilise supply of feedstock from dryland production in the wheat/sheep belt is a key part of the project mix. The results of various approaches to market and business analysis by this and related projects are presented in this series of reports (Volume 3c).

Prior research and development – WA Search and FloraSearch Stage 1 and 2

Development of a mallee industry in WA was commenced by CALM in 1992 with the objective to create a new large-scale industry based on a tree crop that would be profitable for farmers as well as being a major part of their capability to control salinity (Bartle and Reeves 1992). The mallee development was the motivation and model for the Search Project. It demonstrated that novel 'short-cycle' crop types might be feasible. This work reached the conclusion that any new crop large enough to provide land management benefits will be locked into bulk production of a relatively low-value commodity, with efficiency of production, security of supply and achievement of quality standards being the most important determinants of market success.

This led to the Search project being undertaken with support of the National Heritage Trust in 1998 followed by the JVAP funded work in eastern Australia which commenced in 2002. FloraSearch Stage 1 (Bennell *et al.* 2008), which focused on eastern Australia, concluded in June 2004 having achieved its goals of:

- Selecting suitable target products such as pulp and paper, reconstituted fibreboard, bioenergy and fodder.

- Identifying and commencing the testing of species with the potential to be productive in short-cycle crop systems, and to supply these industries within the FloraSearch region.

- Developing a spatial analytical system suitable for regional analysis of current and potential industry based on these products and species.

The work being undertaken in eastern and western Australia was ultimately brought together under one project (FloraSearch Stage 2) supported by JVAP and the CRC - Plant Based Mangement of Dryland Salinity. This project provided an update and expansion of earlier FloraSearch work as the project evolved from an initial context and screening phase (Stage 1) to a more targeted and development phase (Stage 2).

This then led into FloraSearch Stage 2, which reported in mid 2006 (Hobbs *et al.* 2008c) having completed its goals of:

- A systematic survey of the native woody perennial flora of southern Australia's wheat-sheep zones, including selection and testing of species suitable for products identified in the FloraSearch stage 1 and WA Search project. This included establishment of a common database of attribute information of prospective native species for eastern and western nodes.

  Assessed the suitability of development species for cultivation and providing a short list of species with merit as commercial crops (development species) or; the subject of domestication in the next phase including plant improvement (focus species). This filtering and process is illustrated in Fig. 2. The current highest priority species (or "Focus Species") include the fodder shrub Old Man Saltbush (*Atriplex nummularia*) for southern Australia, and Koojong (*Acacia saligna*) for Western Australia. The next highest priority (or "Development Species") included: *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.*

- Further developing spatial analysis tools to consider opportunities at the regional scale for new large-scale industries based on products from woody perennial production systems. This work progressed, becoming a sophisticated tool able to support the systematic regional evaluation of perennial crop options. The analyses presented showed that many industries are profitable across vast regions of southern Australia.

- Establishment of field trials in WA, SA, Victoria and NSW to evaluate development species (a component of a collaborative CRC project).

It is the final stage (Stage 3) of this work being reported here and the report reflects major developments in project structure, emerging issues in dealing with climate variability and evolutions in some product areas. This report should be read in conjunction with the earlier FloraSearch Stage 1 and 2 project reports (Bennell *et al.* 2008, Hobbs and Bennell 2008, Hobbs 2008a, Hobbs *et al.* 2008c), WA Search (Olsen *et al.* 2005) and Acacia Search (Maslin and MacDonald 2004).

FloraSearch Stage 3 - Report Structure

The FloraSearch Stage 3 report is presented in 3 sections (described below) due to the overall length of the material and to allow separation by topic to assist in ease of access to information by the reader. There have been several authors who have contributed to this report often with a focus on a particular aspect of the research or a particular regional view. To reflect this contribution the report sections are provided as chapters with the principal contributors nominated as authors.

FloraSearch 3a - Developing Species for Woody Biomass Crops

This section describes the detailed evaluation and development of species identified in FloraSearch Stage 2. Data on the performance of development species from CRC evaluation trials, WA mallee plantings and other trials have been collated to provide up to date information on allometrics and productivities for key species. Species selected for ongoing development (focus species) have been the subject of comprehensive reviews and summaries of these reviews and the first stage result from plant improvement trials are reported.

FloraSearch 3b – Reviews of High Priority Species for Woody Biomass Crops

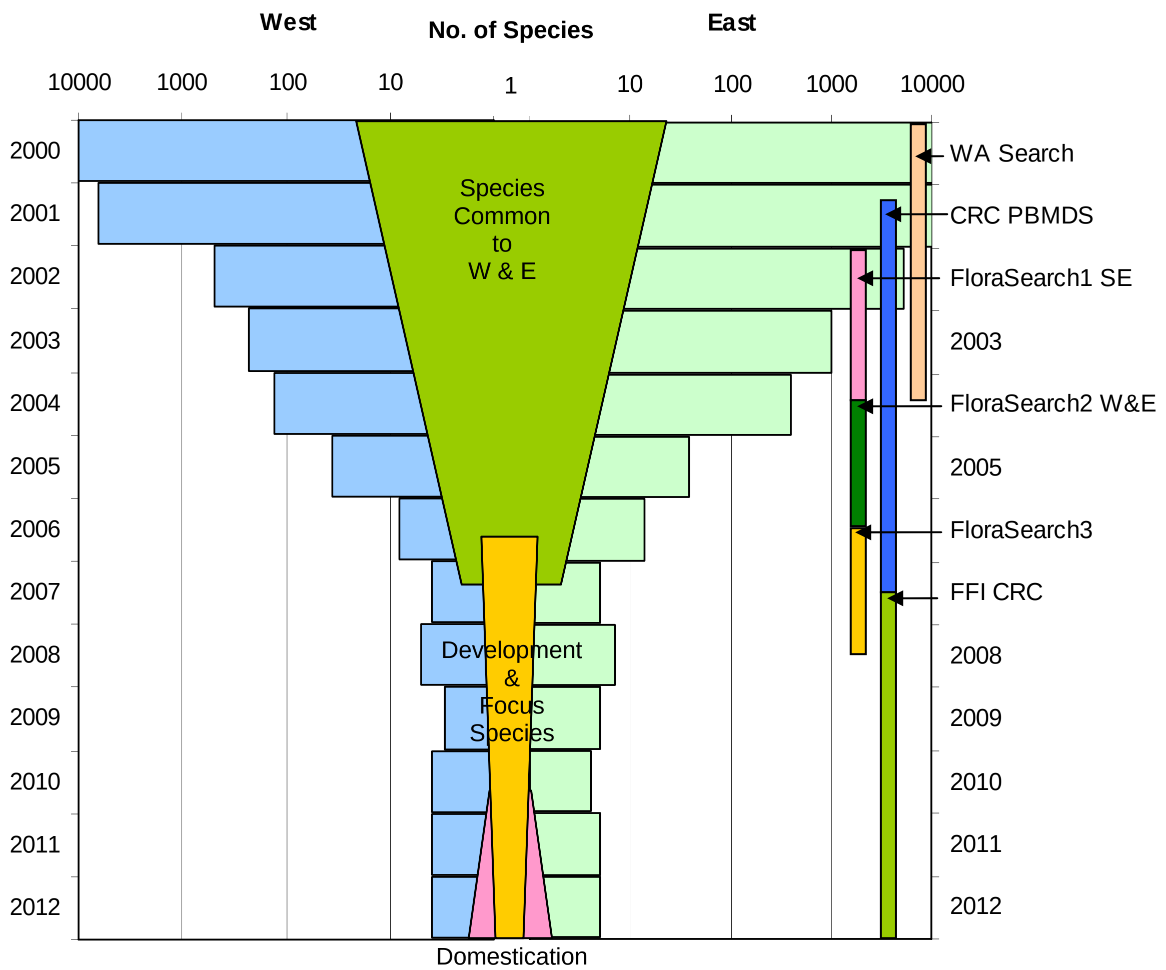
Key focus species, Koojong (*Acacia saligna*), Oldman Saltbush (*Atriplex nummularia*) and Flooded Gum (*Eucalyptus rudis*) have been identified for plant improvement and further development. These species have been the subject of comprehensive species and domestication review and are reported in the FloraSearch 3b report.

FloraSearch 3c - Regional Industry Potential for Woody Biomass Crops

This report concentrates on biomass industry development issues and approaches to help identify the spatial scale and economic potential of new woody biomass crops in the wheat-sheep zone of southern Australia.

Fig. 2. Results of an Australian native species identification, sifting and selection process to develop woody biomass crop germplasm for domestication in southern Australia by FloraSearch and WA Search projects in partnership with Cooperative Research Centres and the Joint Venture Agroforestry Program (FloraSearch 1, 2 & 3).

CRC=Cooperative Research Centre, PMBDS=Plant-based Management of Dryland Salinity, FFI=Future Farm Industries, SE=South Eastern Australia, W&E= western and eastern Australian nodes.



2. Species Performance and Agronomy

Trevor J. Hobbs[1,2], Craig Neumann[1,2], Daniel Huxtable[2,3], David J. McKenna[1,2], Brendan George[2,4] and John Bartle[2,3]

[1] Department of Water, Land and Biodiversity Conservation, Urrbrae SA 5064
[2] Future Farm Industries Cooperative Research Centre, Crawley WA 6009
[3] Department of Environment and Conservation, Bentley WA 6983
[4] Department of Primary Industries, Tamworth NSW 2340

Introduction

The Search (Olsen *et al.* 2004) and FloraSearch (Bennell *et al.* 2008) projects have identified several potential short-cycle woody crop industry types suited to the 250-650mm winter dominated rainfall zone of southern Australia. The FloraSearch and Search projects identified a number of Australian plant species that have potential for agroforestry development in lower rainfall regions through a detailed process of product testing, screening and bioclimatic modelling (Olsen *et al.* 2004, Bennell *et al.* 2008, Hobbs *et al.* 2008c). Within this array of species there are 4 functional groups of species that match each biomass industry class as identified in FloraSearch Stage 2 reports (Hobbs *et al.* 2008c). The four major *Biomass Industry* Groups of Species include; 1/ *Pulpwood Species*; 2/ *Bioenergy Species;* 3/ *Oil Mallee Species*; and 4/ *Fodder Species*.

Many of these species identified by our earlier WA Search and FloraSearch work (Olsen *et al.* 2004, Bennell *et al.* 2008, Hobbs *et al.* 2008c) have seldom been trialed or commercially grown within the targeted region and therefore very little information exists on their suitability or productive capacity in that region.

The lack of productivity and yield data has hindered early attempts to evaluate the potential of biomass industries in the medium to lower rainfall regions of southern Australia. In the 1990’s several trial sites were established as part of the *Australian Low Rainfall Tree Improvement Group* program for predominantly high rainfall sawlog species with a view of their expansion into lower rainfall areas (Harwood *et al.* 2005, Fairlamb and Bulman 1994; Rural Solution SA 2003). These sites contain a limited number of species and provenances with some poor experimental replication of plots on many sites. The publicly reported observations from this study have been limited to height performance data only. In the Australian Low Rainfall Tree Improvement Group program for developing sawlog species for agroforestry, Harwood *et al.* (2005) highlights that 'the development of regional plantation estates sufficient to supply local processing industries will be vital for the commercial success of low rainfall plantation forestry.' The use of suitable improved genetics with the potential to reliably provide high quality feedstock for large-scale local processing industries is vital in the successful establishment of both a regional plantation resource and the industries it will support.

For a limited number of prospective species, growth and survival data from existing trials, plantations, and revegetation sites has been analysed to identify germplasm worthy of further evaluation and permit the development of preliminary growth and productivity models for a range of biomass industries. Many of these species have not been subject to the trials of the Australian Low Rainfall Tree Improvement Group program or previously evaluated beyond survival, height and occasionally stemwood volumes. The work of the FloraSearch team aims to build from this limited prior knowledge by collating and re-evaluating existing information, and establishing new woody biomass crop trials to better understand yield from new species and planting systems.

Key areas of this work include:

- Developing allometric equations between simple measurements and plant biomass and fractions;
- Establishing trials of potential woody biomass crop species and evaluating their performance at a range of sites;
- Collating new and value adding to existing data on plantation productivity;
- Investigating influences of agronomy practices on plantation productivity; and
- Developing models to predict productivity rates in new locations.

We have conducted biometric and allometric studies in the lower rainfall regions of South Australia and Western Australia. These aim to provide reliable and robust methodologies to rapidly assess the primary productivity of low rainfall species using simple plant observations and allometric models, and to quantify production rates for a range of species grown on dryland sites in these regions. Further, existing measurements from other studies and new FloraSearch trials have been analysed and biometric relationships used to determine plantation productivity and yield of biomass components. Finally, for a selected range of species, spatial models of regional productivities and yields have been constructed so that we can evaluate the capability of native species to provide plantation feedstock to biomass industries or sequester carbon in the region.

Allometrics

Most existing assessments of plantation productivity are focussed on assessing height and stem diameters. These measures are suitable for estimating stemwood volumes for classical forestry where the focus is on the recoverable solid timber. For many biomass industries the focus is on the whole plant biomass and the relative proportions of stemwood, bark, twig and leaf fractions. Biomass industry productivity assessments require assessment methodologies that can be used to rapidly and reliably assess both total biomass and yield ratios of each biomass fraction.

Allometrics is a commonly used technique to non-destructively assay plantation productivity from a limited number of measurements (biometrics). In classical forestry industries these allometric models are often based on measurements of tree diameter at breast height or basal area calculations (± tree height) to determine stemwood volumes or biomass, with models often being species specific (Snowdon *et al.* 2000, 2002, Grierson 2000, Kiddle *et al.* 1987). However, allometric models based on high rainfall forestry trees are unlikely to be reliable predictors of productivity for the mallee and shrub lifeforms more suited to lower rainfall regions. New allometric models must be developed to non-destructively and efficiently assess plantations of low rainfall agroforestry species.

New robust and reliable allometric models can then be applied to the results of rapid assessment biometric methodologies to determine the primary productivity of plantations of low rainfall agroforestry species. Reliable assessments of standing biomass of known age plantations are used to determine annual productivity rates, with the most productive species selected for use in new biomass industries or carbon sequestration plantings. Regional predictions of biomass production using geographic information system technologies, observed species productivity rates and regional productivity models (Raupach *et al.* 2001) can then be integrated with spatial data on industrial infrastructure, production systems and economic models to determine the commercial viability of proposed industries in the region (Bennell *et al.* 2008, Ward and Trengove 2004, Hobbs *et al.* 2008c).

Plant biometrics and allometric relationships

South Australian trees, mallees and shrubs

Plants were sampled from dryland environments in the River Murray dryland corridor (RMDC; within 25km of the river; Hobbs and Bennell 2005) and Upper South East (USE; Hobbs *et al.* 2006) regions from forestry and revegetation sites of known age. The plant species were chosen to represent those species most highly ranked for agroforestry development for the regions (Hobbs *et al.* 2008c). The species selected included forestry tree species, small trees and mallees, and shrubs. A minimum of 3 individuals of each species and location were chosen for detailed biometric measurements of plant morphology and biomass sampling.

Individual plant measurements included height, crown width, distance to neighbouring plants, stem count and circumference at two lower section heights (basal and intermediate: 0.5m and 1.3m for trees and mallees; and 0.2m and 0.8m for shrubs), and visual ranking of leaf density using reference photographs (8 classes). The stemwood volume (outer bark) of each plant was calculated from stem height and circumferences using standard forestry formulas for tree volumes of each stemwood section (1. lower section – cylinder volume; 2. mid section - Smalian's frustrum of a paraboloid volume, and 3. upper section - paraboloid volume).

Samples of wood and bark were taken from each basal and intermediate height for each plant with an additional sample taken half way between the intermediate height and the top of the plant. The diameter of the wood (minus bark) and bark thicknesses were measured across the north-south axis of the sample, and used to determine the bark proportion of the outer bark stemwood volume. The green weight of the wood only and bark only samples were measured immediately. The green volume of the wood only samples was determined by displacement in water, and the separate wood and bark samples were oven dried to a steady dry-weight to determine wood basic density and the moisture content of each sample component.

The whole of each plant was destructively sampled and sorted into three biomass fractions:
1. stemwood and bark (>20mm diameter); 2. twig and bark (2-20mm diameter); and 3. leaf, fine twig and bark (<2mm diameter) and each fraction weighed immediately. Samples (>200g) from each green biomass fraction was weighed immediately, oven dried to a steady dry-weight and reweighed to determine their moisture content. The total dry biomass of each plant was determined from the green weight of each biomass fraction and the observed moisture content of oven-dried subsamples. Whole plant carbon contents were calculated from the sum of dry biomass fractions and the commonly accepted generic conversion factor of 0.5 (Snowdon *et al.* 2002).

Allometric relationships between simple measurements of height, crown area, basal stem area, leaf density, stemwood volumes and observations of total green biomass (including stemwood and bark; twig and bark; and leaf, fine twig and bark) were plotted, explored visually and tested using linear regressions. Interactions between these simple measurements and lifeform or plant genera groupings were also evaluated.

Biometrics

One hundred and one individual plants were measured and destructively sampled for the biometric studies. These represent 26 species (see Table 2) and include 2 generic species groupings (17 Eucalypts, 9 non-Eucalypts) and 3 lifeform types (10 tree, 10 mallee, 7 shrub forms). Important agroforestry species were sampled more than once (e.g. Sugargum *Eucalyptus cladocalyx*, Swamp Yate *Eucalyptus occidentalis*, Mallee Box *Eucalyptus porosa*, Old Man Saltbush *Atriplex nummularia*) from different ages and plantations designs (e.g. blocks and windbreaks). The age of plantations sampled for this study ranged from 3 year old fodder shrubs to a maximum of 13.5 years for one tree species (overall average 9.6 years Table 2 and Table 3 provide summaries of a number of key plant characteristics for species destructively sampled in the biometric studies. Relationships between green biomass, dry biomass and carbon content are presented in Table 4. The average proportion of dry biomass to green biomass by weight (incorporating different moisture contents of each fraction) for all species ranges between 0.386 for Old Man Saltbush *Atriplex nummularia* fodder shrubs and 0.66 for the mallee *Eucalyptus calycogona* (mean=0.55). The carbon content expressed as a proportion of green biomass by weight ranges between 0.19 for Old Man Saltbush and 0.33 for Golden Wattle *Acacia pycnatha* (mean=0.28).

Individual plant morphological measurements were converted into a range of biometric parameters commonly used to predict above ground plant biomass (see Table 5). These include plant height, basal stem area (outer bark), crown area (from crown widths), stemwood volume (outer bark; from plant height and 2 stemwood area observations), and foliage density. Foliage density classes were expressed as a percent of maximum density (i.e. very dense 100%, dense 86%, moderately dense 71%, moderate 57%, moderately sparse 43%, sparse 29%, very sparse 14%, no leaves 0%)

Allometric Relationships

Allometric relationships between these morphological parameters and individual plant green biomass were explored. Separate analyses were conducted for total green biomass and green biomass fractions: 1. wood (>20mm diameter) and bark; 2. twig (2-20mm diameter) and bark; and 3/ leaf, fine twig (<2mm diameter) and bark. The biomass from fractions 1 and 2 were combined to create a fourth class (i.e. wood and bark + twig and bark) and tested against the morphological parameters. Preliminary plots and results illustrate a linear relationship between many parameters (and their interactions) and green biomass values (Fig. 3). Simple linear relationships between stemwood volume and total above ground green biomass for different lifeform by species group are represented by the SIMPLE formulas presented in Table 1.

Table 1. Simple linear relationships between stemwood volume and total above ground green biomass for different lifeform by species group.

Species and Lifeform Group	**Total Green Biomass Formula [kg/plant]**
All Species (Unsorted) (r^2 = 0.83; n=101)	**= 1.64 x (Stemwood Volume x 1000 [m^3])**
Tree (Eucalypt) (r^2 = 0.93; n=27)	= 1.42 x (Stemwood Volume x 1000 [m^3])
Tree (Non-Eucalypt) (r^2 = 0.93; n=12)	= 1.86 x (Stemwood Volume x 1000 [m^3])
Mallee (Eucalypt) (r^2 = 0.73; n=36)	= 2.64 x (Stemwood Volume x 1000 [m^3])
Shrub (Non-Eucalypt) **(r^2 = 0.59; n=26)**	= 2.43 x (Stemwood Volume x 1000 [m^3])

Due to non-normal distributions of data the biometric parameters and biomass values were transformed using natural logarithms prior to testing the strength of allometric relationships (see Hobbs *et al.* 2006). Green biomass and biomass fraction model equations take the form:

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

where y = green biomass [kg/plant], x = predictor morphological variables, a = predictor factor and c = intercept of the linear regression (see Table 7).

Table 2. Plant species measured and destructively sampled for biometric studies, including some key plant characteristics (mean values, n=3).

Species (plantation type)	Rainfall [mm]	Age [years]	Height [m]	Crown Width [m]	Lifeform [Tree/Mallee/Shrub]	Foliage Density [%]	Total Green Biomass [kg/plant]	Proportion Green Biomass by Weight		
								Wood & Bark	Twig & Bark	Leaf, Fine Twig & Bark
Acacia ligulata (block)	247	8.5	1.80	2.97	S	81	26.30	0.09	0.60	0.31
Acacia mearnsii (block)	492	12.5	9.9	3.3	T	57	128.2	0.79	0.12	0.09
Acacia oswaldii (block 1, n=2)	253	8.5	1.35	1.72	S	57	7.55	0.10	0.57	0.32
Acacia oswaldii (block 2)	340	12.5	2.03	2.90	S	95	44.54	0.19	0.41	0.40
Acacia pycnantha (block 1)	340	13.5	4.10	3.80	T	43	50.73	0.55	0.28	0.17
Acacia pycnantha (block 2)	387	7.0	3.4	3.2	S	86	68.0	0.37	0.22	0.41
Acacia rigens (block)	340	12.5	2.60	2.13	S	100	42.07	0.27	0.35	0.38
Allocasuarina verticillata (block 1)	340	12.5	5.67	3.27	T	43	80.32	0.64	0.19	0.17
Allocasuarina verticillata (block 2)	492	10.9	9.6	4.9	T	38	344.6	0.81	0.07	0.12
Atriplex nummularia (block 1)	251	7.5	1.90	3.20	S	81	28.69	0.14	0.55	0.31
Atriplex nummularia (block 2)	466	3.0	1.8	2.5	S	86	19.7	0.30	0.31	0.40
Callitris gracilis (block)	253	8.5	2.13	1.37	S	76	4.42	0.14	0.41	0.45
Corymbia maculata (block)	492	10.8	8.0	3.2	T	52	50.9	0.74	0.12	0.14
Eucalyptus calycogona (block)	261	8.5	2.70	2.53	M	57	26.01	0.29	0.25	0.46
Eucalyptus camaldulensis (windbreak)	460	10.7	11.2	4.9	T	57	232.6	0.79	0.09	0.12
Eucalyptus cladocalyx (block)	460	6.7	7.1	2.7	T	71	59.9	0.58	0.21	0.22
Eucalyptus cladocalyx (windbreak)	460	6.7	5.8	2.4	T	86	67.0	0.60	0.17	0.24
Eucalyptus cyanophylla (block)	261	9.5	2.88	2.53	M	62	35.32	0.29	0.26	0.45
Eucalyptus diversifolia (mixed block)	460	12.7	5.5	4.3	M	66	175.5	0.41	0.39	0.20
Eucalyptus dumosa (block)	387	12.0	3.3	2.7	M	62	35.8	0.43	0.32	0.25
Eucal*yptus globulus* (block)	460	10.7	13.8	3.5	T	57	194.9	0.75	0.09	0.16
Eucalyptus gracilis (block)	261	6.6	1.77	1.97	M	91	10.65	0.06	0.35	0.59
Eucalyptus incrassata (mixed block)	460	12.7	3.6	4.3	M	71	92.2	0.40	0.31	0.29
Eucalyptus largiflorens (windbreak)	261	10.5	3.77	2.57	T	52	32.57	0.54	0.22	0.24
Eucalyptus leucoxylon (block)	492	10.7	9.7	2.9	T	43	81.4	0.81	0.08	0.12
Eucalyptus occidentalis (block)	460	5.7	10.0	3.3	T	57	137.1	0.74	0.09	0.17
Eucalyptus occidentalis (windbreak)	460	6.7	8.6	2.3	T	57	78.9	0.67	0.12	0.21
Eucalyptus oleosa (block)	261	10.4	2.93	3.53	M	76	40.35	0.32	0.28	0.40
Eucalyptus porosa (block 1)	261	9.5	2.37	3.13	M	76	21.29	0.23	0.39	0.38
Eucalyptus porosa (block 2)	340	12.4	5.33	4.40	M	71	98.43	0.54	0.18	0.28
Eucalyptus porosa (block 3)	387	6.7	3.9	3.8	M	71	50.3	0.34	0.23	0.43
Eucalyptus socialis (block)	261	10.5	3.30	4.50	M	71	80.40	0.33	0.30	0.37
Eucalyptus viminalis (block)	460	5.7	11.1	3.9	T	52	177.4	0.74	0.08	0.18
Melaleuca uncinata (block)	340	12.4	1.83	1.70	S	100	17.63	0.12	0.44	0.44

Table 3. Mean wood properties, bark proportions and moisture contents of biomass fractions for plant species sampled for biometrics study.

Species (plantation type)	Basic Density [kg/m^3]	Proportion Bark to Stemwood		Proportion Moisture by Weight			
		By Volume	By Weight	Wood & Bark	Wood Only	Twig & Bark	Leaf, Fine Twig & Bark
	(n=9)#	(n=9)	(n=9)	(n=9)	(n=9)	(n=3)	(n=3)
Acacia ligulata (block)	840	0.33	0.32	0.36	0.35	0.32	0.55
Acacia mearnsii (block)	650	0.15	0.18	0.39	0.38	0.47	0.54
Acacia oswaldii (block 1; n=2)	869	0.26	0.23	0.35	0.31	0.36	0.46
Acacia oswaldii (block 2)	859	0.17	0.19	0.33	0.32	0.32	0.55
Acacia pycnantha (block 2)	675	0.21	0.23	0.38	0.36	0.47	0.57
Acacia pycnantha (block)	785	0.20	0.21	0.30	0.27	0.39	0.41
Acacia rigens (block)	776	0.21	0.23	0.37	0.37	0.37	0.49
Allocasuarina verticillata (block 1)	723	0.24	0.25	0.36	0.36	0.43	0.51
Allocas*uarina verticillata* (block 2)	724	0.20	0.20	0.39	0.38	0.45	0.54
Atriplex nummularia (block 1)	793	0.09	0.05	0.32	0.32	0.28	0.64
Atriplex nummularia (block 2)	626	0.00		0.49	0.49	0.53	0.76
Callitris gracilis (block)	619	0.23	0.24	0.46	0.44	0.44	0.38
Corymbia maculata (block)	601	0.44	0.42	0.54	0.46	0.50	0.47
Eucalyptus calycogona (block)	775	0.21	0.23	0.31	0.30	0.33	0.37
Eucalyptus camaldulensis (windbreak)	483	0.26	0.24	0.60	0.60	0.57	0.58
Eucalyptus cladocalyx (block)	634	0.30	0.30	0.49	0.46	0.47	0.46
Eucalyptus cladocalyx (windbreak)	600	0.27	0.26	0.52	0.47	0.47	0.46
Eucalyptus cyanophylla (block)	787	0.37	0.33	0.34	0.34	0.37	0.37
Eucalyptus diversifolia (mixed block)	581	0.15	0.16	0.49	0.49	0.46	0.48
Eucalyptus dumosa (block)	767	0.24	0.25	0.36	0.35	0.40	0.49
Eucalyptus globulus (block)	530	0.16	0.14	0.54	0.53	0.53	0.50
Eucalyptus gracilis (block)	830	0.24	0.26	0.34	0.31	0.39	0.43
Eucalyptus incrassata (mixed block)	726	0.27	0.27	0.40	0.39	0.48	0.47
Eucalyptus largiflorens (windbreak)	687	0.30	0.28	0.37	0.36	0.40	0.46
Eucalyptus leucoxylon (block)	657	0.33	0.33	0.46	0.43	0.49	0.47
Eucalyptus occidentalis (block)	538	0.16	0.13	0.51	0.50	0.50	0.51
Eucalyptus occidentalis (windbreak)	604	0.16	0.14	0.48	0.48	0.50	0.48
Eucalyptus oleosa (block)	793	0.28	0.27	0.35	0.33	0.40	0.38
Eucalyptus porosa (block 1)	668	0.27	0.26	0.40	0.39	0.44	0.48
Eucalyptus porosa (block 2)	663	0.26	0.22	0.41	0.41	0.43	0.49
Eucalyptus porosa (block 3)	577	0.20	0.21	0.48	0.48	0.48	0.58
Eucalyptus socialis (block)	757	0.27	0.26	0.33	0.32	0.37	0.37
Eucalyptus viminalis (block)	487	0.25	0.21	0.59	0.57	0.53	0.49
Melaleuca uncinata (block)	711	0.19	0.21	0.37	0.38	0.36	0.42

number of samples per species and location.

Table 4. Relationships between total green biomass, dry biomass and carbon content of plant species measured and destructively sampled for biometrics study (mean values, n=3).

Species (plantation type)	Total Green Biomass [kg/plant]	Dry Biomass [kg/plant]				Proportion Dry Biomass to Green Biomass by Weight	Proportion Carbon to Green Biomass by Weight
		Wood & Bark	Twig & Bark	Leaf, Fine Twig & Bark	Total		
Acacia ligulata (block)	26.30	1.47	10.67	3.74	15.89	0.604	0.302
Acacia mearnsii (block)	128.2	60.0	8.3	5.2	73.5	0.573	0.287
Acacia oswaldii (block 1, n=2)	7.55	0.50	2.79	1.33	4.62	0.612	0.306
Acacia oswaldii (block 2)	44.54	5.78	12.35	7.90	26.02	0.584	0.292
Acacia pycnantha (block 1)	50.73	19.69	8.54	5.14	33.38	0.658	0.329
Acacia pycnantha (block 2)	68.0	15.3	7.9	12.0	35.2	0.517	0.259
Acacia rigens (block)	42.07	7.17	9.19	8.20	24.56	0.584	0.292
Allocasuarina verticillata (block 2)	344.6	169.3	13.6	19.3	202.3	0.587	0.293
Allocasuarina verticillata (block)	80.32	32.98	8.66	6.63	48.27	0.601	0.300
Atriplex nummularia (block 1)	28.69	2.75	11.38	3.16	17.29	0.603	0.301
Atriplex nummularia (block 2)	19.7	2.9	2.8	1.9	7.6	0.386	0.193
Callitris gracilis (block)	4.42	0.34	1.00	1.25	2.59	0.585	0.293
Corymbia maculata (block)	50.9	16.8	3.1	3.9	23.8	0.468	0.234
Eucalyptus calycogona (block)	26.01	5.20	4.41	7.51	17.11	0.658	0.329
Eucalyptus camaldulensis (windbreak)	232.6	71.7	9.3	11.3	92.3	0.397	0.198
Eucalyptus cladocalyx (block)	59.9	17.4	6.5	7.1	31.0	0.517	0.259
Eucalyptus cladocalyx (windbreak)	67.0	19.1	5.9	8.7	33.6	0.502	0.251
Eucalyptus cyanophylla (block)	35.32	6.60	5.91	9.99	22.51	0.637	0.319
Eucalyptus diversifolia (mixed block)	175.5	35.8	37.5	18.4	91.7	0.522	0.261
Eucalyptus dumosa (block)	35.8	9.6	6.8	4.0	20.4	0.569	0.284
Eucalyptus globulus (block)	194.9	66.8	8.2	15.8	90.8	0.466	0.233
Eucalyptus gracilis (block)	10.65	0.44	2.24	3.58	6.26	0.588	0.294
Eucalyptus incrassata (mixed block)	92.2	21.7	14.9	14.3	50.9	0.552	0.276
Eucalyptus largiflorens (windbreak)	32.57	11.03	4.31	4.32	19.66	0.603	0.302
Eucalyptus leucoxylon (block)	81.4	34.6	3.1	5.0	42.7	0.525	0.262
Eucalyptus *occidentalis* (block)	137.1	50.2	6.2	11.7	68.1	0.497	0.248
Eucalyptus occidentalis (windbreak)	78.9	26.7	4.7	8.4	39.8	0.505	0.252
Eucalyptus oleosa (block)	40.35	8.41	6.83	9.91	25.15	0.623	0.312
Eucalyptus porosa (block 1)	21.29	3.01	4.67	4.16	11.83	0.556	0.278
Eucalyptus porosa (block 2)	98.43	31.24	10.14	14.17	55.55	0.564	0.282
Eucalyptus porosa (block 3)	50.3	8.6	6.1	8.6	23.3	0.464	0.232
Eucalyptus socialis (block)	80.40	17.77	15.15	18.61	51.53	0.641	0.320
Eucalyptus viminalis (block)	177.4	52.9	6.9	15.6	75.4	0.425	0.212
Melaleuca uncinata (block)	17.63	1.38	4.97	4.47	10.81	0.613	0.307

Table 5. Summary of key plant attributes tested for developing allometric models of total green biomass and biomass fractions (mean values, n=3).

Species (plantation type)	Height [m]	Basal Area [cm²] at 0.5m height	Crown Area [m²]	Foliage Density [%]	Stemwood Volume x 1000 [m³]	Green Biomass [kg/plant] Total	Wood & Bark	Twig & Bark	*Wood & Bark + Twig & Bark*	Leaf, Fine Twig & Bark
Acacia ligulata (block)	1.8	63[#2]	6.9	81	14.1	26.3	2.3	15.7	18.0	8.3
Acacia mearnsii (block)	9.9	180	9.7	57	82.4	128.2	99.9	15.6	115.5	11.5
Acacia oswaldii (block 1; n=2)	1.4	22[#1]	2.6	57	2.1	7.6	0.8	4.3	5.1	2.4
Acacia oswaldii (block 2)	2.0	133[#2]	6.6	95	23.4	44.5	8.6	18.3	26.9	17.6
Acacia pycnantha (block 1)	4.1	68	11.5	43	16.2	50.7	28.0	14.0	42.0	8.7
Acacia pycnantha (block 2)	3.4	97	8.3	86	14.5	68.0	24.7	15.0	39.7	27.8
Acacia rigens (block)	2.6	92	3.7	100	17.3	42.1	11.3	14.6	25.9	16.2
Allocasuarina verticillata (block 1)	5.7	184	8.4	43	54.8	80.3	51.5	15.2	66.7	13.7
Allocasuarina verticillata (block 2)	9.6	484	19.1	38	173.9	344.6	275.8	24.7	300.5	41.8
Atriplex nummularia (block 2)	1.8	68[#2]	4.8	86	6.3	19.7	5.7	6.1	11.7	7.8
Atriplex nummularia (block)	1.9	133[#1]	8.2	81	12.7	28.7	4.1	15.8	19.9	8.8
Callitris gracilis (block)	2.1	17[#2]	1.5	76	3.1	4.4	0.6	1.8	2.4	2.0
Cor*ymbia maculata* (block)	8.0	114	7.8	52	32.0	50.9	36.7	6.2	42.9	7.2
Eucalyptus calycogona (block)	2.7	76[#2]	5.1	57	8.9	26.0	7.6	6.6	14.1	11.9
Eucalyptus camaldulensis (windbreak)	11.2	450	19.1	57	172.4	232.6	181.7	21.4	203.1	26.9
Eucalyptus cladocalyx (block)	7.1	119	5.7	71	30.2	59.9	33.4	12.3	45.7	13.1
Eucalyptus cladocalyx (windbreak)	5.8	142	4.5	86	28.5	67.0	39.4	11.1	50.4	15.9
Eucalyptus cyanophylla (block)	2.9	62	5.2	62	9.8	35.3	10.1	9.3	19.4	15.9
Eucalyptus diversifolia (mixed block)	5.5	209	15.6	66	51.6	175.5	70.5	69.0	139.5	35.2
Eucalyptus dumosa (block)	3.3	63	6.5	62	7.8	35.8	14.9	11.6	26.5	8.8
Eucalyptus globulus (block)	13.8	224	10.1	57	126.1	194.9	144.4	17.3	161.7	31.8
Eucalyptus gracilis (block)	1.8	31[#1]	3.0	91	2.5	10.7	0.7	3.7	4.4	6.3
Eucalyptus incrassata (mixed block)	3.6	132	14.8	71	19.0	92.2	36.2	28.5	64.7	26.9
Eucalyptus largiflorens (windbreak)	3.8	95	5.4	52	19.8	32.6	17.5	7.2	24.6	7.9
Eucalyptus leucoxylon (block)	9.7	172	6.6	43	61.1	81.4	64.9	6.1	71.0	9.5
Eucalyptus occidentalis (block)	10.0	238	8.7	57	95.9	137.1	101.3	11.9	113.2	23.2
Eucalyptus occidentalis (windbreak)	8.6	134	4.5	57	49.7	78.9	51.5	9.4	60.8	16.9
Eucalyptus oleosa (block)	2.9	86	9.9	76	14.1	40.4	12.9	11.3	24.3	16.1
Eucalyptus porosa (block 1)	2.4	68	7.8	76	7.4	21.3	5.0	8.3	13.3	8.0
Eucalyptus porosa (block 2)	5.3	218	17.9	71	57.6	98.4	52.7	17.8	70.5	27.9
Eucalyptus porosa (block 3)	3.9	93	11.7	71	11.6	50.3	16.7	11.7	28.4	21.5
Eucalyptus socialis (block)	3.3	137	16.0	71	25.8	80.4	26.6	24.1	50.7	29.7
Eucalyptus viminalis (block)	11.1	313	12.6	52	129.9	177.4	129.3	14.8	144.1	31.7
Melaleuca uncinata (block)	1.8	73[#1]	2.3	100	10.9	17.6	2.2	7.7	9.9	7.7

[1] basal area at 0.1m height, [2] 0.2m

Table 7 contains a summary of analyses using stemwood volume measurements to predict total biomass and biomass fractions. The interaction of species groups and lifeform classes on biomass predictions from morphological measurements are often significant (see Hobbs *et al.* 2006 for details). The resulting generalised model (r^2=0.86) of total green biomass (kg/plant) from stemwood volume (outer bark) measurements (with no species group or lifeform interactions) is presented in Table 6. However, by including 4 lifeforms by species group classes (1/ Tree Eucalypt, 2/ Tree Non-Eucalypt, 3/ Mallee Eucalypt, 4/ Shrub Non-Eucalypt) as model interactions stronger predictions can be made (r^2=0.90) of total green biomass (kg/plant) from stemwood volume (outer bark) calculations (see Table 6).

Table 6. Normalised relationships between stemwood volume and total above ground green biomass for different lifeform by species group.

Species and Lifeform Group	Total Green Biomass Formula [kg/plant]
All Species (Unsorted) **(r^2 = 0.86; n=101)**	$\mathbf{= e^{0.8460 \times \ln((\text{Stemwood Volume} \times 1000\ [m^3]) + 1) - 1.2475} - 1}$
Tree (Eucalypt) (**r^2 = 0.94**; n=27)	$= e^{0.8276 \times \ln((\text{Stemwood Volume} \times 1000\ [m^3]) + 1) + 1.1711} - 1$
Tree (Non-Eucalypt) (**r^2 = 0.97**; n=12)	$= e^{1.1120 \times \ln((\text{Stemwood Volume} \times 1000\ [m^3]) + 1)} - 1$
Mallee (Eucalypt) (**r^2 = 0.83**; n=36)	$= e^{0.8704 \times \ln((\text{Stemwood Volume} \times 1000\ [m^3]) + 1) + 1.4332} - 1$
Shrub (Non-Eucalypt) (**r^2 = 0.79**; n=26)	$= e^{1.3086 \times \ln((\text{Stemwood Volume} \times 1000\ [m^3]) + 1)} - 1$

Fig. 3. Linear relationships between plant stemwood volume measurements and above ground green biomass for trees, mallees and shrubs.

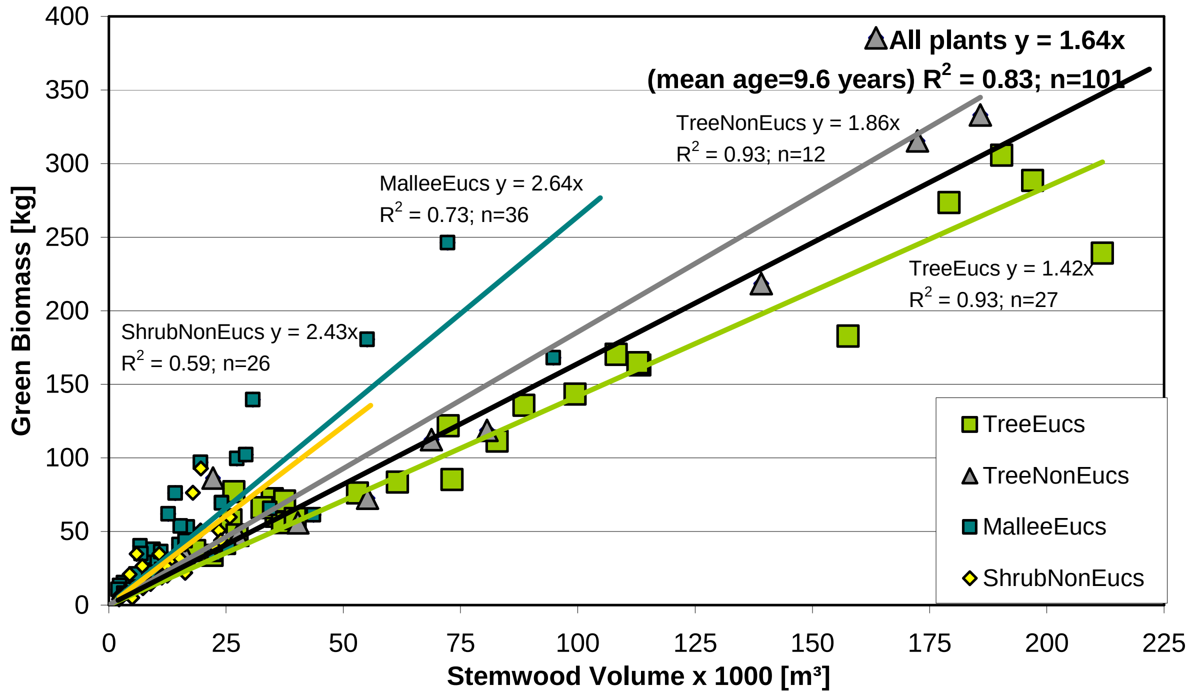


Table 7. South Australian tree, mallee and shrub biometric studies selection of highly ranked normalised allometric models to predict the above ground green biomass (kg/plant) from plant morphological measurements and lifeform/species observations.

Variable (*y*)	Predictor (*x*)	n	r^2	Allometric Model Parameters#	
				Factor (*a*)	Intercept (*c*)
Total Green Biomass	**Stemwood Volume x 1000 [m³]**	101	0.86	0.8460	1.2475
	By Lifeform Group	101	0.90	-	-
	Tree (Eucalypt)	27	0.94	0.8276	1.1711
	Tree (Non-Eucalypt)	9	0.97	1.1120	ns
	Mallee (Eucalypt)	36	0.83	0.8704	1.4332
	Shrub (Non-Eucalypt)	29	0.70	1.3018	ns
Wood & Bark	**Stemwood Volume x 1000 [m³]**	101	0.86	1.2106	-0.8178
	By Lifeform Group	101	0.90	-	-
	Tree (Eucalypt)	27	0.97	0.9419	0.3344*
	Tree (Non-Eucalypt)	9	0.96	1.0460	ns
	Mallee (Eucalypt)	36	0.86	1.0192	ns
	Shrub (Non-Eucalypt)	29	0.45	0.9437	-0.6244*
Twig & Bark	**Stemwood Volume x 1000 [m³]**	101	0.39	0.3757	1.3111
	By Lifeform Group	101	0.67	-	-
	Tree (Eucalypt)	27	0.46	0.5921	ns
	Tree (Non-Eucalypt)	9	0.74	0.6417**	ns
	Mallee (Eucalypt)	36	0.66	0.7503	0.5578*
	Shrub (Non-Eucalypt)	29	0.81	0.9677	ns
Wood & Bark + Twig & Bark	**Stemwood Volume x 1000 [m³]**	101	0.90	0.9475	0.5816
	By Lifeform Group	101	0.92	-	-
	Tree (Eucalypt)	27	0.95	0.8743	0.7717
	Tree (Non-Eucalypt)	9	0.97	1.0799	ns
	Mallee (Eucalypt)	36	0.85	0.9946	0.6464**
	Shrub (Non-Eucalypt)	29	0.75	1.1198	ns
Leaf, Fine Twig & Bark	**Stemwood Volume x 1000 [m³]**	101	0.53	0.4993	1.0384
	By Lifeform Group	101	0.71	-	-
	Tree (Eucalypt)	27	0.63	0.6903	ns
	Tree (Non-Eucalypt)	9	0.77	0.6604**	ns
	Mallee (Eucalypt)	36	0.64	0.6174	1.0856
	Shrub (Non-Eucalypt)	29	0.69	0.9460	ns

(# at $p<0.001$ significance levels unless indicated: * $p<0.05$; ** $p<0.01$; ns=not significant)

For more detailed studies of oil mallee species we have used the "Wood and Bark" and "Twig and Bark" Mallee (Eucalypt) models identified above (Table 7) but have also derived a replacement model for the "Leaf and Fine Twig" model. Using height, crown area and foliage density (0-100%) data collected from the "River Murray Dryland Corridor" and "Upper South East" studies (Hobbs and Bennell 2005; Hobbs *et al.* 2006) we have improved the mallee "Leaf and Fine Twig" model by 10% and have gained further discriminatory power for evaluations of harvestable "Leaf and Fine Twig" fractions. This new model is represented by the equation presented in Table 8.

For the "Field Trials of Woody Germplasm" project, where stemwood volume has not yet been measured we have developed a plant volume to green biomass model from data gathered in the River Murray Dryland Corridor and Upper South East biomass studies (see Fig. 4). This model allows us to estimate above ground plant green biomass by using height and crown diameter data only, and is only 2% less capable than models based on stemwood volume measurements (see Table 8). Further, where crown width data is absent, we can estimate above ground plant biomass by softer correlations with height only data (see Fig. 5 and Table 8).

Table 8. Additional green biomass allometric relationships used in the Oil Mallee study, Field Trials of Woody Germplasm (FTWG) project and Old Man Saltbush coppice study, based on South Australian biometric data.

Species and Lifeform Group	**Green Biomass Formula [kg/plant]**
Mallee (Eucalypt) Green Leaf & Fine Twig Green Biomass (r^2=0.74; n=36)	$= e^{0.6338 \times \ln(H.CA.FD + 1) - 2.0014} - 1$
FTWG Generic Total Above Ground Plant Green Biomass (r^2=0.84; n=101)	$= 3.2289 \times \text{Plant Volume } [m^3]^{0.8158}$
FTWG Generic Total Above Ground Plant Green Biomass (r^2=0.62; n=101)	$= 9.0554 \times \text{Height } [m]^{1.1967}$
FTWG Old Man Saltbush Total Above Ground Plant Green Biomass (r^2=0.94; n=386)	$= 4.1496 \times \text{Plant Volume } [m^3]^{0.8158}$

where, H.CA.FD = Height [m] x Crown Area [m^2] x Foliage Density [0 to 100%], Foliage Density expressed as a percent of maximum density (i.e. very dense 100%, dense 86%, moderately dense 71%, moderate 57%, moderately sparse 43%, sparse 29%, very sparse 14%, no leaves 0%) and Plant Volume = Height [m] x Crown Area [m^2].

Fig. 4. The relationship between above-ground plant volume (height [m] x crown area [m²]) and green biomass from trees, mallees and shrubs destructively sampled in SA biometric studies.

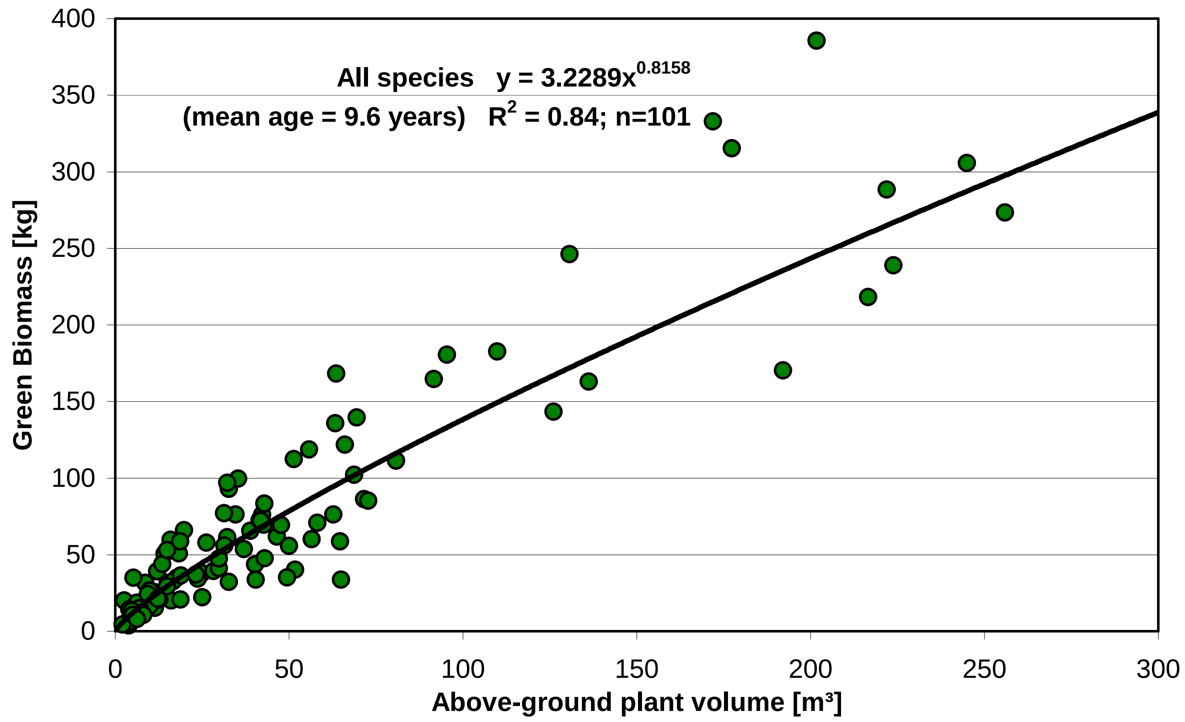
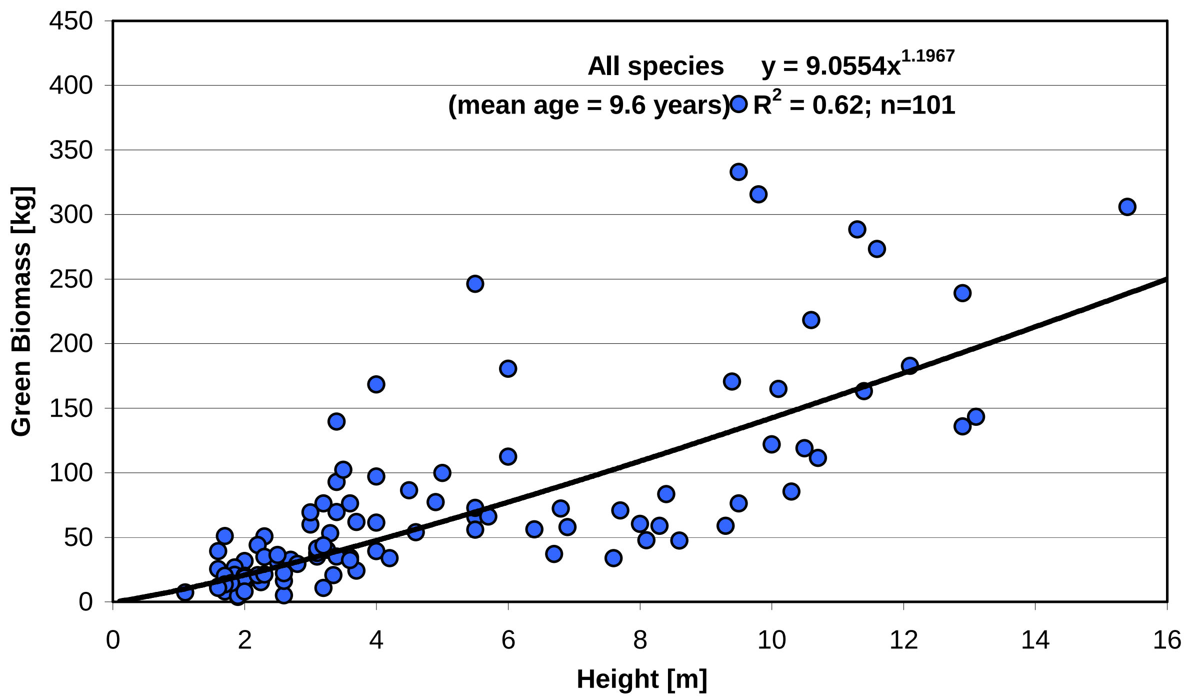
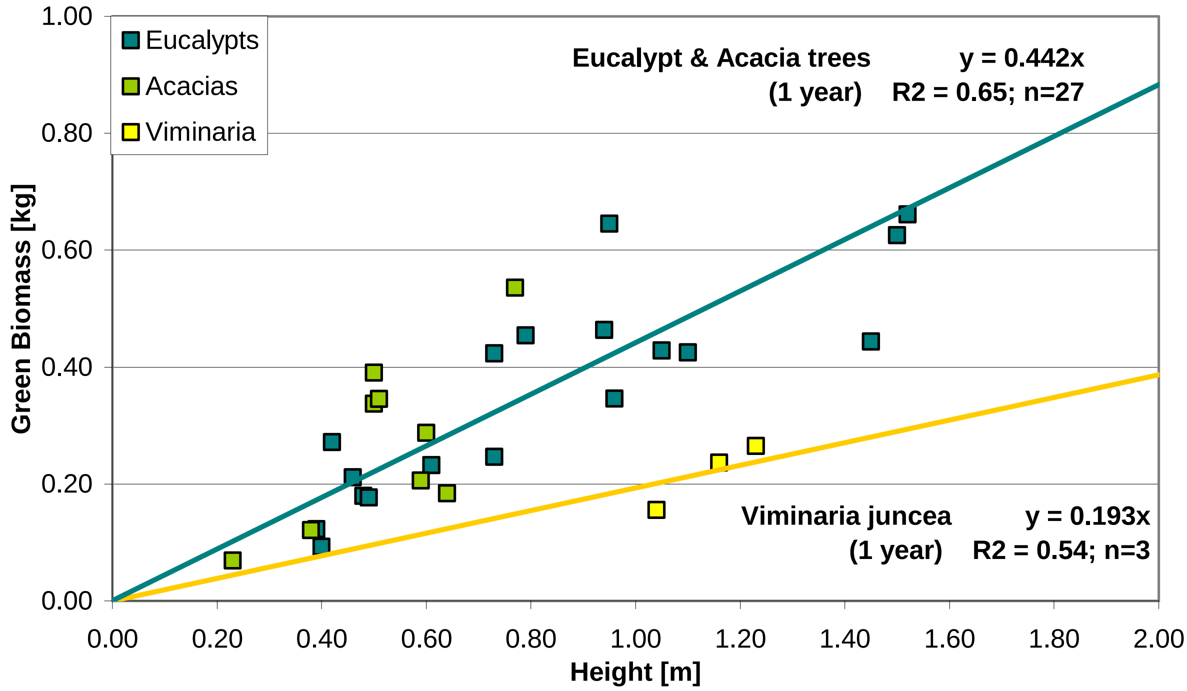


Fig. 5. The relationship between height and above ground green biomass from trees, mallees and shrubs destructively sampled in SA biometric studies.



After severe plant losses due to cockatoo attack, the 2004 Lucindale-South East trial site for the Field Trials of Woody Germplasm project was to be replanted in the following year. The majority of site was cleared in June 2005 in anticipation of new plantings. In the process of grubbing and clearing 30 remaining 1 year old survivors from part of the site were measured (height and crown width), weighed, dried and re-weighed. Three individuals of *Acacia leucoclada, Acacia pycnantha, Acacia retinodes* (swamp), *Eucalyptus cladocalyx, Eucalyptus globulus* ssp. *bicostata, Eucalyptus occidentalis, Eucalyptus polybractea* and *Viminaria juncea* were collected, and 12 *Eucalyptus camaldulensis*. These simple results, and relationships between height and green plant biomass are represented in Fig. 6. Eucalypts and Acacia had little difference in their relationships between height and plant biomass, however, *Viminaria juncea* was noticably different from other species.

Fig. 6. Linear relationships between plant height and above ground green biomass for very young age trees at the Lucindale-South East trial site.



South Australian Old Man Saltbush (Atriplex nummularia)

To generate the allometric models for Old Man Saltbush we collected a set of destructive biomass measurements for plants ranging in age from 1 year to 7.5 years of age. Destructive biomass measurements for the 1 year old *Atriplex nummularia* plants were conducted at the Old Man Saltbush plant improvement trial site at Monarto, SA. This site contains 19,008 trial plants collected from 27 different provenances of *Atriplex nummularia* ssp. *nummularia* and *Atriplex nummularia* ssp. *spathulata* across Australia. The site was established in July/August 2006 with the commercial clone Eyres Green included in the trial as a control against which productivity would be gauged. At 12 months of age there was large variability in the size and form of individual plants from the different provenances and subspecies. Plants were therefore selected in order to represent the available range of sizes from smallest to largest individuals and also to represent the available variation in leaf density and branching form. We therefore selected 10 individuals from subspecies *spathulata* and 10 individuals from each of three growth forms of subspecies *nummularia,* plus 3 Eyres Green individuals. For each of the 43 plants we measured plant height and the width along the row and perpendicular to the row. All plants were then harvested at ground level with the green biomass of each individual separated and weighed on site into the edible (leaf and fine stem < 3mm) and woody fractions (all material > 3mm).

Biomass measurements for older *Atriplex nummularia* plants were collected by destructively sampling individuals that were planted in the "Field Trials of Woody Germplasm" trial sites at Murray Bridge and Roseworthy in South Australia in 2004 and 2005. At these two sites, there was a combination of *Atriplex nummularia* ssp. *nummularia* germplasm collected from near Yando in Victoria, and the commercial clone, Eyres Green. At Murray Bridge, each of these provenances was planted in 2004 as 4 replicated plots of 8 rows of 8 plants at 3m by 1.5m spacing. In late Autumn 2007, we measured the height and width along and across the row for the 16 plants in the northwest quadrant of each plot. We then cut these plants back to a height and width of approximately 50-60cm and weighed the green biomass (leaf and stems combined) removed from each. For two of the 16 plants from each plot of Yando, and for all plants from each plot of Eyres Green, we subdivided and weighed the edible (leaf and fine stem < 3mm) and woody (all material > 3mm) green biomass fractions. The 2005 plantings consisted of Eyres Green in 2 plots of 2 rows of 6 plants at 3m by 1.5m spacing. All of these plants were also cut back using the same protocol as for the 2004 plants.

The biomass of the remaining standing in-ground stems was visually estimated using the modified Adelaide technique of Andrew *et al.* (1979). This approach requires taking a branch unit of known weight that is representative of the branches within the plant to be measured. A count is then made of the number of representative branch equivalents on the plant, which is then multiplied by the weight of the branch unit to get the standing biomass. We then combined this with the weight of harvested material in order to calculate whole-plant biomass.

At the Roseworthy site, there were 4 plots of the Yando provenance planted in 2004 and 4 plots of Eyres Green planted in 2005, all containing 4 rows of 6 plants at 3m by 1.5m spacing. All of these plants were also sampled in the late autumn of 2007 using the same destructive sampling outlined above. Two plants from each plot were again separated into the edible and woody fractions and the remaining biomass was estimated using the Adelaide technique.

The final destructive sampling dataset presented here is for 3 plants of unknown provenance of *Atriplex nummularia* sampled from an ungrazed plantation near Waikerie in SA, and 3 plants from an ungrazed plantation near Bordertown, SA. These plants were destructively harvested at ground level and separated into their respective edible and woody fractions.

We used the destructive biomass data to generate predictive allometric models for total green biomass (Fig. 7) and edible green biomass (Fig. 8) based on the estimated volume of each plant as an elliptical cylinder. Equations were generated for the Eyres Green clone, the other non-cv. Eyres Green, and for all saltbush combined. The higher productivity per unit volume of the larger Eyres Green individuals is evident in both models (yellow regression lines) but in both cases the combined model was very similar to the model for the non-cv. Eyres Green (black and green regression lines respectively). Predictive power is good for both the total and edible green biomass components for all saltbush combined with R^2 values of 0.94 and 0.89 respectively.

Because we had both *Atriplex nummularia* ssp. *nummularia* and *Atriplex nummularia* ssp. *spathulata* in the 1 year old trial site at Monarto, we generated predictive models based on the different subspecies and cv. Eyres Green for young individuals in this age bracket. Models for total green biomass (Fig. 9) and edible green biomass (Fig. 10) highlight the differences in growth form that are evident at this early stage of development for these subspecies. *Atriplex nummularia* ssp. *spathulata* are smaller plants that have a higher biomass per unit volume than *Atriplex nummularia* ssp. *nummularia.* Unfortunately we do not have destructive biomass data for older individuals of *Atriplex nummularia* ssp. *spathulata* to be able to make predictions for these older and larger individuals. The combined predictive models for total and edible green biomass again closely approximated those of the subspecies *nummularia* and showed good predictive power with R^2 values of 0.93 and 0.91 respectively. Comparison of the total and edible green biomass data indicates that at this young age there is a higher proportion of leaf than woody stem components in young plants compared to older plants.

Fig. 7. ***Atriplex nummularia*** **relationships between plant elliptical cylinder volume and above ground green biomass.**

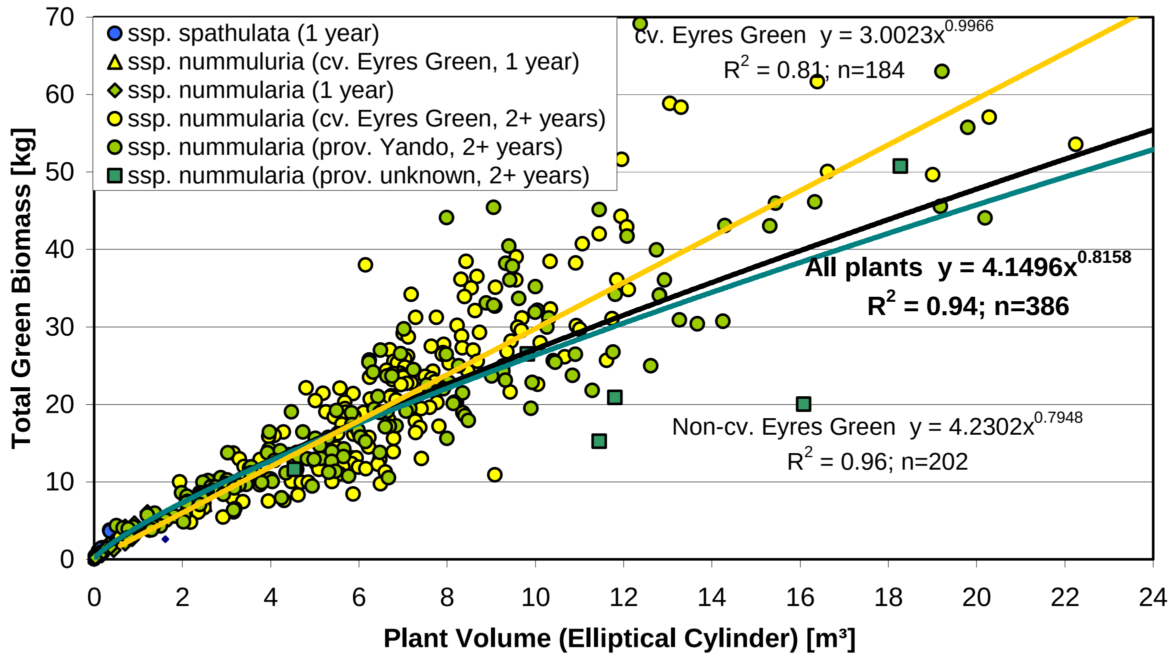


Fig. 8. Edible fraction ***Atriplex nummularia*** **relationships between plant elliptical cylinder volume and edible green biomass.**

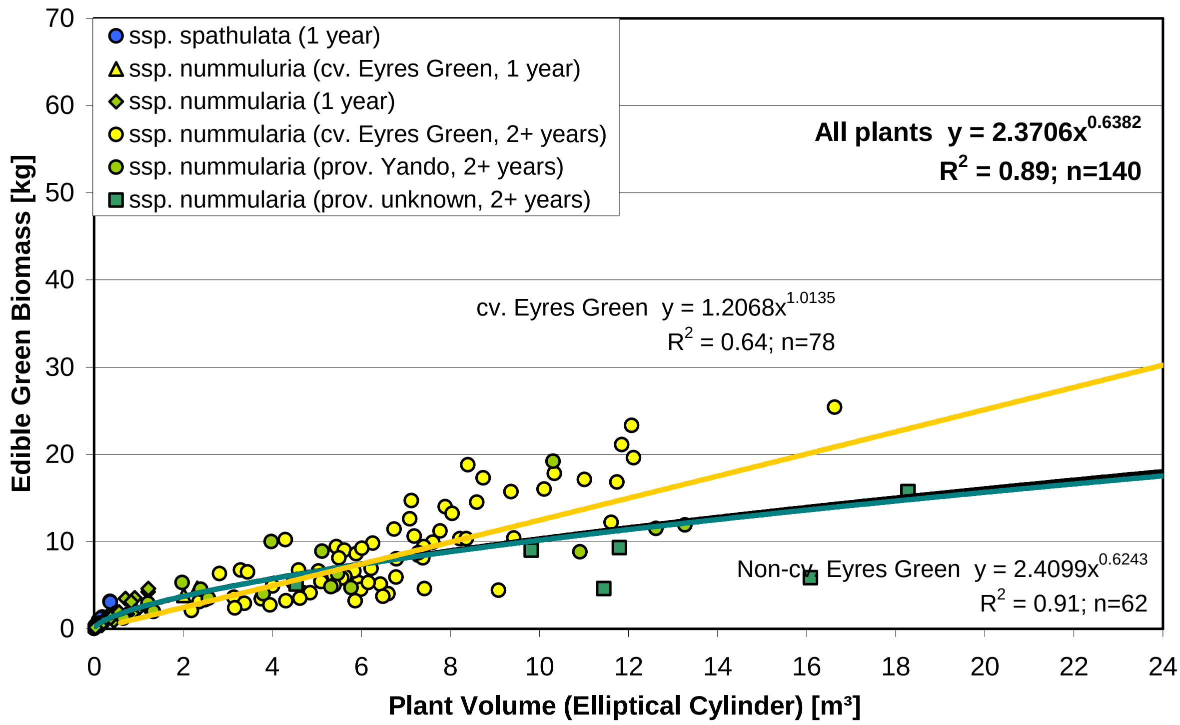


Fig. 9. Young age (1 year old) *Atriplex nummularia* relationships between plant elliptical cylinder volume and above ground green biomass.

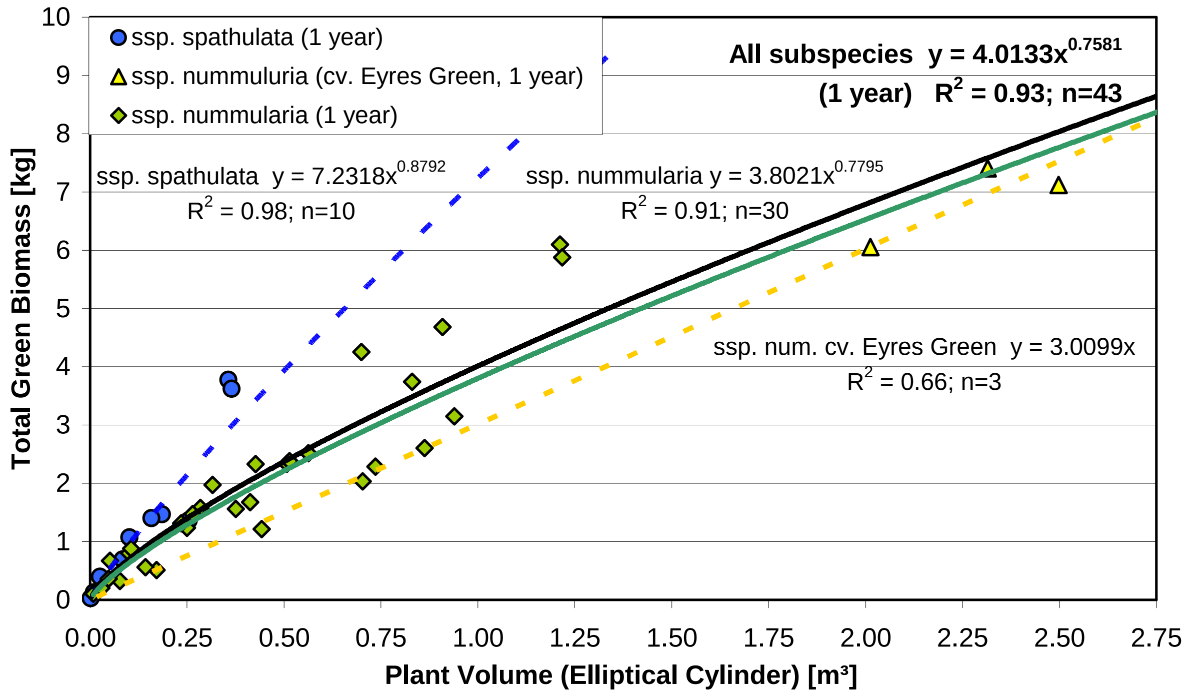
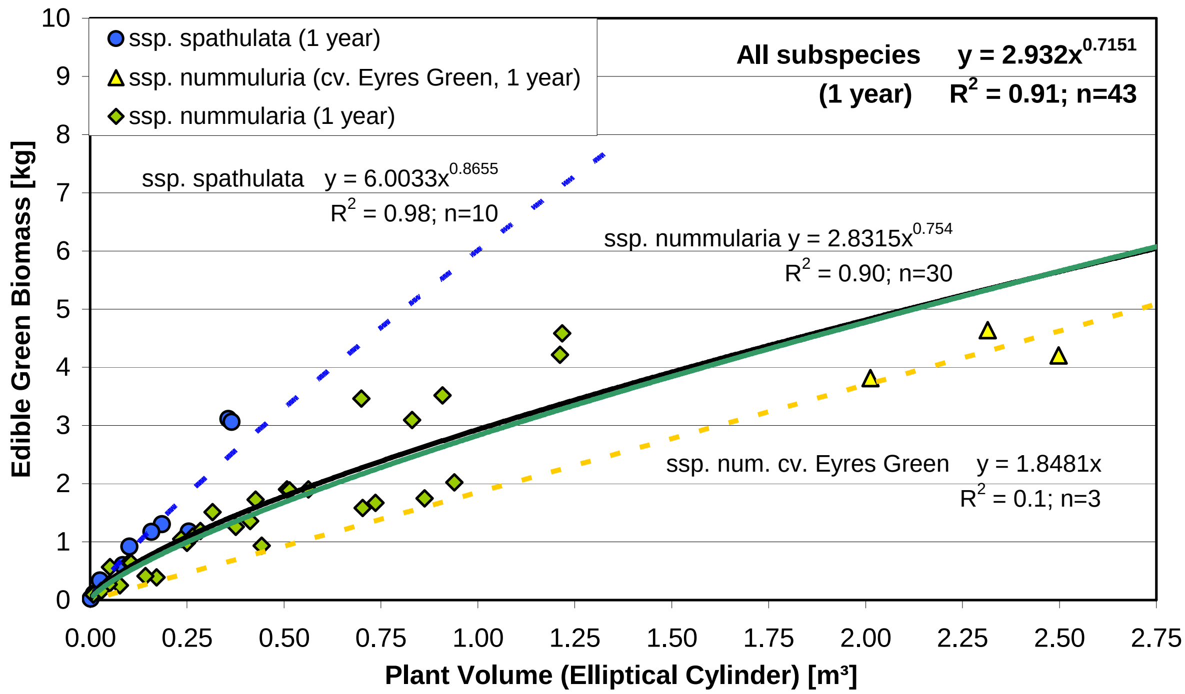


Fig. 10. Young age (1 year old) edible fraction *Atriplex nummularia* relationships between plant elliptical cylinder volume and edible green biomass.



Western Australian Acacia saligna, mallees and trees

In Western Australian studies, regression equations have been developed for simple biometric characters to green standing biomass for a number of species (Table 9). The relationship between stem basal area (10cm above ground) for *Acacia saligna* data, for three form types is presented in Fig. 11. The relationship between tree stem basal area (15cm above ground) for *Casuarina obesa* data is presented in Fig. 12. The relationship between tree stem basal area (15cm above ground) for *Eucalyptus occidentalis* data is presented in Fig. 12.

Little allometric work has been done on *Eucalyptus rudis* to date. Four plots of four year old *E. rudis* in a mixed species trial at east Katanning were assessed by the authors in October 2007. After weighing the whole tree, a selection of 36 trees of different size classes was reduced to woody material greater than 2cm diameter over bark. A summary of data appears below (Table 10).

Fig. 11. *Acacia saligna* relationships between plant stem basal measurements and above ground green biomass.

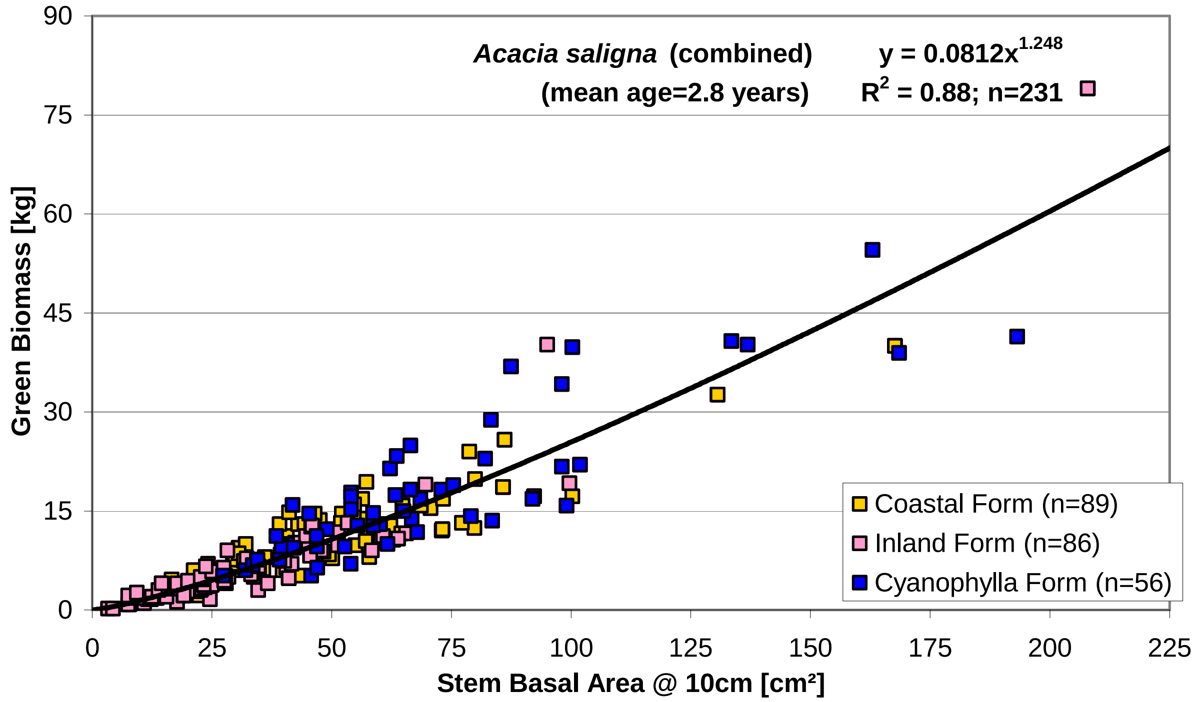


Fig. 12. ***Casuarina obesa*** **relationships between tree stem basal measurements and above ground green biomass.**

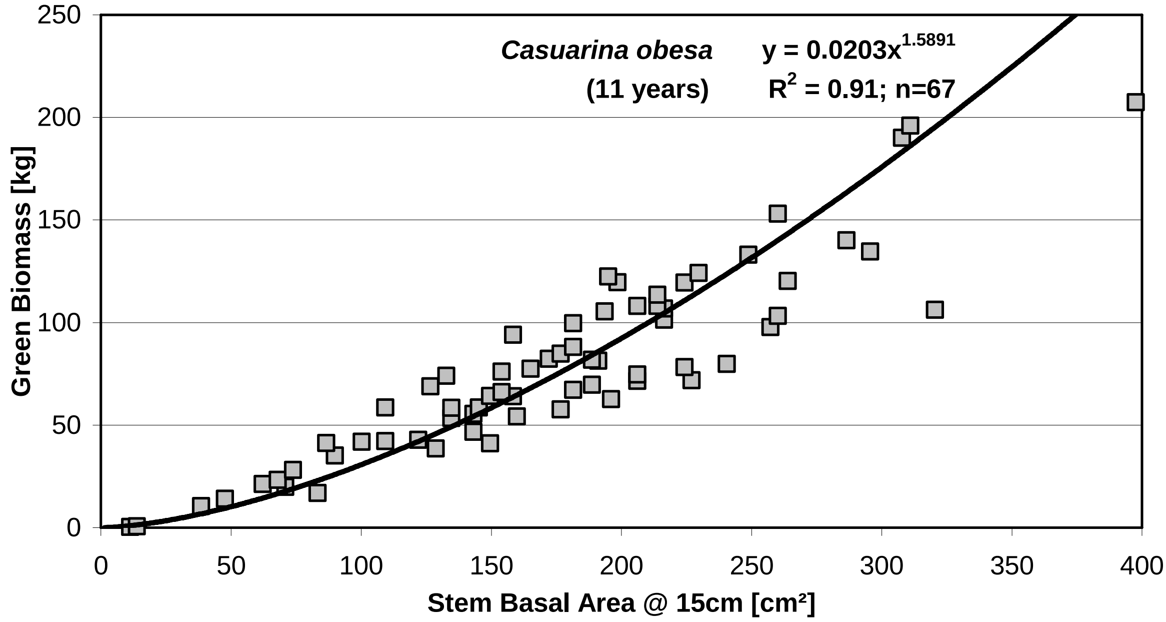


Fig. 13. ***Eucalyptus occidentalis*** **relationships between tree stem basal measurements and above ground green biomass.**

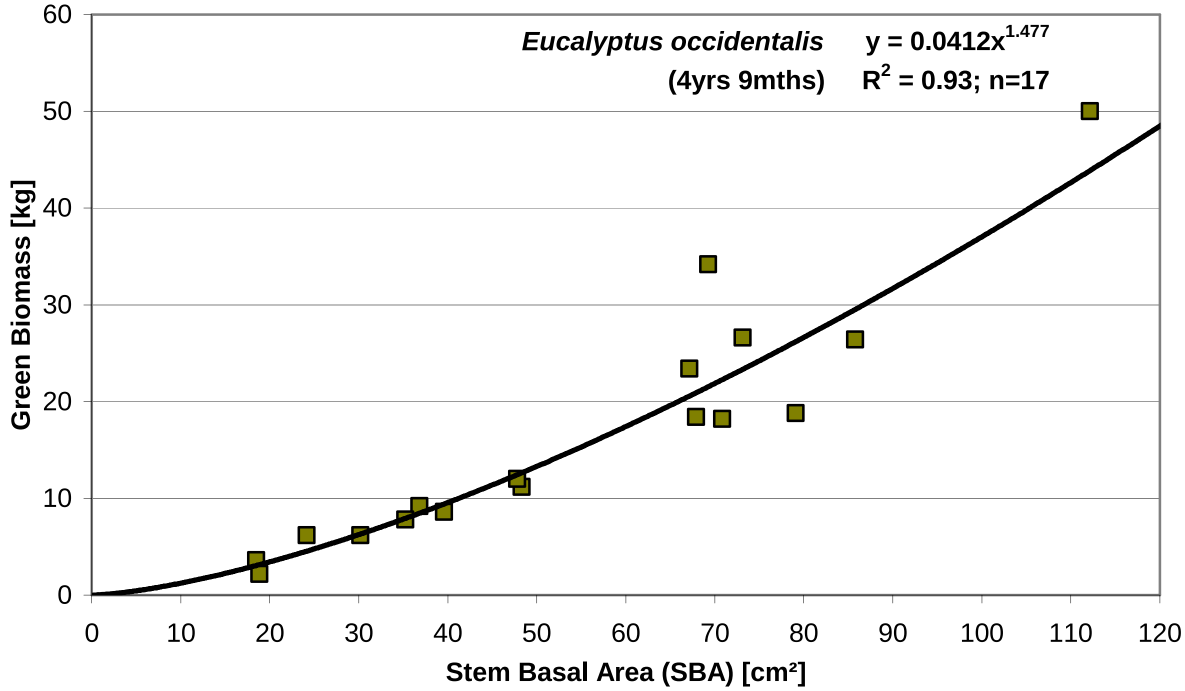


Table 9. Allometric relationships for selected species from Western Australian biometric studies.

Species and Lifeform Group	Total Green Biomass Formula [kg/plant]
Acacia saligna (2.8 years; n=231)	$= 0.0812 \times SBA^{1.248}$
Casuarina obesa (11 years; n=67)	$= 0.0203 \times SBA^{1.5891}$
***Eucalyptus loxophleba ssp. lissophloia* [coppice]** (2.5 years; n=889)	$= (0.202xCVI+1.3514)^2$
Eucalyptus occidentalis (4.75 years n=17)	$= 0.0412 \times SBA^{1.477}$
***Eucalyptus polybractea* [coppice]** (2.5 years; n=999)	$= (0.2093 \times CVI + 1.4663)^2$
***Eucalyptus polybractea* [saplings]** (9 years; n=115)	$= e^{0.17808(Ht) + 1.09582 \times \ln(SBA) - 0.01283(Nstems) - 2.19801}$
***Eucalyptus polybractea* [saplings]** (3 years; n=145)	$= e^{(0.11235xA + 0.50312 \times \ln(CVI) + 0.55390 \times \ln(SBA) - 0.00238(Nstems) + 3.38805)/1000}$

Where: CVI = Crown Volume Index [m^3]
SBA = Stem Basal Area at 10cm above ground [cm^2]
(15cm for *Casuarina obesa* & *Eucalyptus occidentalis*)
Ht = Tree Height [m]
Nstems = Number of stems at 10cm above ground
A = Plant Age [years; integer values]

Table 10. *Eucalyptus rudis* green biomass (>2cm diameter) relationships.

Plot	Numbe r of Trees	Survival	Plant Stem (>2cm) Green Biomass [kg]	Plot Stem (>2cm) Green Biomass [t/ha]	Stem (>2cm) Green Biomass [t/ha/yr]	Stem as % of Total Plot Green Biomass
1	54	84.4%	9.4	12.7	2.9	55.9%
2	68	94.4%	8.9	13.4	3.1	55.9%
3	32	50.0%	9.4	7.5	1.7	55.8%
4	45	70.3%	10.4	11.7	2.7	55.9%
5	53	82.8%	10.8	14.3	3.3	56.1%
Summary	***n=252***	***76.4%***	***9.8***	***11.9***	***2.8***	***55.9%***

Species and Provenance Trials

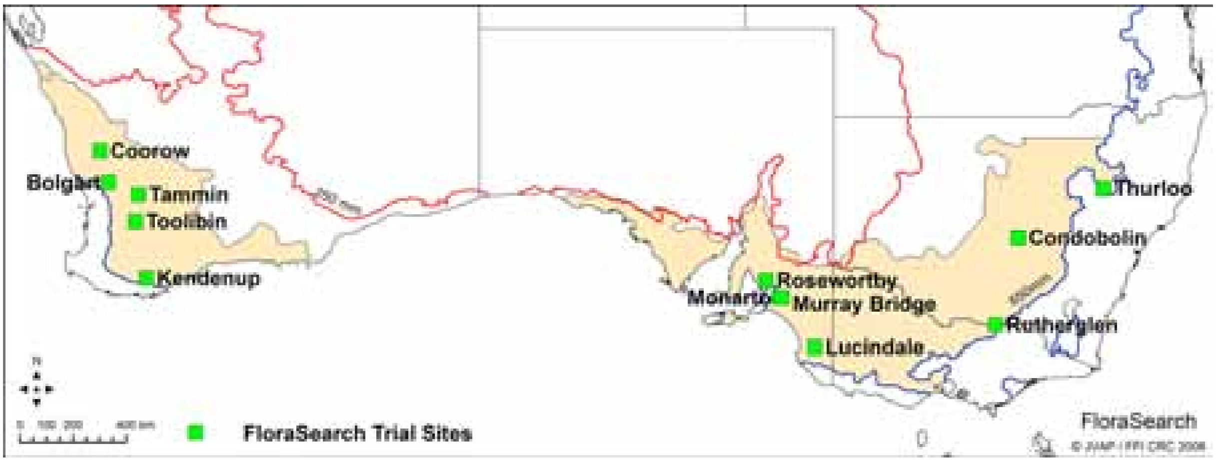
Field Trials of Woody Germplasm Project

A key goal of the FloraSearch project is to evaluate, select and develop a suite of improved woody perennial species that will provide valuable planting stock for large-scale commercially-viable biomass crops for diverse agricultural landscapes in the lower rainfall regions of southern Australia. To provide new information on the suitability and growth of species targeted for the lower rainfall regions (<650mm MAR) a wide range of germplasm has been gathered for series of field trials across South Australia, Western Australia, New South Wales and Victoria as part of the "Field Trials of Woody Germplasm" project (Fig. 14). This work started with a broad range of species for planting in 2004 and 2005, and continued with more focussed selections of germplasm for provenance and some family evaluations planted in 2005 and 2006. Sites were chosen across a range of soil types and climatic zones to allow preliminary investigations of germplasm by environment (GxE) interactions of desired species growth and product traits. Through a better understanding of GxE interactions we hope to determine each species' predicted suitability and productivity in the broader targeted region (Costa e Silva *et al.* 2006, Callister *et al.* 2007). Such understanding enables a more confident selection of germplasm for future breeding and development as future woody biomass crops (Eldridge *et al.* 1994).

In 2004, 6 field trial sites were established in SA (3), WA (2) and Vic (1). In 2005, a single trial site was established in NSW and the three SA sites expanded to contain additional species and provenances including a selection of fodder species at Murray Bridge. In 2006, a series of provenance and germplasm improvement trials were established at sites in SA (2), WA (5), NSW (2) and Vic (1) and include a range of 'development' species and 2 'focus' species (*Acacia saligna* and *Atriplex nummularia*).

This following section reports on results to date for species and provenances trials. Later sections (Section 4 - Plant improvement strategies and Section 5 - Breeding and evaluation trials) detail plant breeding / provenance and family trials for *Acacia saligna* and *Atriplex nummularia*.

Fig. 14. Trial sites established by FloraSearch and the Field Trials of Woody Germplasm project in 2004, 2005 and 2006.



2004 Trials (3 years old)

Species and site selection

Several Australian tree and shrub species with potential for development as woody biomass crops in the wheat-sheep zone of southern Australia have been identified by the FloraSearch and Search projects (Olsen *et al.* 2004, Bennell *et al.* 2008, Hobbs *et al.* 2008c). Germplasm representing the most prospective species (and limited provenances selections) was gathered in 2003 for nursery propagation and trial site establishment in 2004.

Seven trial sites were selected in 2003 to represent a range of soil types within climatic zones with potential for woody crop production in the medium to lower rainfall regions of South Australia, Western Australia, New South Wales and Victoria (Hobbs *et al.* 2008c). A balance between effective experimental coverage and the available resources influenced the size, number and location of the trial sites. Due to site limitations, regional interests and weed concerns, not all the selected germplasm could be included within every trial site (see Appendix A - Table 39). Six trial sites were successfully established in the winter-spring period of 2004 (Table 11). The eastern and western regions have 2 separate, regionally specific, suites of species at the respective sites. Due to localised dry conditions the northern New South Wales site could not be planted in 2004.

Table 11. Summary details of field trials established in 2004

Site, State	Lati-tude (°)	Long-itude (°)	Soil group (description)	Average annual rainfall (mm)		2004 Plantings		
				Long term	Since establish-ment	Germ-plasm present	No. of individ-uals	Survival after 3 years
Murray Bridge, SA	-35.12	139.24	Tenosol (Red-Brown Earth)	357	352	56	12868	78%
Roseworthy, SA	-34.53	138.69	Calcarosols (Sandy clay loam)	402	402	25	2856	78%
Lucindale South East, SA	-36.79	140.35	Sodosol (Deep white sand over clay)	519	398	20	1856	65%
Rutherglen, Vic	-36.05	146.47	Chromosols (Loam)	617	470	26	4864	76%
Coorow, WA	-30.11	116.16	Sodosol (Deep yellow sand over clay)	373	300	24	4223	62%
Toolibin, WA	-32.51	117.36	Podosol (Gravelly sand over lateritic clays)	394	383	25	3856	55%

Experimental Design

The typical minimum treatment for each germplasm at each site was 96 individual plants located in 4 replicates (4 rows of 6 plants) across each site. For a number of trial sites and species, where space and seedlings permitted, this was increased to 256 individual plants located in 4 replicates (8 rows of 8 plants). Plot rows were located 3m apart with 1.5m plant spacing along the row, resulting in a planting density of 2222 plants per hectare and aimed at maximising production rates for short-rotation woody crop types. The minimum experimental layout incorporated randomised block designs, and where site layouts permitted, latinized and row-column designs were identified using CycDesigN software (Whitaker *et al.* 2002) and applied. For a limited number of chosen germplasm additional sets of experimental blocks have been established to study the impact of different silvicultural treatments (e.g. coppicing and regrowth). The survival and growth of all plants has typically been monitored annually.

Assessments conducted at 3 years of age included individual observations of survival and measurements of individual plant height and crown width using a telescopic survey pole.

Allometric relationships and green biomass calculations

Additional performance evaluations have been determined using estimates of individual plant and plot green biomass growth using allometric relationships developed from data by Hobbs *et al.* (2006) for tree, mallee and shrub species in lower rainfall regions of southern Australia. The cylindrical volume of each individual trial site plant was determined using the product of crown area by height calculations, and the standing green biomass of each plant estimated using the linear allometric relationship (Fig. 4, Table 8; "FTWG plant volumes" equation):

$$\textit{Above ground green biomass [kg/plant]} = 3.2289 \times (\textit{Height [m]} \times \textit{Crown Area [m}^2\textit{]})^{0.8158}$$

Average annual above-ground productivity (green tonnes/ha/year) for each species and site was calculated from data on plant survival, planting density and estimates of green plant biomass. Long-term mean annual rainfall (MAR) and monthly rainfall data for the duration (and preceding 6 months) of all trials were acquired from Bureau of Meteorology weather stations (http://www.bom.gov.au) in closest proximity to each trial site. Observed annual biomass accumulation rates for each species and locality was then linearly adjusted to 500mm mean annual rainfall equivalent using each site's mean annual rainfall during the growth event, allowing us to undertake simple standardised comparisons of species' performance across sites.

Establishment and survival

In 2004, 30,523 individuals were planted over 6 trial sites representing 80 different sets of germplasm and 60 species. Western sites contained 32 germplasm and eastern sites contained 56 with only 8 germplasm common to both regions. Murray Bridge was the most extensive site and contained all 56 of the eastern suite of germplasm (see Appendix A - Table 39). Despite poor weather conditions after establishment the mean 3 year old survival rate across all sites was 72% and at some individual sites was 78% (Table 11). This indicates that the bulk of the species selected had the survival characteristics necessary to persist in the prevailing dry conditions. As each site represents a differing mix of soil and climate, species suitability varied across sites and was expressed not only in the survival statistics present in Table 11 but in the productivity rates of individual germplasm at each site.

Survival rates on the 3 duplex soil sites (Coorow, Lucindale; Toolibin, mean 61%) were substantially lower than loamy sites (Murray Bridge, Roseworthy, Rutherglen; mean 77%). Low survival rates at Lucindale can be partially attributed to damage caused by a large number of cockatoos that seemed to enjoy pulling up the taller seedlings shortly after planting.

Table 12. Three year old survival, height, crown width and productivity of the best performing 6 species at 6 field trial sites across southern Australia.

Site	Species [Provenance]	Survival	Height [m]	Crown Width [m]	Biomass Product-ivity Rate [green t/ha/yr]
SA Murray Bridge	*Atriplex nummularia* [cv. Eyres Green]	99%	1.48	2.50	16.8
	Atriplex nummularia [Yando]	99%	1.45	1.81	10.3
	Acacia saligna ssp. *saligna* [Mandurah]	98%	2.08	1.65	9.0
	Eucalyptus occidentalis [Redhill cult.]	99%	2.98	1.39	8.5
	Acacia saligna ssp. *lindleyi* [Parkeyerring]	98%	2.4	1.46	7.9
	Eucalyptus loxophleba ssp. *lissophloia* [Newdegate]	96%	2.26	1.46	7.3
	Average	**98%**	**2.11**	**1.71**	**10.0**
SA Roseworthy	*Eucalyptus cladocalyx* [Wirrabara SFMB]	93%	3.95	2.01	18.8
	Atriplex nummularia [Yando]	97%	1.74	2.48	18.1
	Eucalyptus loxophleba ssp. *lissophloia* [Newdegate]	93%	3.53	1.88	15.0
	Eucalyptus camaldulensis var. *camaldulensis* [Lake Albacutya]	97%	3.53	1.79	14.8
	Eucalyptus occidentalis [Redhill cult.]	91%	3.92	1.59	12.8
	Eucalyptus globulus ssp. *bicostata* [Wee Jasper & Mt. Bryan FS]	89%	2.73	1.95	12.4
	Average	**93%**	**3.24**	**1.95**	**15.3**
SA Lucindale SE	*Acacia saligna* ssp. *lindleyi* [Parkeyerring]	92%	2.68	2.07	16.9
	Eucalyptus petiolaris [Ungarra]	100%	2.53	1.77	14.8
	Eucalyptus viminalis ssp. *cygnetensis* [Williamstown]	44%	4.52	2.35	12.8
	Acacia retinodes var. *retinodes* (swamp form) [BSC]	27%	3.71	2.97	9.4
	Eucalyptus occidentalis [Redhill cult.]	88%	2.71	1.29	8.7
	Eucalyptus camaldulensis var. *camaldulensis* [Lake Albacutya]	96%	1.99	1.22	7.4
	Average	**74%**	**3.02**	**1.95**	**11.7**
Vic Rutherglen	*Acacia saligna* ssp. *lindleyi* [Parkeyerring]	97%	4.02	2.43	25.2
	Eucalyptus petiolaris [Ungarra]	99%	3.62	2.19	20.6
	Eucalyptus viminalis ssp. *cygnetensis* [Williamstown]	97%	4.38	1.99	20.3
	Eucalyptus camaldulensis var. *camaldulensis* [Lake Albacutya]	99%	4.27	1.96	20.0
	Eucalyptus ovata [Back Valley]	86%	3.77	2.02	17.6
	Eucalyptus porosa [Laura]	99%	3.23	2.03	16.7
	Average	**96%**	**3.88**	**2.10**	**20.1**
WA Coorow	*Acacia lasiocalyx* [Muntadgin]	75%	3.86	2.34	19.4
	Paraserianthes lophantha [Boddington]	66%	3.49	2.63	17.6
	Acacia bartleana [Dandaragan]	86%	4.59	1.76	15.7
	Acacia saligna ssp. *saligna* [Mandurah]	69%	3.44	2.22	14.8
	Acacia saligna ssp. *lindleyi* [Parkeyerring]	59%	3.84	2.06	12.3
	Eucalyptus rudis [Narrogin]	91%	2.69	1.74	10.9
	Average	**74%**	**3.65**	**2.12**	**15.1**
WA Toolibin	*Acacia lasiocalyx* [Muntadgin]	80%	2.99	1.85	11.3
	Paraserianthes lophantha [Boddington]	75%	3.01	1.96	11.2
	Acacia saligna ssp. *saligna* [Mandurah]	76%	2.30	1.91	9.0
	Acacia saligna ssp. *lindleyi* [Parkeyerring]	69%	2.70	1.69	7.6
	Eucalyptus occidentalis [Bundaleer cult.]	69%	3.24	1.45	7.0
	Alyogyne hakeifolia [Salmon Gums]	65%	2.16	1.83	6.7
	Average	**72%**	**2.73**	**1.78**	**8.8**

Species with broad site success - Generalists

There were a number of species that performed well across a range of sites indicating good potential for widespread application. *Eucalyptus occidentalis* was consistently productive at all trial sites and among the top 6 best performers at most sites (Table 12). The germplasm for *Eucalyptus occidentalis* differed between WA and SA but both originated from improved seedlot material from SA. At Rutherglen it averaged 4.4m in height over 3 years but produced slightly less total biomass than the best performing species at that site (Table 12 & Appendix A - Table 39). Within the eastern suite of species *Eucalyptus camaldulensis* var. *camaldulensis* was amongst the top 7 most productive species at all eastern state sites. *Eucalyptus cladocalyx* also performed well on all eastern sites except Lucindale where it experienced frost damage. At Roseworthy, *Eucalyptus cladocalyx* was clearly the first choice for biomass production. *Eucalyptus petiolaris* was planted extensively in the east and was a consistently productive species, performing notably well at Rutherglen and Lucindale sites. The ability of this generalist group of species to adapt to a wide range of soil types and climatic conditions makes them an attractive proposition for woody crop development.

Species with site limitations - Site specialists

Some species showed preferences for specific sites and out-performed the generalist species group at some locations. These species may have a bio-physical capacity to survive and grow more quickly within a narrower range of soil types and climatic zones than some generalist species. *Acacia lasiocalyx* and *Paraserianthes lophantha* were consistently the best performers at both WA sites with *Eucalyptus rudis* also performing reliably in the west. However, *Acacia lasiocalyx* and *Eucalyptus rudis* failed to perform at their only eastern site at Murray Bridge (see Appendix A - Table 39). The degree of site specificity of *Paraserianthes lophantha* is unknown as it was not grown at any of the eastern sites. *Eucalyptus loxophleba* ssp. *lissophloia* was widely planted with the exception of Toolibin and performed best at the more northerly sites, typically averaging over 2.7 m high but performed less well at the 2 most southern sites, with and average height of <1.7 m (Table 12 and Appendix A - Table 39). *Eucalyptus viminalis* ssp. *cygnetensis* was planted across the eastern sites and was one of the best performers at Rutherglen and Lucindale but performed poorly at the drier and warmer Roseworthy and Murray Bridge sites (Table 12). *Eucalyptus ovata* and *Eucalyptus porosa* performed well at the Rutherglen site, however *Eucalyptus ovata* experienced poor survival rates at other sites and *Eucalyptus porosa* survived well and grew more slowly at Murray Bridge. Both *Acacia retinodes* var. *retinodes* and *Eucalyptus globulus* ssp. *bicostata* performed well at Lucindale but growth and survival were reduced by lower rainfalls at other sites. While species within this group thrived at 1 or more sites they proved less resilient and productive at a wider range of locations. However, in an area that meets their specific requirements they may out perform some of the more generalist species.

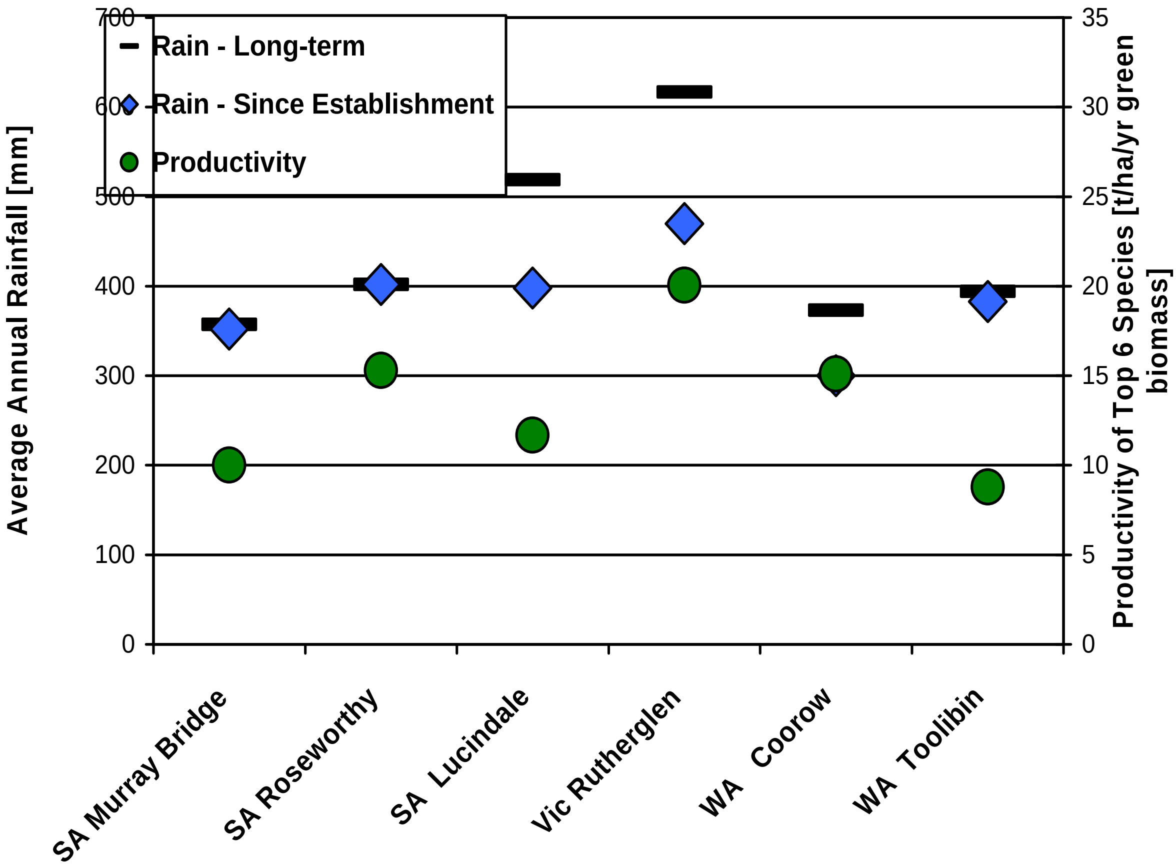
Site productivity

We used the mean productivity (green biomass/ha/year) of the 6 best performers at 3 years of age at each site as an indicative assessment of each site's potential productivity (Table 12). Examination of the relationship between rainfall (Table 11) and site productivity (Table 12) revealed productivity levels rising and falling fairly uniformly in response to rainfall received at each site during growing seasons (Fig. 15). However, the WA Coorow site is generally more productive than its 300mm rainfall would indicate (Fig. 15) and contrasts heavily (twice as productive) with the more southerly, and higher rainfall, WA Toolibin site (Table 11).

The typically higher rainfall and cooler southern sites at Rutherglen (617 mm MAR) and Lucindale (519 mm MAR) both received approximately 24% less rainfall during the growth event compared to their long term averages (Fig. 15). With fertile and deep loam soils, the Rutherglen site typically out performed the Lucindale site with duplex soils and white sandy topsoil. At Rutherglen, *Eucalyptus viminalis* ssp. *cygnetensis* plots recorded an average height of 4.5 m after 3 years of growth.

The two lower rainfall sites in South Australia (Murray Bridge 357 mm MAR, Roseworthy 402 mm MAR) both recorded close to average annual rainfall over the years since establishment (Table 11 and Fig. 15). The soils on both sites contain calcium carbonate through their soil profiles and survival rates across the sites was relatively uniform (78%). The Roseworthy site, with sandy clay loams, had higher average productivity rates than the Murray Bridge site with red-brown earths (Table 12).

Fig. 15. Maximum productivity (average of top 6 germplasm) and rainfall at 6 trial sites in lower rainfall regions (< 650 mm mean annual rainfall) of southern Australia.



Across-site comparisons

Rainfall is a primary driver to plant productivity (Fig. 15) in these environments and creates difficulties in comparing productivity rates across sites that experience different amounts of rainfall (and to a lesser extent evaporation and temperature regimes). To allow more meaningful comparisons of germplasm performance across sites we have applied a simple standardisation method where we have linearly adjusted each germplasm by site productivity value to a 500mm rainfall equivalent (green tonnes of biomass/ha/year). The standardised rainfall-adjusted performance of the 20 best and most widespread germplasm is presented in Table 13. These results must be viewed with some caution as not all species are represented on all sites. Average across-site rainfall-adjusted productivity values can be strongly influenced by limited site representation. For example, the average productivity figures for *Acacia lasiocalyx*, *Paraserianthes lophantha*, *Acacia bartleana* and *Eucalyptus rudis* are biased by their outstanding performance at the Coorow and Toolibin sites, and absence or poor representation at other sites. Similarly, *Eucalyptus porosa* performed well at Rutherglen and Murray Bridge but was not present elsewhere. Between-site variations in germplasm performance is high in many cases (e.g. *Acacia lasiocalyx* and *Eucalyptus rudis*) and should always be considered in germplasm selections.

While an attempt has been made to normalise the results in relation to rainfall, other climatic and edaphic influences remain. *Eucalyptus viminalis* ssp. *cygnetensis* showed distinct preference for the cooler southern sites at Rutherglen and Lucindale and performed modestly in warmer northern locations. Strong soil preferences were evident for some germplasm, as demonstrated by *Eucalyptus polybractea* and *Atriplex nummularia* that performed best on loamy soils and less well on sandy soils (Table 13 and Table 11).

Table 13. Normalised 3 year old productivity of the best performing species and provenances at 6 field trial sites across southern Australia.

Species [Provenance]	Site Productivity [t/ha/yr green biomass] (at 500mm mean annual rainfall equivalent)#						
	SA Murray Bridge	SA Rose-worthy	SA Lucin-dale SE	Vic Ruther-glen	WA Coorow	WA Tooli-bin	Aver-age
Paraserianthes lophantha [Boddington]					29.35	14.65	22.00
Atriplex nummularia [cv. Eyres Green]	21.43						21.43
Acacia saligna ssp. *lindleyi* [Parkeyerring]	11.20	11.86	21.28	26.75	20.42	9.87	16.90
Acacia saligna ssp. *saligna* [Mandurah]	12.80				24.61	11.71	16.37
Acacia bartleana [Dandaragan]					26.15	5.68	15.92
Acacia lasiocalyx [Muntadgin]	0.48				32.38	14.81	15.89
Eucalyptus petiolaris [Ungarra]	7.43	14.84	18.64	21.94			15.71
Eucalyptus camaldulensis var. *camaldulensis* [Lake Albacutya]	9.71	18.42	9.26	21.26			14.66
Eucalyptus cladocalyx [Wirrabara SFMB]	9.31	23.32	6.72	14.45			13.45
Eucalyptus occidentalis [Redhill cult./ Bundaleer cult.]	12.13	15.97	10.90	16.71	10.42	9.08	12.53
Eucalyptus viminalis ssp. *cygnetensis* [Williamstown]	2.78	8.63	16.09	21.57			12.27
Eucalyptus porosa [Laura]	2.97			17.71			10.34
Atriplex nummularia [Yando]	13.18	20.41	3.58	*13.69	5.67	1.46	9.67
Eucalyptus loxophleba ssp. *lissophloia* [Newdegate]	10.41	18.65	2.88	6.78	9.06		9.56
Eucalyptus rudis [Narrogin]	0.79				18.10	8.38	9.09
Acacia retinodes var. *retinodes* (swamp form) [BSC]	4.30	11.29	11.87	8.52			8.99
Alyogyne hakeifolia [Salmon Gums]						8.74	8.74
Eucalyptus globulus ssp. *bicostata* [Mt. Bryan FS/ Mt. Bryan CS]	2.78	9.03	6.31	11.87			7.50
Eucalyptus ovata [Back Valley]	1.13	4.44	2.78	18.68			6.76
Eucalyptus polybractea [Collie cult.]	4.43	7.71	1.96	10.03	3.52	4.01	5.28
#Average annual rainfall recorded over the growing period in mm.	352	402	398	470	300	383	

* Linear extrapolation of 2 year old data due to accidental heavily grazing by sheep in third year.

2005 Short Cycle Trials (2 years old)

Species and site selection

In 2003, seven trial sites were selected across southern Australia to represent a range of soil types and regional climatic zones but due to localised dry conditions the northern NSW site could not be planted in 2004 (Hobbs *et al.* 2008c). The seventh site, at Thurloo in NSW, was established in the following year (2005) to represent the north eastern area of higher summer rainfalls and heavier clay loam soils (Table 14). The species planted at Thurloo were those planned for the site the year before and held over in the nursery until planting conditions in northern NSW were conducive to establishment. The Thurloo site was planted in 2005 with the same germplasm that went into the original eastern states trials from repotted 2004 plants. These older seedlings had some constrained root development. In 2004, the Lucindale SE site suffered massive damage from corellas shortly after planting leading to a large section of the original trial being discarded. Replacement plants were grown for planting in 2005 from the original 2004 germplasm (same seed stock as 2004 plants).

Additional new species and provenances were also selected for planting in 2005 from germplasm that was not available in 2003 or identified as prospective species/provenances in late 2004 (see Table 41). This suite of new germplasm plantings was extensively planted at Murray Bridge, with a smaller number of germplasm introduced to remaining trial site areas of Lucindale and Roseworthy sites. As a result there are 3 groups of plantings that are only partially comparable due to differences in species and pre-planting treatment.

Table 14. Summary details of field trials established in 2005.

Site, State	Latitude (°)	Longitude (°)	Soil group (description)	Average annual rainfall (mm)		2005 Plantings		
				Long term	Since establishment	Germplasm present	No. of individuals	Survival after 2 years (%)
Murray Bridge, SA	-35.12	139.24	Tenosol (Red-Brown Earth)	357	371	64	5592	68
Roseworthy, SA	-34.53	138.69	Calcarosols (Sandy clay loam)	402	395	8	768	57
Lucindale, South East SA	-36.79	140.35	Sodosol (Deep white sand over clay)	519	373	56	3456	72
Thurloo, NSW	-31.39	150.12	Brown Sodosol (Sandy clay loam over clay)	617	552	24	4543	81

Experimental Design

The typical treatment for each germplasm at each site was the same as in 2004 and the 2222 plants per hectare densities used in the previous year, repeated. The minimum experimental layout incorporated randomised block designs, and where site layouts permitted, latinized and row-column designs were identified using CycDesigN software (Whitaker *et al.* 2002) and applied. At Thurloo extra blocks of the same germplasm where included to study the impact of different silvicultural treatments (e.g. coppicing and regrowth).

However, for a limited number of germplasm at Murray Bridge and Lucindale, insufficient numbers of plants could be obtained and smaller sets of experimental blocks have been established to provide some indication of productivity for that germplasm (Table 41). In other cases novel germplasm and known forestry species have been included in these smaller plots. Many of these germplasm have been reduced to half plots or 2 replicates or both, though in some cases as little as 6 individuals have been planted. The reliability of the results of these smaller plantings is therefore reduced and is used only as an indicative figure. The survival and growth of the 2005 plantings has typically been monitored annually along with the 2004 plantings and the same allometrics applied to the 2005 plantings that were used to calculate green biomass for the 2004 plantings.

Results

Establishment and survival

The majority of the 2005 trials were focussed at Murray Bridge (SA), Lucindale (SE SA) and Thurloo (NSW) sites with more limited plantings at Roseworthy (SA). Four sets of trials representing 146 different sets of germplasm, 115 species and 14359 individuals were planted (Table 14 and Table 41). Despite the poor weather conditions after establishment the mean 2 year old survival rate across all sites was 72.5%. Survival rates of the initial germplasm selections at Thurloo (i.e. planted in 2004 elsewhere) averaged 81% and were generally higher than expected with the persistence of below average rainfall in the region. The lower survival rates at the other sites indicate that some of the more speculative species and traditional forestry species did not fair as well as the germplasm typically planted in 2004. With fewer identical germplasm across sites planted in 2005 germplasm by environment analyses were limited.

Species with broad site success - Generalists

In the 2004 plantings there were a number germplasm that performed well across a range of sites that we identified as “generalists”. The 2005 plantings at Thurloo and Lucindale again contained some of that germplasm and some closely related germplasm. At Thurloo, *Eucalyptus cladocalyx*, *Eucalyptus camaldulensis* var. *camaldulensis, Atriplex nummularia, Acacia saligna* ssp. *lindleyi, Eucalyptus petiolaris* and *Eucalyptus occidentalis* were again amongst the first choices for biomass production (Table 41). At Lucindale, *Eucalyptus camaldulensis* var. *camaldulensis, Eucalyptus petiolaris,* and *Eucalyptus occidentalis* also performed well, although only *Eucalyptus camaldulensis* var. *camaldulensis* as one of the top six most productive germplasm for that site. The *Eucalyptus cladocalyx* planted at the Lucindale site in 2005 again struggled with only a 55% survival rate. In most cases, apart from *Eucalyptus cladocalyx* and *Atriplex nummularia*, most of the best performing germplasm at Thurloo produced more biomass at Lucindale when included at both sites.

Species with site limitations - Site specialists

In the 2004 plantings we identified germplasm that showed preferences for specific sites and out-performed the generalist group at some locations. The results from the 2005 plantings exhibit more of these examples. Two provenances of *Acacia retinodes* var. *retinodes* (hill form) were included in the 2005 trials at Thurloo and Lucindale (Table 41). The Clare/Spalding provenance at Thurloo was the 5th most productive germplasm at that site and the Harrogate provenance was the most productive germplasm planted at Lucindale in 2005. At both sites these ‘hill forms’ of *Acacia retinodes* var. *retinodes* produced more green biomass than the ‘swamp forms’ planted at those same sites in the same year (66% more at Lucindale and 31% more at Thurloo), though the Parawa ‘swamp form’ planted at Lucindale was the 6th most productive germplasm at that site in the 2005 plantings. At Lucindale, *Acacia mearnsii* (18.3 t/ha/year of above-ground green biomass) and *Eucalyptus viminalis* were some of the most productive germplasm, with 2 provenances of *Eucalyptus viminalis* ssp. *cygnetensis* and an example of *Eucalyptus viminalis* ssp. *viminalis* all rating in the most productive 2005 plantings at that site with productivity rates ranging from 18.3 to 11.9 t/ha/year. However, *Eucalyptus viminalis* ssp. *viminalis* only returned 1.7 t/ha/yr at Murray Bridge with a 79% survival rate in 2 small plots and *Acacia mearnsii* failed to perform at Roseworthy. *Eucalyptus aromaphloia* ssp. *sabulosa* and a provenance of *Eucalyptus globulus* ssp. *bicostata* from Wee Jasper also exceeded 10 t/ha/year at Lucindale. *Eucalyptus aromaphloia ssp. sabulosa* failed at Murray Bridge.

At Murray Bridge *Eucalyptus gomphocephala* was included in 2 plots of 12 plants and proved to be the third best producer of biomass planted at Murray Bridge in 2005 (7.8 t/ha/year), behind *Atriplex nummularia* [cv. Eyres Green] and *Atriplex amnicola* (Table 41). *Eucalyptus porosa* [Flinders Ranges], *Chenopodium nitrariaceum, Eucalyptus tereticornis* ssp. *tereticornis* and *Eucalyptus banksii* complete the top 6 germplasm with productivity rates ranging from 4.7 to 2.14 t/ha/year. *Eucalyptus porosa* [Flinders Ranges], *Chenopodium nitrariaceum* and *Eucalyptus banksii* were also all included at Lucindale but only *Eucalyptus banksii* produced higher productivity at the southern site (4.2 t/ha/year) than it did at the Murray Bridge site (2.14 t/ha/year). Two other *Eucalyptus porosa* provenances were placed in the 2005 trials, 'Adelaide Plains' at Lucindale and 'Laura' at Thurloo. While not directly comparable across all sites it's interesting to note that the 'Adelaide Plains' germplasm at Lucindale returned very similar productivity rates (3.5 t/ha/yr) to the 'Flinders Ranges' germplasm (3 t/ha/year) on that site. *Eucalyptus porosa* [Laura] yielded 4.3 t/ha/year at Thurloo.

Site productivity

An examination of the best 2005 performers at each of the South Australian sites indicates a similar relationship to that found in the assessment of the 3 year old germplasm (Table 41). Examination of the site productivity results from the Thurloo site places it roughly at a similar rate to Lucindale and Roseworthy. Higher rainfall and fertile clay loam soils at Thurloo resulted in good productivity rates for some species. The rainfall at Murray Bridge and Roseworthy was near long-term average levels, but Lucindale was well below average (-140mm; see Table 14). The good performance of *Atriplex nummularia* and *Eucalyptus gomphocephala* at Murray Bridge and *Atriplex nummularia* at Roseworthy indicate the overall poorer total site survival rates is largely a product of the speculative nature of some germplasm introduced in 2005 and not a true indication of site productivity.

2005 Fodder Shrub Trials (2 years old)

Species and site selection

In 2005, a trial using a range of fodder shrub species was established on the SA Murray Bridge site (Table 42). A very small number of species were also introduced to Roseworthy (SA) and Lucindale (SA) due to trial site space limitations and limited nursery stock (Table 41). A single fodder species, *Atriplex nummularia* [Yandoo] was also established at Thurloo (NSW) and Toolibin (WA).

Experimental Design

The typical treatment for the fodder group at each site mirrored the 2004 methods and repeated the 2222 plants per hectare densities used that year. The experimental layout again incorporated randomised blocks designs using CycDesigN software (Whitaker *et al.* 2002).

Due to insufficient nursery stock for some plant species, smaller plots and fewer replicates than the 2004 experimental design were used in some cases (Table 42, Table 41). Consequently, several germplasm have been reduced to half plots or 2 replicates or both. At worst, 2 germplasm are only represented by 6 individuals. These smaller plantings can only provide indicative site suitability and productivity information. The survival and growth of the 2005 fodder plantings has typically been monitored annually along with the other plantings on site and the same "FTWG plant volumes" allometrics have been been applied to calculate green biomass production rates.

Table 15. Two year old survival, height, crown width and productivity of the best performing species at 4 field trial sites planted in 2005.

Site	Species [Provenance]	Survival	Height [m]	Crown Width [m]	Biomass Product-ivity Rate [green t/ha/yr]
SA Murray Bridge	*Atriplex nummularia* [cv. Eyres Green]	96%	1.23	1.92	14.51
	Atriplex amnicola [Yorke Peninsula]	96%	0.74	2.87	12.69
	Eucalyptus gomphocephala [NM]	96%	1.66	1.40	7.82
	Atriplex rhagodioides [Moorook]	100%	0.95	1.69	7.51
	Atriplex cinerea [Yorke Peninsula]	100%	1.03	1.69	7.28
	Eucalyptus porosa [Flinders Ranges]	100%	1.00	1.28	4.66
	Chenopodium nitrariaceum [Hay]	93%	0.84	1.10	3.26
	Eucalyptus tereticornis ssp. *tereticornis* [NSWF]	92%	1.23	0.91	2.90
	Eucalyptus banksii [Tenterfield]	88%	0.81	0.93	2.14
	Eucalyptus cladocalyx [Lower Eyre Peninsula]	82%	0.90	0.83	1.82
	Eucalyptus oleosa [Port Wakefield NTB]	88%	0.63	0.92	1.74
	Average	**94%**	**1.00**	**1.41**	**6.03**
SA Roseworthy	*Atriplex nummularia* [cv. Eyres Green]	99%	1.44	2.66	30.45
	Eucalyptus oleosa [Port Wakefield NB]	89%	0.79	1.00	2.43
	Acacia iteaphylla [NM]	95%	0.65	0.73	1.52
	Eucalyptus viridis ssp. *viridis* [NSWF]	80%	0.88	0.58	1.03
	Average	**91%**	**0.94**	**1.24**	**8.86**
SA Lucindale SE	*Acacia retinodes* var. *retinodes* (hill form) [Harrogate]	99%	2.52	1.80	16.80
	Eucalyptus camaldulensis var. *camaldulensis* [Lake Albacutya]	100%	2.53	1.52	13.82
	Acacia mearnsii [BSC]	99%	2.35	1.62	13.62
	Eucalyptus viminalis ssp. *cygnetensis* [Williamstown]	96%	2.31	1.48	11.34
	Eucalyptus viminalis ssp. *cygnetensis* [Mount Barker]	94%	2.33	1.47	11.13
	Acacia retinodes var. *retinodes* (swamp form) [Parawa]	94%	2.12	1.51	11.12
	Eucalyptus viminalis ssp. *viminalis* [Cleland]	100%	1.94	1.31	8.85
	Eucalyptus aromaphloia ssp. *sabulosa* [Balmoral]	96%	1.88	1.28	7.67
	Average	**97%**	**2.25**	**1.50**	**11.79**
NSW Thurloo	*Atriplex nummularia* [Yando]	99%	1.45	1.36	8.62
	Eucalyptus cladocalyx [Wirrabara SFMB]	92%	2.08	1.3	8.19
	Eucalyptus camaldulensis var. *camaldulensis* [Lake Albacutya]	94%	2.10	1.15	7.99
	Acacia saligna ssp. *lindleyi* [Parkeyerring]	95%	1.83	1.09	6.03
	Acacia retinodes var. *retinodes* (hill form) [Clare/Spalding]	94%	1.67	1.16	5.89
	Eucalyptus petiolaris [Ungarra]	85%	1.48	1.27	5.73
	Eucalyptus occidentalis [Redhill cult.]	90%	1.76	1.00	4.73
	Eucalyptus porosa [Laura]	93%	1.2	1.15	4.27
	Average	**93%**	**1.70**	**1.18**	**6.43**

Results

The 2005 fodder trials saw 49 different sets of germplasm, 41 species and 2857 individuals established. Despite the poor weather conditions after establishment the mean 2 year old survival rate across all sites was 74.8% and at Murray Bridge were the bulk of the plantings were located it was 70% (Table 42, Table 41). Of the 48 sets of germplasm planted at Murray Bridge, *Atriplex nummularia* [cv. Eyres Green], *Atriplex amnicola, Atriplex rhagodioides* and *Atriplex cinerea* produced the best productivity rates returning 12.7, 10.3, 7.5 and 7.3 t/ha/year respectively. Of these 4 only the *Atriplex nummularia* 'Eyres Green' cultivar was planted at other sites (Roseworthy and Lucindale).

At Roseworthy *Atriplex nummularia* 'cv. Eyres Green' was the most productive of any germplasm planted in 2005, returning a green biomass accumulation rate of 30.5 t/ha/year at that site. The cultivar 'Eyres Green' planted at Lucindale, despite fairly modest productivity figures (7.2 t/ha/yr) was more productive than the Yandoo provenance (3.0 t/ha/year) planted at the same site in the same year. The Yandoo provenance of *Atriplex nummularia* was planted at Thurloo, Toolibin and Lucindale but was not included at Murray Bridge in 2005. The survival rate of this species was 88% or better at each location it was planted, though at Toolibin the Yandoo provenance recorded productivity rates of just 1.2 t/ha/year while at the Thurloo site that same provenance produced 8.6 t/ha/year.

Several other chenopods had green biomass accumulation rates between 2 and 5 t/ha/year, at Murray Bridge (Table 41), including *Atriplex paludosa,* 3 provenances of *Rhagodia spinescens, Rhagodia parabolica, Rhagodia crassifolia, Chenopodium nitrariaceum, Chenopodium auricomum, Maireana convexa, Atriplex vesicaria, Rhagodia candolleana* and *Maireana pyramidata*. The best non-chenopods were *Eremophila maculata, Acacia longifolia* var. *longifolia* and *Myoporum platycarpum* with green biomass accumulation rates of 2, 1.9 and 1.8 t/ha/year respectively.

Table 16. The top 12 best performing 2 year old fodder shrubs at Murray Bridge (planted 2005).

Species [Provenance]	Survival	Height [m]	Crown Width [m]	Green Biomass [t/ha/yr]
Atriplex amnicola [Yorke Peninsula]	96%	0.74	2.87	14.51
Atriplex nummularia [cv. Eyres Green]	96%	1.23	1.92	10.34
Atriplex rhagodioides [Moorook]	100%	0.95	1.69	7.51
Atriplex cinerea [Yorke Peninsula]	100%	1.03	1.69	7.28
Rhagodia spinescens [Mannum]	100%	0.75	1.61	5.07
Atriplex paludosa [Port Gawler]	100%	0.57	1.61	4.11
Rhagodia spinescens [Penong]	96%	0.62	1.51	4.09
Rhagodia parabolica [NM]	100%	0.68	1.45	3.96
Rhagodia spinescens [Hay]	100%	0.66	1.37	3.66
Rhagodia crassifolia [Narung]	96%	0.59	1.48	3.61
Chenopodium nitrariaceum [Hay]	93%	0.84	1.10	3.26
Chenopodium auricomum [SARDI]	100%	0.75	1.01	3.20
Average	**98%**	**0.78**	**1.61**	**5.88**

2006 Provenance Trials (1 year old)

Species, provenance and site selection

Building on the early field trial results a further 4 trials were established in 2006 containing germplasm from up to 8 provenances of the most promising species identified in the 2004 trials. Sites planted included Monarto (SA), Thurloo (NSW), Rutherglen (Vic) and Crossman (WA). In total the 2006 trials contain 39,520 individual plants, from 20 species, 36 sub species or varieties, and 87 provenances (see Table 43). The purpose of these sites is to identify superior provenances and make selections of the best germplasm from within the most promising species to become the basis of commercially-viable woody biomass crops.

A number of further germplasm was intended for the 2006 trials but due to the inability to obtain seed for the nursery the following germplasm was omitted from the trials: *Acacia retinodes* var *retinodes-normanville* [Normanville SA]; *Eucalyptus oleosa* ssp. *corvina* [Ravensthorpe WA]; *Eucalyptus oleosa* ssp. *cylindroidea* [Esperance WA]; *Eucalyptus oleosa* ssp. *oleosa* [Swan Hill Vic]; and *Viminaria juncia* [Esperance WA].

The process of growing out the germplasm also proved problematic in 2006 with a number of quality control problems and plant development issues and diseases affecting some of the germplasm. Several of the selected germplasm failed at this stage or had numbers reduced to a level were their inclusion at all sites was not possible. The following germplasm were excluded from the trials at this point due to nursery failure: *Eucalyptus aromaphloia* ssp. *aromaphloia* [Mt Lonarch Vic]; *Eucalyptus ovata* ssp. *ovata* [Ballarat Vic]; *Eucalyptus ovata* ssp. *ovata* [Bairnsdale Vic]; *Eucalyptus polybractea* [CLM25 WA]; *Eucalyptus porosa* [Streaky Bay SA]; and *Eucalyptus porosa* [Broken Hill NSW].

The Monarto site contained the bulk of the 2006 plantings, containing 20 species, 36 subspecies or varieties, 87 provenances and 23488 plants (Table 17). The Thurloo site contained 15 species, 21 subspecies or varieties, 68 provenances and 5952 plants. Despite reasonable conditions prior planting a failure to receive follow up rain in the area caused this site to fail and no measurements were undertaken. The Rutherglen site contained 14 species, 21 subspecies or varieties, 70 provenances and 6720 plants. The Crossman site contained 10 species, 13 subspecies or varieties, 35 provenances and 3360 plants. Due to weed concerns only approved species from the *Eucalyptus* genera were sent to WA. The Monarto numbers quoted above also include 6 individual species plantings of comparison species or species of interest and another 8 clonal hybrids that are not part of the formal provenance trial.

Further to this work, extensive provenance and family collections have been made for 2 ‘focus’ species (*Acacia saligna* and *Atriplex nummularia*) and a series of trials for these 2 species established in 2006. The details of these collections and trials are detailed in Section 4 - Plant improvement strategies, and Section 5 - Breeding and Evaluation Trials. One of these provenance and family trials (*Atriplex nummularia*) is co-located with the Monarto trees and mallees provenance trial sites and we have included a very brief summary of those results in this section for simple comparisons of productivity rates (Table 18).

Table 17. Summary details of trial sites established in 2006.

Site, State	Lati-tude (°)	Longi-tude (°)	Soil group (description)	Average annual rainfall (mm)		2006 Plantings		
				Long term	Since establish-ment	Germ-plasm present	No. of individ-uals	Survival after 1 years (%)
Monarto, SA	-35.12	139.14	Red Dermosol (sandy loam over clay)	391	322	87	23488	90
Rutherglen, Vic	-36.05	146.47	Chromosols (Loam)	617	289	21	6720	Not assessed
Thurloo, NSW	-31.39	150.12	Brown Sodosol (Sandy clay loam over clay)	630	499	21	5952	Not assessed
Crossman, WA	-32.81	116.80	Sodosol (Yellow sand over clay)	614	~500	13	3360	Not assessed

Experimental design and evaluation

The typical short cycle treatment for the provenance trials followed the 2004 methods at 2222 plants per hectare. The minimum experimental layout incorporated randomised block designs, and where site layouts permitted, latinized and row-column designs were identified using CycDesigN software (Whitaker *et al.* 2002) and applied. Most sites used 4 replicate plots of 4 rows of 6 plants (96 plants), as space was an issue. However, at Monarto 4 replicate plots of 8 rows of 8 plants (256 plants) were used were the number of available plants allowed, and the smaller plot size used for coppice experiments of the same species or for species with restricted available plants numbers.

Monarto was the only site measured in 2007 (1 year old) and this included individual assessments of height and survival. Both the 2006 Rutherglen and Crossman plantings were not measured at 1 year of age due to time and staff constraints. These preliminary measurements at Monarto provide an indicative evaluation of young age productivity.

Preliminary evaluations of plant growth are based on allometric relationships (Hobbs *et al.* 2006) between height and above ground green biomass (see "FTWG height equation", Table 8), i.e.:

$$\textit{Above ground green biomass [kg/plant]} = 9.0554 \times \text{Height [m]}^{1.1967}$$

Average annual above-ground productivity (green tonnes/ha/year) for each germplasm and plot was calculated from data on plant survival, planting density and these estimates of green plant biomass.

Results

Establishment and survival

The survival rate across the Monarto site was 90% with only 8 of the 87 provenances averaging less than 80% survival and 51 of the 87 provenances averaging 90% survival or better (Table 43). Some of that early mortality can be attributed to poor nursery stock. The seedlings of *Eucalyptus oleosa* ssp. *oleosa* [Menzies WA] and *Eucalyptus oleosa* ssp. *ampliata* [Port Lincoln SA] both had underdeveloped root systems at the time of planting and the seedlings of *Eucalyptus viminalis* ssp. *cygnetensis* [Onkaparinga River SA] were year old stock planted several weeks after the initial plantings to fill a gap left by a late nursery failure. Several of the provenances of *Eucalyptus* *cladocalyx* and *Eucalyptus globulus* ssp. *bicostata* were also afflicted by what appeared to be a fungal disease at planting but rapidly improved once in the ground and subsequently all have recorded survival rates over 80%.

Species with broad success across provenances

At 1 year of age *Eucalyptus occidentalis* has proved the most productive species at Monarto with every provenance recording a survival rate of 95% or better with average heights ranging from 0.76 to 0.92 m. The best provenance of *Eucalyptus occidentalisis* is from Truslove WA (Table 18 and Table 43). Most provenances *Viminaria juncea* grew quickly at this site with all but 1 provenance recording average heights between 0.63 and 0.90 m (cf. prov 'Perth WA' at 0.44m), but this species generally had lower survival rates.The annual productivity rates for *Viminaria juncea* also tend to overestimate its productivity when compared with other germplasm within the model used for this assessment. In contrast, *Acacia retinodes*, had uniform survival rates above 90% and with heights 0.51 and 0.76 m. The most productive provenance was *Acacia retinodes* var *retinodes* (swamp form) from Fryerstown in Victoria.

Other species to do well were *Eucalyptus cladocalyx* (0.43 to 0.60 m) and *Acacia mearnsii* (0.41 to 0.51 m) (Table 18 & Table 43). *Acacia mearnsii* had a survival rate of 95% or better across all provenances, while *Eucalyptus cladocalyx* had two cultivars record less than 90% survival ('Bundaleer' 89% and 'Wirrabara' 83%). The best provenances of these 2 species were the 'Grampians Vic' for *Acacia mearnsii* and 'Cape Border SA' for *Eucalyptus cladocalyx.*

Eucalyptus petiolaris and Eucalyptus polybractea both had good survival rates across the site with only the 'West Wyalong' provenance of *Eucalyptus polybractea* (90% survival) recording a survival rate under 97% (Table 18 and Table 43). *Eucalyptus petiolaris* had little difference between its 2 provenances (0.44 and 0.46 m) while *Eucalyptus polybractea* proved the best of the mallees with heights between 0.37 and 0.43 m. Other species with a close range of more modest results include *Eucalyptus aromaphloia*, *Eucalyptus porosa* and *Acacia decurrens*

Species with wider variation across provenances

The performance of *Eucalyptus globulus* was the most variable species. The provenance *Eucalyptus globulus* ssp. *bicostata* [Barkly Vic] recorded the best survival rate for the species at 90%, but the most productive provenance was *Eucalyptus globulus* ssp. *globulus* from Ottway, Vic. recording an average height of 0.63 at a survival rate of 89% (see Table 18 and Table 43). However, other provenances faired less well, the *Eucalyptus globulus* ssp. *globulus* cultivar from the Western Australian Forest Products Commission only averaged 0.38 m in height (67% survival). The poorest of the *Eucalyptus globulus* ssp. *bicostata* came from Wee Jasper, NSW averaging even less height at only 0.32 m but had a much better survival rate (87%). Other species with a large range of provenance results include *Eucalyptus ovata*, *Eucalyptus viminalis* and *Eucalyptus oleosa.*

Other species at Monarto

A group of 8 "Saltgrow" *Eucalyptus camaldulensis* hybrids were planted on the Monarto site along with 1 provenance of *Eucalyptus camaldulensis* from Silverton, NSW and 1 provenance of the closely related species *Eucalyptus rudis* from WA. The "Saltgrow" hybrids include 4 clonal cultivars of *Eucalyptus camaldulensis* x *Eucalyptus grandis* and 4 clonal cultivars of *Eucalyptus camaldulensis* x *Eucalyptus globulus* ssp. *globulus.* Each hybrid plot contains 1 of the crosses and equal numbers rows and individuals for each of the 4 clones. There are 8 plots of each cross, 4 large 8x8 plant plots and 4 smaller 4x6 plant plots designed for coppice experiments in the future. *Eucalyptus rudis* is planted in the 4 row by 6 plant configuration, while *Eucalyptus camaldulensis* has been planted in 3 plots of 4 rows by 8 plants.

The *Eucalyptus camaldulensis* x *Eucalyptus grandis* hybrids generally out performed the *Eucalyptus camaldulensis* x *Eucalyptus globulus* ssp. *globulus* hybrids. The best of the *globulus* crosses (0.48 m, 97% survival) only just out-performed the poorest *grandis* cross (0.67 m, 63% survival) (see Table 18 and Table 43). The best of the *grandis* crosses achieved 89% survival and averaged 0.66 m in height. By comparison, the Silverton *Eucalyptus camaldulensis* performed best of all the *camaldulensis* relatives and achieved 100% survival and averaging 0.72 m in height, and the *Eucalyptus rudis* planted on site achieved 91% survival and 0.62 m. Only the best 2 *grandis* clones achieved better results than *Eucalyptus rudis*.

Acacia saligna ssp. *saligna* is also planted at Monarto in 4 plots of 4 rows by 8 plants. At Monarto, *Acacia saligna* has a survival rate of 87% and average heights of only 0.36, lower than expected for this species. Other comparions species included the mallee species *Eucalyptus cneorifolia, Eucalyptus horistes* and *Eucalyptus loxophleba* ssp. *lissophloia* (Table 18).

Discussion and conclusions

Early results, seasons and limited resources

Since the establishment of the 2004 trials, most sites received significantly less rainfall than their long-term average values (Table 11, Table 14, Table 17). In some cases, unusual summer rain produced normal annual figures, but resulted in less effective rainfall for plant growth. Lower than average and unseasonable rainfalls may have retarded the productivity of some species and influenced mortality rates, especially for those species that have evolved in different climate and soil environments than those found at each trial site. To prevent early mortality several sites were given small supplementary watering in the first summer after planting where necessary to assist in plant establishment. *Acacia decurrens*, *Acacia mearnsii*, *Viminaria juncea* and some *Eucalyptus globulus* seemed to suffer the most from the dry conditions especially at Murray Bridge. Unseasonal summer rain did assist some species to survive in otherwise dry seasons.

Early results can sometimes be misleading as some species that initially grew strongly in the 2004 trials such as *Viminaria juncea*, have more recently deteriorated once the soil moisture stores were depleted. However, several hardy mallee species (e.g. *Eucalyptus loxophleba*, *Eucalyptus porosa*, *Eucalyptus polybractea*) initially grew slowly but are now strong and persistent biomass producers (see Appendix A - Table 39). The species with the best survival and productivity rates across most sites have been considered favourably for development as their ability to persist widely in drier conditions reduces the economic risk over the life of a plantation. Consequently, some of the best 1 year old species from the 2004 plantings were selected for the 2006 provenance trials. Recent comparisons between species performance rankings based on 2004 and 2005 plantings allow us to more confidently select species and provenances for longer-term production rates and future development as woody crops.

With such a large target area and limited resources it was inevitable that not all soil types or climatic zones could be represented within the trials. Our trial sites provide a reasonable representation of the dominant soils and climatic gradients of the wheat-sheep zone of southern Australia. Due to trial site area limitations and some nursery propagation failures not all germplasm have been reliably tested through our trials. Indicative positive results of some species on limited sites suggest further evaluations are needed. For example, the 2005 fodder trials have been restricted to a single site and results for other soil types or climates cannot be predicted with great reliability at this stage for much of the germplasm included in that set of experiments. *Eucalyptus gomphocephala* in the 2005 trials at Murray Bridge (Table 41), is an example of a species that has performed extremely well but has only been included at 1 site in a limited planting. This again suggests more extensive work is warranted to predict the species performance over a wider range of sites.

Table 18. Average provenance and best performing provenances at Monarto trials established in 2006 (1 year old).

Species [Provenance]		Survival	Height [m]	Green Biomass [t/ha/yr]
Acacia decurrens (2 provs)	Avg	88%	0.31	4.50
Acacia decurrens [Bungonia]	Best	92%	0.35	5.39
Acacia mearnsii (6 provs)	Avg	97%	0.48	8.22
Acacia mearnsii [Grampians]	Best	98%	0.51	9.04
Acacia retinodes (6 provs)	Avg	96%	0.59	10.54
Acacia retinodes var. *retinodes* (swamp form) [Fryerstown]	Best	98%	0.76	14.31
Acacia saligna [WA]		87%	0.36	5.38
Eucalyptus aromaphloia (4 provs)	Avg	88%	0.37	5.48
Eucalyptus aromaphloia ssp. *sabulosa* [Little Desert]	Best	89%	0.41	6.17
Eucalyptus camaldulensis (9 provs/hybrid/clones)	Avg	88%	0.58	9.40
Eucalyptus camaldulensis [Silverton]	Best	100%	0.72	13.62
Eucalyptus cladocalyx (6 provs)	Avg	92%	0.51	8.40
Eucalyptus cladocalyx [Cape Border]	Best	97%	0.60	10.77
Eucalyptus cneorifolia [Kingscote]		92%	0.36	5.54
Eucalyptus globulus (7 provs)	Avg	83%	0.46	6.90
Eucalyptus globulus ssp. *globulus* [Ottway]	Best	89%	0.63	10.50
Eucalyptus horistes [WA]		95%	0.33	5.07
Eucalyptus loxophleba ssp. *lissophloia* [WA]		97%	0.44	7.36
Eucalyptus occidentalis (6 provs)	Avg	97%	0.84	16.07
Eucalyptus occidentalis [Truslove]	Best	99%	0.92	18.21
Eucalyptus oleosa (5 provs)	Avg	84%	0.31	4.23
Eucalyptus oleosa ssp. *oleosa* [Mallala]	Best	94%	0.41	6.54
Eucalyptus ovata (5 provs)	Avg	90%	0.37	5.74
Eucalyptus ovata ssp. *ovata* [Adelaide Hills]	Best	94%	0.46	7.56
Eucalyptus petiolaris (2 provs)	Avg	98%	0.45	7.71
Eucalyptus petiolaris [Koppio Hills]	Best	99%	0.46	7.95
Eucalyptus polybractea (5 provs)	Avg	96%	0.41	6.64
Eucalyptus polybractea [CLM42]	Best	98%	0.43	7.34
Eucalyptus porosa (4 provs)	Avg	95%	0.33	5.12
Eucalyptus porosa [Fleurieu Penn]	Best	95%	0.35	5.50
Eucalyptus rudis [WA]		91%	0.62	10.41
Eucalyptus viminalis (7 provs)	Avg	82%	0.45	6.46
Eucalyptus viminalis ssp. *cygnetensis* [Flinders Chase]	Best	90%	0.55	8.98
Viminaria juncea (8 provs)	Avg	85%	0.68	11.23
Viminaria juncea [McLoughlins Beach]	Best	84%	0.90	15.23

Previous plant biometric studies in SA (Hobbs *et al.* 2005, 2006) and WA (this report) show stronger allometric relationships for assessing total plant biomass using more detailed morphological measurements (stem diameters and volumes) and lifeform groupings than the generic plant volume (height x crown area) relationship used in most FloraSearch trial site assessments to date. As only a height to biomass relationship was used to assess the plants at Monarto at year 1, future assessments will include additional plant measurements to more confidently assess plant biomass using the more reliable allometric relationships mentioned earlier. Likewise, the simple cylindrical volume models used to assess the older trials will also be superseded as the plants develop and species specific models are applied to the most promising germplasm. Future assessments will include additional plant measurements (and destructive sampling to determine plant biomass fractions) to more confidently assess plant biomass and improve germplasm selections for maximum crop yields.

Building on past work

Eucalyptus camaldulensis, *Eucalyptus cladocalyx*, *Eucalyptus polybractea* and *Eucalyptus occidentalis* have been included in several past trials and studies conducted by others (Kiddle 1987, Eastham 1993, Wildy 2000a,b). Applying new allometric relationships (Hobbs *et al.* 2006) to data previously collected on other sites has confirmed that many of these species are productive (above-ground plant biomass/ha/year) across a range of sites. Results from our field trials support several of these earlier species selections for farm forestry potential and identify several new candidates for development (e.g. *Acacia saligna, Atriplex nummularia, Eucalyptus loxophleba* ssp. *lissophloia, Eucalyptus petiolaris, Eucalyptus rudis, Eucalyptus viminalis* ssp. *cygnetensis*). Their generally consistent performance across these studies strengthens the case for further development of this range of germplasm for short-rotation crops and provides a benchmark for performance of new species trialled. Other notable fodder species include *Atriplex amnicola*, *Atriplex rhagodioides* and *Atriplex cinerea.*

Future directions

Young age (<4 years) assessments of survival, growth and yield of fodder species are valid for the seasons and sites experienced in this study. However, these young age assessments of trees and mallees may be somewhat premature - only providing early estimates of the productive potential of these germplasm. More reliable evaluations will be gained as the trees and mallees mature, and the differences in germplasm between and within species may become more apparent. The use of early evaluations can enable fast-tracking of selections, reduce the cost of plant improvement programs and promote the process of developing commercially viable cultivars. However, we acknowledge that more reliable evaluations would be gained from assessments made closer to their age of harvest. The continued periodic assessment (~3 year interval) of these trials is required. The assessment of the other remaining 2006 provenance trials at Crossman and Rutherglen should be conducted in 2009 to identify suitable germplasm for different soils and climates. Selections of the most productive and hardy germplasm can then be made and germplasm advanced into breeding programs and clonal cultivar production.

Our research has already identified several species with widespread potential (“Generalists”) for agroforestry in lower rainfall regions of southern Australia. We have also noted several species that are more regional or soil specific in their application (“Site specialists”) and these have the potential to be more productive in some environments than “generalist” species. However, these “Site specialists” require more detailed assessments of site characteristics (e.g. soils, climate) to match individual species’ requirements.

The next steps - New sites, species and provenances

Although the 2004 trials were not specifically designed to measure differences in subspecies and provenance growth rates, the trials did include multiple sets of germplasm for some species. Two subspecies of the fast growing species, *Acacia saligna,* were included at several sites. At these sites *Acacia saligna* ssp. *saligna* consistently out performed (+21%) *Acacia saligna* ssp. *lindleyi.* This variation between germplasm of the same species is also illustrated by *Atriplex nummularia* at Murray Bridge, where the cultivar 'Eyres Green' almost doubled the productivity of the Yando provenance (Table 12). *Atriplex nummularia* has continued to perform well in most of the trials established in 2005. These examples show the potential productivity gains that can be achieved by examining subspecies and provenance variations to locate the best germplasm for woody crop breeding and development.

Building on these early results the FloraSearch program is progressing the domestication of several of the species, including *Acacia saligna* and *Atriplex nummularia.* These 2 species have already been established in provenance/family trials across southern Australia, and are discussed in greater detail in later sections (Section 4 - Plant improvement strategies and Section 5 - Breeding and evaluation trials) The 2006 provenance trials also contain diverse germplasm from a range of candidate species. As these plants mature and new data is analysed it is anticipated that new selections will emerge to become the basis of commercially-viable woody biomass crops across the lower rainfall regions of southern Australia.

Species Productivity and Yields

The growth rate and product yields of short-cycle woody biomass crops are a major driver of their commercial viability. The short-term productivity (1-10 years) of many of the subject species reviewed and evaluated by the FloraSearch team is typically poorly known in the medium to lower 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 focussed on long-cycle stemwood volumes and been conducted in higher rainfall regions (typically >800mm mean annual rainfall) with fewer studies in the mid-rainfall zone (650-800mm).

Field trials, research and surveys conducted by FloraSearch, WA Search and through the "Field Trials of Woody Germplasm" project have significantly added to knowledge on short-cycle woody biomass crop productivity and yields in recent years. Results from the "Field Trials of Woody Germplasm" project has been detailed in an earlier section of this report. In this section we highlight additional datasets gathered and recent investigations into plantation productivity for a targeted range of species in lower rainfall regions. In the last few years some oil mallee species (e.g. *Eucalyptus polybractea, E. loxophleba* ssp. *lissophloia, E. horistes*), Koojong Wattle (*Acacia saligna*) and Old Man Saltbush (*Atriplex nummularia*) have been the subject of plantation productivity research. In South Australia, the FloraSearch team has been co-funded by the SA Centre for Natural Resource Management and the Australian Government to conduct regional studies of plantation growth and carbon sequestration rates.

FloraSearch has also compiled other plantation productivity data from trials conducted by other researchers, literature searches and other national forestry databases (e.g. TreDat). 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 did identify several sites containing species of interest to FloraSearch and some addtional surveys have been conducted.

The FloraSearch/FTWG "productivity database" data has been linked to spatial information on soils and climate and has been used to create simple empirical models for most species of interest to the FloraSearch project. These simple species models are based on 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 and Forest Productivity Index models (Raupach *et al.* 2001, Australian Greenhouse Office 2007).

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. Western Australian FloraSearch activities have included some productivity studies of mallee coppice systems. In South Australia, we have also conducted preliminary Eucalypt oil yield evaluations for a range of oil-bearing species and indicative assessments of the influence of species choice on economic values.

Productivity studies in South Australia

In South Australia, the Department of Primary Industries and Resources and Forestry SA have conducted several years of research in identifying species suitable for development as sawlog species in lower rainfall regions (Hobbs *et al.* 2008c). This work gained momentum in the 1990's through the SA Farm Tree Improvement Program and later evolved into a part of a national approach as the Australian Low Rainfall Tree Improvement Group program (ALRTIG; Harwood *et al.* 2005, Fairlamb and Bulman 1994; Rural Solution SA 2003). There is overlap of species selections between ALRTIG selections and species identified by the FloraSearch process, and where productivity data is available on these overlapping species we have utilised previously gathered data on growth rates and conducted new analyses to identify better evaluations of plantation productivity (Hobbs *et al.* 2008c).

FloraSearch, in partnership with the SA Centre for Natural Resource Management, has conducted two regional studies on biomass productivity in the River Murray Dryland Corridor and Upper South east regions (Hobbs and Bennell 2005; Hobbs *et al.* 2006). Summaries of the River Murray Dryland Corridor study have been previously presented in the FloraSearch 2 report (Hobbs *et al.* 2008c) covering predominantly mallee and shrub species. The following Upper South East subsection provides details of a study with a greater emphasis on lower rainfall tree species in a region that borders on the Tasmanian Bluegum hardwood pulp and Pine softwood estates of the Green Triangle traditional forestry region.

Upper South East region

To bolster existing trial site information from Primary Industries and Resources SA (PIRSA) and Forestry SA, and to provide information on species not grown in PIRSA/Forestry SA trials, FloraSearch targeted 35 new plantations in the region (Fig. 16, Hobbs *et al.* 2006). These surveys represented 19 species (Table 19), with multiple measurements (either by provenance, location, planting design or combined) for Swamp Yate (*Eucalyptus occidentalis*), Sugargum (*E. cladocalyx*), Tasmanian Bluegum (*E. globulus*), River Redgum (*E. camaldulensis*), Rough-barked Manna Gum (*E. viminalis ssp. cygnetensis*), Spotted Gum (*Corymbia maculata*), and Ridge-fruited Mallee (*E. incrassata*). The height, crown width, stem count and circumferences at basal and intermediate heights, leaf density and plant spacing were measured for typically 30 individuals for most species and sites. Additional data from the biometrics study (3 to 6 plants) were also included in this dataset.

All PIRSA, Forestry SA and FloraSearch trial site and survey productivity data was combined from sites within, and immediately neighbouring, the Upper South East (USE) region. Conversion of this data to stemwood productivity rates and application of allometric relationships were used to determine estimates of total plant productivity and yields of biomass components and totals for each species and site. Observed and estimated plant biomass productivity values for each species and location from the biometrics and productivity studies were standardised to an annual biomass accumulation rate to account for the different ages of the plant studied. The average annual rainfall for each sampled locality was extracted from spatial coverages of annual rainfall (CSIRO Land and Water 2001) using ArcGIS (ESRI 2005). Observed and modelled annual biomass accumulation rates for each species and locality was then standardised to an annual rainfall of 500mm using a simple linear relationship to permit a simple comparison of each species' relative biomass productivity. Summaries of the FloraSearch productivity surveys and observations are presented in Table 19, Table 20 and Fig. 17.

Productivity data from the top 10% best performing plots for each species and trial/survey site location were extracted from the combined productivity dataset. These selections were aimed at identifying the best performing plant species, provenances and genetic choices suited to the local soil and climatic conditions and excluded plant germplasm that was either poorly suited to that site or plots which had suffered from poor management or a significant environmental event. Appendix B (Table 44 and Table 45) contains summaries of plot and survey data from the 74 sites, 46 species, and 1,731 plots determined from measurement on over 13,872 individual plants.

From the array of species contained within this combined productivity dataset FloraSearch has previously identified which species are suitable for each biomass industry class based on product testing results and published literature (Hobbs *et al.* 2008c). The four major *Biomass Industry* product groups and species suited to the Upper South East region are listed in Table 21. We have created bioclimatic distribution models for these species from climatic GIS data and natural and plantation location data (see Hobbs *et al.* 2006). A fifth group (*Habitat Species*) comprises native species which naturally occur within a given region. Fifteen species were selected to represent different lifeforms which are both productive and common to the region. These *USE Habitat Species* include Black Wattle (*Acacia mearnsii*), Blackwood (*Ac. melanoxylon*), Golden Wattle (*Ac. pycnantha*), Drooping Sheoak (*Allocasuarina verticillata*), River Redgum (*Eucalyptus camaldulensis*), Coastal White Mallee (*E. diversifolia*), White Mallee (*E. dumosa*), Pink or Hill Gum (*E. fasciculosa*), Ridge-fruited Mallee (*E. incrassata*), SA Bluegum (*E. leucoxylon*), Peppermint Box (*E. odorata*), Red Morrell Mallee (*E. oleosa*), Swamp Gum (*E. ovata*), SA Mallee Box (*E. porosa*), Red Mallee (*E. socialis*) and Rough-barked Manna Gum (*E. viminalis ssp. cygnetensis*). Productivity data for species within each of these five "*Biomass Industry Groups*" was extracted from the "*Top 10% Species Plots*" productivity dataset.

For developing productivity models the productivity of plots planted at a density of greater than 1000 trees or plants per hectare (tph) were proportionally reduced to the equivalent of 1000tph so not to bias per hectare productivity rates (1500tph rate for saltbush fodder species). The productivity of plots with less than 1000tph were <u>not</u> increased proportionally to their plant density. These rules were designed to create conservation models and estimates of plantation productivity.

Increased productivity rates per hectare could be expected for many, if not all, species observed in our study using higher planting densities. For species and plots with a crown area of less than $10m^2$ it is likely that higher planting densities than 1000tph are possible. An indicative optimum planting rate per hectare for each species may be deduced from dividing the hectare area (i.e. $10{,}000m^2$) by the crown area of the species. This 'crown' density of plants per hectare may be appropriate for short-cycle plantings but the optimum density to maximise biomass productivity per hectare will depend on the degree of plant competition for light, water and other nutrients.

Planting at rates higher than the 'crown' density rate may potentially increase productivity per hectare, however, this can only be accurately determined from more detailed trials and research. Where the observed planting density is lower than the calculated 'crown' density for a plantation it is likely that the productivity per hectare can be increased by planting at a higher rate than the observed rate. The 'crown' density data suggests that the minimum planting density for the short cycle biomass crops in the region is 1200 plants per hectare for trees and mallees and 1800 plants per hectare for saltbush fodder. A range of factors, including species selection, rainfall, topography, water table depth, soil types and fertility and crop management will influence the optimal planting rate in each paddock.

Fig. 16. Location of FloraSearch survey sites and farm forestry trial sites in the Upper South East region and neighbouring area (Forestry SA, Primary Industries and Resources SA, FloraSearch Field Trial of Woody Germplasm).

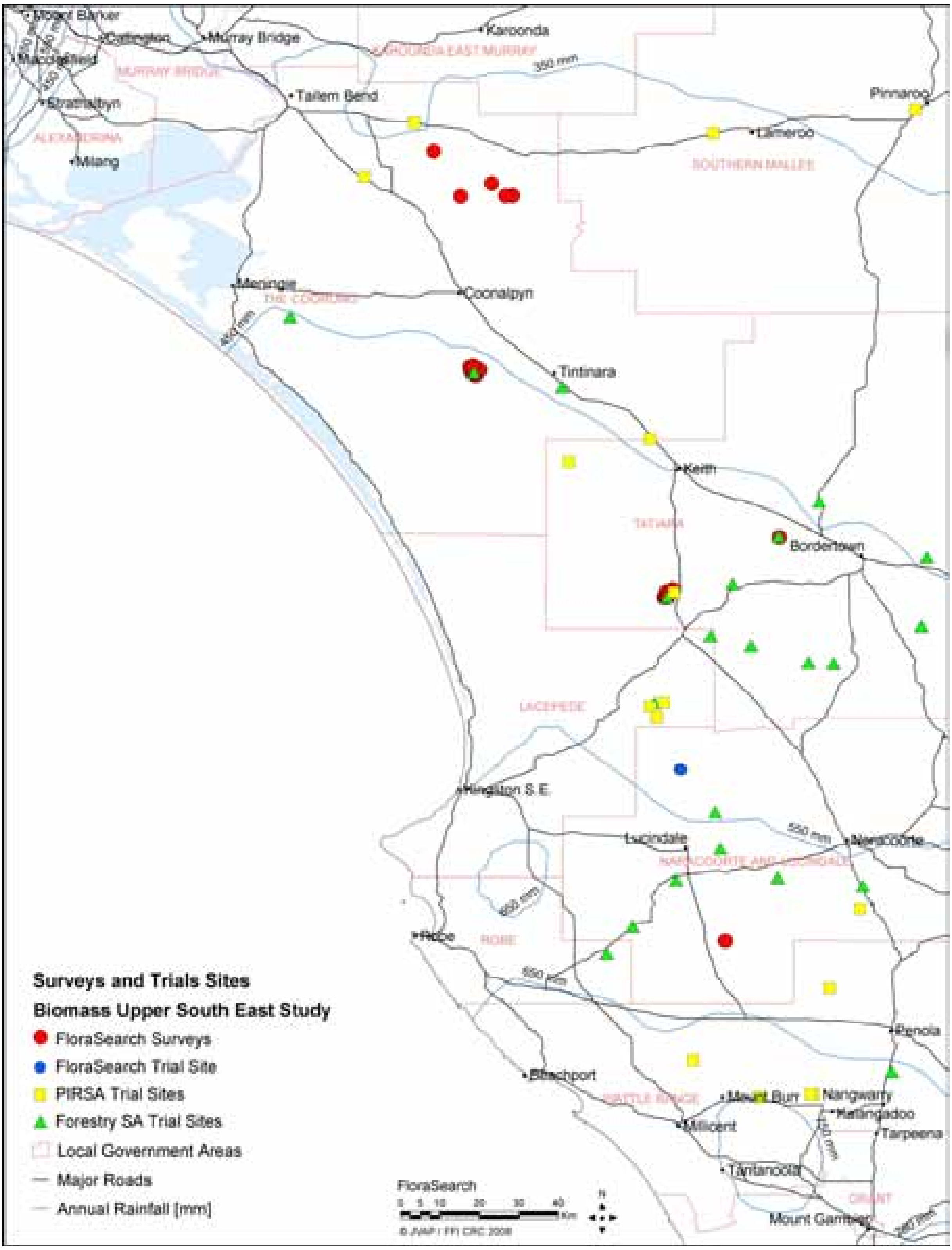


Table 19. Surveyed growth observations, stemwood volumes and biomass productivity of plant species in the Upper South East region.

Species #	Annual Rainfall [mm]	Age [years]	Observations	Height [m]	Basal Area [cm²]	Crown Area [m²]	Foliage Density [%]	Stemwood Volume x 1000 [m³plant]	Total Green Biomass [kg/plant]
Acacia mearnsii	492	12.5	32	9.89	186	10.56	57	80.48	136.99
Acacia pycnantha	387	7.0	3	3.37	97	8.32	86	14.47	68.03
Allocasuarina verticillata	492	10.9	30	8.58	477	28.43	38	195.37	365.29
Atriplex nummularia (ungrazed)	466	3.0	30	1.62	76	5.45	86	5.60	11.72
Corymbia maculata	492	10.8	25	9.01	273	9.68	52	99.40	134.84
Corymbia maculata	492	6.9	28	10.23	224	6.85	57	86.93	127.55
Eucalyptus camaldulensis	362	7.6	30	5.70	156	7.45	57	30.92	54.19
Eucalyptus camaldulensis	492	9.9	30	8.20	165	4.19	43	45.37	73.78
Eucalyptus camaldulensis [windbreak]	376	7.7	30	9.64	206	6.35	43	73.33	108.21
Eucalyptus camaldulensis [windbreak]	460	10.7	33	11.39	565	17.78	57	222.40	275.93
Eucalyptus cladocalyx [1]	460	10.7	30	14.92	520	22.02	57	327.72	382.40
Eucalyptus cladocalyx [2]	460	6.7	33	5.63	103	5.84	71	23.87	43.83
Eucalyptus cladocalyx [windbreak 1]	460	6.7	30	4.97	148	4.08	86	28.54	52.26
Eucalyptus cladocalyx [windbreak 2]	460	6.7	30	6.39	145	5.22	86	34.12	59.24
Eucalyptus diversifolia	460	12.7	3	5.50	209	15.58	66	51.55	175.49
Eucalyptus dumosa	387	12.0	31	3.80	74	8.14	62	12.83	39.75
Eucalyptus globulus	460	10.7	33	12.53	238	9.32	57	131.71	176.20
Eucalyptus globulus	492	6.8	30	11.13	250	7.21	57	100.30	144.45
Eucalyptus globulus ssp. globulus [1]	606	4.9	12	18.00	280	12.96	57	210.89	268.87
Eucalyptus globulus ssp. globulus [2]	606	4.9	12	19.20	267	9.91	57	212.12	270.63
Eucalyptus gomphocephala [windbreak]	460	12.0	6	12.35	1493	24.99	74	730.19	727.52
Eucalyptus grandis	492	6.8	30	10.57	236	8.65	57	90.41	133.11
Eucalyptus incrassata	374	8.0	30	3.73	95	6.13	71	13.41	41.35
Eucalyptus incrassata	460	12.7	3	3.55	132	14.79	71	18.97	92.23
Eucalyptus leucoxylon	492	10.7	33	8.60	233	7.65	43	72.43	107.66
Eucalyptus occidentalis	460	5.7	34	9.75	274	9.10	57	109.12	155.19
Eucalyptus occidentalis	492	9.9	30	10.46	207	6.30	57	89.50	129.83
Eucalyptus occidentalis [windbreak 1]	460	6.7	32	8.15	142	4.80	57	48.95	79.66
Eucalyptus occidentalis [windbreak 2]	460	6.7	30	10.23	191	5.28	57	89.15	129.96
Eucalyptus occidentalis [windbreak 3]	460	6.5	6	12.12	235	6.83	57	123.03	171.87
Eucalyptus oleosa	387	6.8	30	2.97	63	6.59	86	9.21	30.14
Eucalyptus porosa	387	6.7	33	3.86	134	12.85	71	23.02	65.60
Eucalyptus saligna	492	6.8	30	9.09	193	8.77	43	68.46	105.46
Eucalyptus viminalis	460	5.7	33	9.95	312	10.68	52	117.50	161.21
Eucalyptus viminalis ssp. cygnetensis	492	9.9	30	11.13	368	11.32	43	148.40	200.64

observations from block plantings except where indicated [windbreak], numbers represent repeated samples at a site.

Table 20. Observed mean annual increments (MAI) of stemwood volume, total green biomass and carbon dioxide sequestration equivalents, and rainfall-standardised values in the Upper South East region.

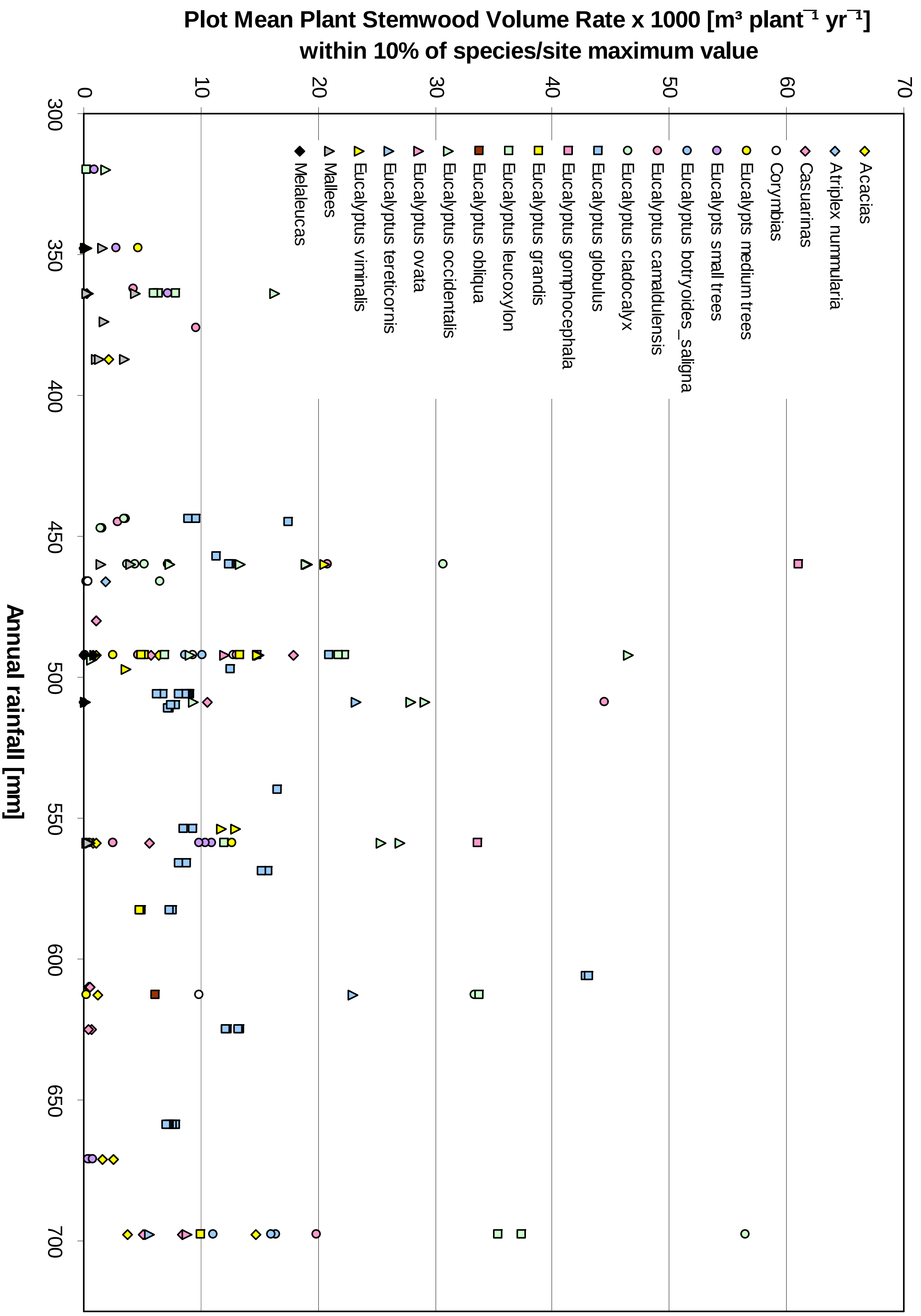
Species #	Annual Rainfall [mm]	Age [years]	Observed Plant Density [plants/ha]	MAI Stemwood Volume [m³/ha/yr]	Green Biomass [t/ha/yr]	CO_2 Sequestration equiv. [t/ha/yr]	MAI Stemwood Volume @ 500mm rainfall [m³/ha/yr]	Green Biomass @ 500mm rainfall [t/ha/yr]	CO_2 Sequestration equiv. @ 500mm rainfall [t/ha/yr]
Acacia mearnsii	492	12.5	3017	19.41	33.04	34.96	19.73	33.58	35.53
Acacia pycnantha	387	7.0	528	1.09	5.14	4.83	1.41	6.64	6.24
Allocasuarina verticillata	492	10.9	395	7.10	13.27	14.28	7.21	13.48	14.51
Atriplex nummularia (ungrazed)	466	3.0	966	1.83	3.83	2.71	1.96	4.11	2.91
Corymbia maculata	492	10.8	432	3.99	5.41	4.61	4.05	5.50	4.69
Corymbia maculata	492	6.9	685	8.69	12.75	10.86	8.83	12.96	11.04
Eucalyptus camaldulensis	362	7.6	142	0.58	1.02	0.74	0.80	1.40	1.02
Eucalyptus camaldulensis	492	9.9	1103	5.07	8.24	6.01	5.15	8.37	6.10
Eucalyptus camaldulensis [windbreak]	376	7.7	1027	9.78	14.43	10.52	13.01	19.19	13.99
Eucalyptus camaldulensis [windbreak]	460	10.7	793	16.42	20.37	14.85	17.85	22.14	16.14
Eucalyptus cladocalyx [1]	460	6.7	793	2.82	5.18	4.90	3.07	5.63	5.32
Eucalyptus cladocalyx [2]	460	10.7	440	13.44	15.69	14.58	14.61	17.05	15.85
Eucalyptus cladocalyx [windbreak 1]	460	6.7	939	4.00	7.33	6.70	4.35	7.97	7.28
Eucalyptus cladocalyx [windbreak 2]	460	6.7	1024	5.22	9.06	8.42	5.67	9.85	9.15
Eucalyptus diversifolia	460	12.7	1279	5.17	17.60	16.82	5.62	19.13	18.29
Eucalyptus dumosa	387	12.0	836	0.90	2.78	2.93	1.16	3.59	3.79
Eucalyptus globulus	460	10.7	898	11.01	14.73	12.53	11.97	16.01	13.62
Eucalyptus globulus	492	6.8	1010	14.79	21.30	18.12	15.03	21.64	18.41
Eucalyptus globulus ssp. globulus [1]	606	4.9	1143	48.91	62.35	53.05	40.35	51.44	43.77
Eucalyptus globulus ssp. globulus [2]	606	4.9	1136	48.89	62.38	53.07	40.34	51.47	43.79
Eucalyptus gomphocephala [windbreak]	460	12.0	500	30.42	30.31	27.21	33.07	32.95	29.58
Eucalyptus grandis	492	6.8	945	12.47	18.37	16.49	12.68	18.66	16.76
Eucalyptus incrassata	374	8.0	1120	1.89	5.81	5.82	2.52	7.77	7.78
Eucalyptus incrassata	460	12.7	712	1.06	5.16	5.16	1.15	5.60	5.61
Eucalyptus leucoxylon	492	10.7	1088	7.34	10.91	10.53	7.46	11.09	10.71
Eucalyptus occidentalis	460	5.7	708	13.54	19.26	17.34	14.72	20.93	18.85
Eucalyptus occidentalis	492	9.9	1198	10.85	15.74	14.42	11.03	16.00	14.66
Eucalyptus occidentalis [windbreak 1]	460	6.7	828	6.06	9.86	9.18	6.58	10.71	9.98
Eucalyptus occidentalis [windbreak 2]	460	6.7	1133	15.10	22.01	20.16	16.41	23.93	21.92
Eucalyptus occidentalis [windbreak 3]	460	6.5	1111	21.03	29.38	26.91	22.86	31.93	29.25
Eucalyptus oleosa	387	6.8	1585	2.15	7.04	7.99	2.78	9.10	10.33
Eucalyptus porosa	387	6.7	1522	5.23	14.89	12.88	6.75	19.24	16.64
Eucalyptus saligna	492	6.8	880	8.80	13.56	12.17	8.94	13.78	12.37
Eucalyptus viminalis	460	5.7	526	10.82	14.85	11.72	11.77	16.14	12.74
Eucalyptus viminalis ssp. cygnetensis	492	9.9	855	12.85	17.37	13.71	13.06	17.65	13.93

observations from block plantings except where indicated [windbreak], numbers represent repeated samples at a site.

Table 21. Species suited to the four major biomass industry classes and climatic zones of the Upper South East region.

Species	Common Name	Biomass Industry Group			
		Pulp-wood	Bio-energy	Oil Mallee	Fodder
Acacia mearnsii	Black Wattle	✓	✓		
Acacia retinodes	Wirilda or Swamp Wattle	✓	✓		
Atriplex nummularia	Old Man Saltbush				✓
Eucalyptus aromaphloia	Scent Bark	✓	✓		
Eucalyptus camaldulensis	River Redgum		✓		
Eucalyptus cladocalyx	Sugargum		✓		
Eucalyptus globulus	Tasmanian Bluegum	✓	✓		
Eucalyptus gomphocephala	Tuart		✓		
Eucalyptus horistes	WA Oil Mallee			✓	
Eucalyptus leucoxylon	SA Bluegum		✓		
Eucalyptus occidentalis	Swamp Yate	✓	✓		
Eucalyptus odorata	Peppermint Box			✓	
Eucalyptus oleosa	Red Morrell Mallee			✓	
Eucalyptus ovata	Swamp Gum	✓	✓		
Eucalyptus petiolaris	Eyre Peninsula Bluegum	✓	✓		
Eucalyptus polybractea	Blue Mallee	✓		✓	
Eucalyptus porosa	SA Mallee Box	✓		✓	
Eucalyptus viminalis ssp. cygnetensis	Rough-barked Manna Gum	✓	✓		

Fig. 17. Plot average annual plant stemwood production rates by annual rainfall for sites and species observations within 10% of each species by site maximum value.



Productivity studies in Western Australia

WA Acacia saligna

In Western Australia, the Department of Environment and Conservations (DEC) have established several *Acacia saligna* trials on a range of sites in the wheat-sheep zone. *Acacia saligna* has been observed to perform strongly compared with other species across a range of site types. We have observed four year old stands with growth rates exceeding 20 dry tonnes of above ground biomass per hectare per year. However, growth rates can vary markedly between and even within sites, and are more frequently in the range of 3-12 dry tonnes of above ground biomass per hectare per year. It has been observed to have dramatic growth in response to increased water availability at sites in south-western Australia. We have also noted pronounced edge effects in block and belt plantings, with plants on the outside rows exhibiting significantly better growth than interior plants. These differences are ostensibly due to the edge plants having access to water from a much greater soil profile volume. In *Acacia saligna* review section of the FloraSearch 3b (Hobbs *et al.* 2009b) we present additional information of productivity data from Australia and overseas.

A trial site was established by WA DEC near Lake Bryde in Western Australia and stem diameters of each plant measured at 2 years of age. In other trials at Katanning and Narrogin productivity assessments were made at 2.8 years of age. Estimated green biomass production has been determined from destructive sampling, stem basal area measurements and allometric equations (Table 9), planting density and plot survival (Table 22).

WA Oil mallees

Trials of *Eucalyptus polybractea* have been extensively planted by WA DEC across a range of sites in the 1990's and during the WA Search project. A notable 10 year old site near Kalannie, with extensive seedling belt plantings, has been very productive (18.7 t/ha/yr of green biomass) and undoubtedly benefits from additional access to water from 2 row belt designs and lateral subsurface water flows on this site (see Table 22). WA DEC is currently conducting a separately study funded by the Joint Venture Agroforestry Program and other partners on "Productivity of mallee agroforestry systems under various competition management regimes" this study will soon provide more detailed information of oil mallee productivity on a range sites and under different silvicultural practices.

WA Trees

Measurements of *Eucalyptus rudis* productivity have been made at a site at Katanning (planted 2003), which had three replicates of each of two provenances. Trees in the core of each plot were measures (height and stem basal area at 10cm), and then some destructive sampling was performed with 36 trees being cut and weighed. Good correlations were found between stem basal area and whole tree biomass to predict productivity rates at these sites (Table 22). Additional data from measurements and productivity estimates of WA Search project plots at Corrigin and Bolgart (greening WA seedlings) have also been included in Table 22. Two trials of *Eucalyptus rudis* provenances were established by WA DEC in 2005 at Gillingarra and Crossman. The mean height (and stem basal area) of the best 10 provenances at 2 years of age was 2.7m (38cm^2 at 1.5m high) for Gillingarra and 3.3m (166 cm^2 at 10cm high) at Crossman.

Other limited studies of tree productivity have been conducted on *Eucalyptus occidentalis* at Katanning (450mm MAR) and *Casuarina obesa* at Mount Barker (732mm MAR). These studies have combined destructive sampling and allometric evaluations (see Table 9) to estimate productivity rates for these tree biomass crops (Table 22).

Table 22. Selected species initial productivity observations at trial sites in Western Australia.

Species (Trial Site)	Annual Rainfall [mm]	Age [years]	Height [m]	Plant Basal Area at 0.1m [cm²]	Plant Density * [plants/ha]	Green Biomass [t/ha/yr]	CO_2 Sequestration equiv. [t/ha/yr]
Acacia saligna (Lake Bryde)	353	2	-	-	*(2000)*	3.7	3.4
Acacia saligna wheatbelt form (SE Katanning)	450	2.8	-	-	2043	5.5	5.0
Acacia saligna coastal form (SE Katanning)	450	2.8	-	-	2069	8.0	7.3
Acacia saligna cyanophylla form (East Beverley)	420	2.6	2.5	70	1000	6.4	5.9
Acacia saligna (Narrogin)	539	2.8	-	-	1732	16.1	14.8
Casuarina obesa (Mount Barker)	732	6.8	7.1	196	425	5.8	5.3
Eucalyptus occidentalis (Katanning)	450	4.8	3.7	54	1216	4.3	3.9
Eucalyptus polybractea (NE Kalannie, seeding, 2row belts)	357	10	5.9	164	2083	20.4	18.7
Eucalyptus rudis (Bolgart)	440	3	-	-	*(1666)*	3.2	2.9
Eucalyptus rudis (Katanning)	450	4	-	-	*(1222)*	4.9	4.5
Eucalyptus rudis (Corrigin)	375	4	-	-	*(1600)*	3.4	3.1
Eucalyptus rudis (Crossman, best 10 provs)	615	2	3.3	166	-	-	-
Eucalyptus rudis (Gillingarra, best 10 provs)	459	2	2.7	38[#1.5]	-	-	-

[#] measurement height [m] if different from 0.1m; * Observed plant density at assessment, (*italics*) represent original planting density.

South Australian oil mallee study

Background

The story of the eucalyptus oil industry began with Joseph Bosisto commencing operations at Dandenong, Victoria in 1852 (Small 1981). Demand for the product encouraged the extraction industry to spread to other states and from 1900 to 1950 Australia was the world's largest supplier of eucalyptus oil. Since that time Australia has been largely priced out of the market and has since become a net importer of these oils. Consequently the establishment of new eucalypt plantations solely for oil extraction is no longer an attractive investment in Australia.

In the second half of the 1900's salinity became an increasing problem due to the removal of native vegetation for agriculture, particularly in the wheatbelt of Western Australia (Stanton-Hicks 2002). Often caused by rising watertables, one of the methods used to combat it is the return of deep-rooted perennials like mallees into the landscape (Eastham *et al.*1993). In Western Australia, in the early 1980's the use of oil mallee species for the production of 1,8-cineole was proposed to provide an extra economic benefit from the salinity mitigation plantings. The long term profitability of these plantings requires larger markets for the commodities, lower production costs and greater efficiencies in the production processes (Stanton-Hicks 2002, Bartle *et al.* 2007).

In the 1990's interest developed in using Western Australian oil mallees as feedstock for integrated tree processing plants (ITP). A trial plant designed to produce electricity, charcoal and activated carbon, as well as cineole was built at Narrogin in W.A. The plant utilises the total above ground biomass produced by the oil mallees rather than just the leaf fraction, as has been the case in most older eucalyptus oil production industries. By generating extra income streams from the other plant fractions the cost of production of the individual products is reduced making them more competitive (Enecon 2001).

Many earlier studies on oil mallees have concentrated on oil production, water use, early growth and young coppice regrowth (Eastham *et al.*1993, Eastham *et al.*1994, Milthorpe *et al.*1994, Wildy *et al.* 2000a, b). The harvest of sapling or coppice regrowth material at 1 to 4 years of growth is in line with traditional eucalyptus oil production practices and has a number of advantages. The short time period between investment and return is attractive to farmers. The plants are maintained in a low bushy state said to reduce competition with surrounding crops. The low thin stems are cheaper and easier to harvest with current technologies and the short rotation maintains the plants in the vigorous juvenile growth stage, increasing oil yields (Wildy *et al.* 2000a).

The very short rotation approach is valid if eucalyptus oil or cineole is the only component of the harvestable biomass with a substantial financial return. If however, the woody fraction has a substantial value as well, then the very short rotation approach may diminish the financial return available from letting the plants grow longer to develop the woody fraction. If that is the case, are the species currently planted for eucalyptus oil production the ones we would select if oil were a secondary or co-product of a renewable energy integrated tree processing plant or a wood fibre integrated tree processing plant?

To address this question it was decided to examine which mallee *Eucalypts* could possibly be used for an ITP scenario in southern Australia. Once the species of interest were chosen, we needed to obtain oil samples and take measurements of each species and apply that data to existing models of productivity. Fortunately a single site was found that contained every species of interest. The Currency Creek Arboretum (CCA), located close to the town of Currency Creek in South Australia, is a specialist eucalypt (*Angophora, Eucalyptus* and *Corymbia*) arboretum (Nicolle 2008). The ability to sample and test at known ages, all the selected species on one site reduced site and climate variations and enabled the sampling and measurements to be conducted over a short time frame for significantly lower costs.

Methods

A literature and data search was conducted to select candidate mallee species for further investigation, with prospective candidates chosen on past oil figures, current and historic oil production and from anecdotal reports of leaf oil. 37 species/subspecies that grow within or adjacent to the FloraSearch zone were selected from across the country.

The Currency Creek Arboretum has plantings of all the species of interest providing the opportunity to sample their productivity under similar conditions at one site. The arboretum was established in 1992 on 32 hectares of well drained non-calcareous sandy loam and has an annual rainfall of around 450 mm. The main site variable is the age of the plants, with plantings ranging from 4.5 to 13.5 years of age at the time of sampling. Each provenance planted at CCA is of single parent seed origin and is planted in rows of four plants within block plantations, but typically in unreplicated plots. Each block consists of rows spaced 3 or 4 meters apart with plants spaced 3 meters apart along the rows. In some instances the number of available individuals was less than four due to mortality. In other cases extra provenances were available and included for comparison (Nicolle 2008). The design of these plantings do not allow for detailed statistical analyses of species differences and variations within each species or provenance. It does however provide useful indication of species performance and contrasts in yields per hectare.

Eucalyptus cneorifolia was of particular interest due to its natural occurrence close by and its history as a species commercially exploited for its leaf oil content. As a result a wild population at Waitpinga and 2 groups of plantation grow specimens at Murray Bridge were included in the sampling along with the CCA plants.

Early autumn was chosen for sampling as most species carry largely healthy mature leaves, being after the spring/summer growing period (Berry 1947, Steer 1995) and before the more dormant winter period (Wildy *et al.* 2000a). Measurements were carried out on the 5th and 6th of March, 2007. Leaf samples were collected on the 7th of March 2007 and sent by airfreight to Perth for leaf oil analysis the following day.

To obtain information on the biomass productivity of each species, several plant measurements were made on all plants within each plot so that allometric relationships with mallee biomass could be applied (see “Mallee” models for “stemwood” and “twig” fractions from Table 7, and mallee “leaf” fractions from Table 8). The following measurements were recorded for each tree: plant spacing; height; crown widths (across row and along row); stem diameters at 0.5m and 1.3m and stem counts at both heights. For smaller plants (<1.5m high) the observation height of stem measurements were reduced to 0.5m or 0.2m. Observations on crown leaf density (0-100%), form and mortality were also recorded. Indicative estimates of biomass production rates (and biomass components) were derived from allometric equations of plant biomass, standing plant density (trees/ha) and age.

Leaf samples were then collected and analysed to obtain an insight into the leaf oil potential of the species. Healthy mature leaves were collected from several positions on each plant and the samples from each provenance combined to form 43 bulked 9 gram samples for testing. These samples were wet weighed in the field, placed in coded bags and kept cool. The samples were then sent fresh by airfreight to Dr Peter Grayling, WA Department of Environment and Conservation for total oil yield, cineole yield and moisture content.

The bioenergy price is derived from the gross calorific value of several eucalypt species against that of Australian export grade steaming coal and the price adjusted to match (Hobbs 2009b, ABARE 2008). The oil values quoted in this study are based on recent international essential oil market prices for February 2008 (George Uhe 2008) and recent exchange rates (AUD=0.9116USD, RBA 2008, 25/03/2008). *Eucalyptus globulus* oil (80% cineole) is valued at AU$7.02/kg and Eucalyptol (99.5% cineole) at AU$9.00/kg. Further details of world Eucalypt oil prices and markets are contained within Hobbs *et al.* 2008c. The chemical makeup of non-cineole components of oil yields have not been identified in this study. The Eucalypt oils market is dominated by trade in cineole, however, other oil component prices have wide ranging values that can be either lower or higher than cineole depending on specific oil types. Without further chemical and market analysis we have nominated the total oil yield values equate to similar prices to that of raw *Eucalyptus globulus* oil.

Results

Leaf oil content

In this study we have focussed in oil yields from fresh leaf fractions of plant biomass as current and proposed oil mallee production systems utilise freshly harvested materials for oil extraction. Yields of volatile Eucalypt oils using current distillation technologies are improved when processing freshly harvested leaves (Abbot 1989). Oil testing results (total oil and cineole content) from 43 bulked fresh leaf samples for a range of Eucalypts are presented in Table 23 and Fig. 18. Surprisingly 2 species with established histories of use for oil production, *Eucalyptus polybractea* and *Eucalyptus viridis* ssp. *wimmerensis,* are located in the lower half of rankings for oil production. *Eucalyptus cneorifolia,* another species with a history of oil extraction, has a wide range of results, for both total oil yield and cineole yield. However, leaf oil content is only one part of the system for producing commercial quantities of oil. The fully system relies on a combination of both leaf oil content and total annual production of leaf biomass per hectare.

Green biomass production

From these exploratory results *Eucalyptus viridis* ssp. *wimmerensis, Eucalyptus odorata, Eucalyptus sporadica* and *Eucalyptus porosa* easily produced the most green biomass (t/ha/yr), all exceeding 6 t/ha/yr and *Eucalyptus viridis* ssp. *wimmerensis* producing almost 9 t/ha/yr (see Table 23). The next

10 productive species returned results from 3.5 to 2.5 t/ha/yr and include the notable oil mallee species *Eucalyptus polybractea*, *Eucalyptus loxophleba* ssp. *lissophloia* and both sub species of *Eucalyptus angustissima.* Fifteen species failed to return results of 1 t/ha/year at this site and suggest little commercial value as crops. Interestingly, *Eucalyptus kochii* ssp. *plenissima, Eucalyptus horistes* and a provenance of *Eucalyptus oleosa* ssp. *oleosa,* all fell within this group of poor performers.

Green biomass fractions

The 4 best producers of total green biomass all had the majority (73%+) of their biomass held in the woody fraction (Table 23). Eight of the following 10 species by contrast had 30% or more of their total green biomass held in the leaf and small twig fraction, the exceptions being *Eucalyptus angustissima* ssp. *quaerenda* (29%) and *Eucalyptus loxophleba* ssp. *lissophloia* (25%). Of the others, 14 species had 40% to 62% of their total green biomass held in the leaf and small twig fraction but only 3 of those species (*Eucalyptus flocktoniae* ssp. *flocktoniae*, *Eucalyptus cneorifolia* and *Eucalyptus oleosa* ssp. *ampliata*) produced around 2 t/ha/yr of total green biomass. These fractional breakdowns are important when considering the economic returns from each species in integrated tree processing enterprises, as the return for investment will depend on the value of each biomas component.

Eucalyptus oil and cineole production

The percentage of leaf and small twig in the total green biomass results directly affects the amount of *Eucalyptus* oil and cineole able to be extracted from any given species. A species that produces more leaf and twig may produce more *Eucalyptus* oil and cineole per hectare than a species with a higher leaf oil content but less leaf and twig biomass per hectare. *Eucalyptus pulverulenta, Eucalyptus porosa, Eucalyptus angustissima* ssp. *quaerenda, Eucalyptus hypochlamydea, Eucalyptus aspratilis, Eucalyptus angustissima* ssp. *angustissima* and *Eucalyptus loxophleba* ssp. *lissophloia* all returned results over 30 kg/ha/year of total oil, however, several of these had only modest cineole yields (Table 23). *Eucalyptus pulverulenta* along with both species of *Eucalyptus angustissima* are also amongst the best cineole producers but *Eucalyptus bakeri,* and *Eucalyptus kochii* ssp. *kochii* rank highly here due to the high proportion of cineole in their oil.

Commodity values and returns

The commercial value of any of these species for oil production or integrated tree processing (ITP) is found in the combination of the returns from Eucalyptus oil and/or biomass for bioenergy components (see Table 23). Fig. 19 also illustrates differences between indicative commodity production values (Australian $/ha/year) due to variations in oil components, prices and plant productivity. *Eucalyptus porosa* and *Eucalyptus odorata* are clearly preferred candidates for oil and bioenergy ITP due to the preferred combination of their oil and biomass production capacities and current commodity prices. *Eucalyptus pulverulenta* heads a list of 8 species that draw their rates of return more from their oil production capacity than their biomass energy value. While *Eucalyptus sporadica* and *Eucalyptus viridis* ssp. *wimmerensis* have similar rates of return due to their bioenergy values. In this limited study and location it must be noted that *Eucalyptus porosa* and *Eucalyptus odorata* may produce significantly better (2 x) returns than the current ITP candidate *Eucalyptus polybractea*.

As the price for the cineole component of *Eucalyptus* oil is higher than the total oil price we have also included the combination of the cineole only value with the bioenergy value of each species in Fig. 19. This changes the order of results to some degree with *Eucalyptus angustissima* ssp. *quaerenda, Eucalyptus pulverulenta* and *Eucalyptus odorata* heading the list of candidates. *Eucalyptus odorata* still remains a strong candidate for oil and bioenergy ITP due to return from the bioenergy commodity stream. Some species, such as *Eucalyptus bakeri* and *Eucalyptus kochii* ssp. *kochii* increase in their overall commodity value due to their high cineole content. The total commodity production value from species that have lower cineole content, but are relatively rich in other oils, will depend on the prices paid for less well known oil types.

Discussion and conclusions

Single site findings and their relevance on a broader scale

While sampling all the species at one site was advantageous from a site influence point of view, many of the species were well out side their natural range and in a soil type on which they are not naturally found. *Eucalyptus bakeri* for example is native to far northern New South Wales and south-eastern Queensland just north of the FloraSearch zone where it grows to 12 m on red earths and grey clay soils (Brooker and Kleinig 1994), far different to the conditions at Currency Creek. While *Eucalyptus bakeri* performed well in this study, it and others may perform better closer to their own environments.

Wildy *et al.* (2000a) found that different species of mallee best suited particular niches and climatic zones. His work suggests that a suite of oil mallee species would need to be developed to select different species to match environments not suited to current oil mallee candidates. Our results from the single Currency Creek Arboretum site (CCA) can only give an indication of what species may prove productive in cultivation, but this work suggest some of the species should be well suited to sites with similar soils and climates to our study location. Some of the best performing species identified in this study may also prove to be adaptable and productive elsewhere. Further research and trials are therefore needed for this evaluation before any premature promotion of these species towards full scale commercial plantings.

Small sample size and species variation

The sample size ranged from 1 to 4 plants of any 1 provenance, located in a single row plot, depending on mortality, and all members of those samples originated from single parent seed sources, not chosen specifically for their oil production qualities (Nicolle 2008). Eucalyptus cneorifolia, a species that occurs naturally close to the CCA with a history of use in the Eucalyptus oil industry, was sampled at three locations away from the CCA in addition to the standard assessment at the CCA. Total oil rates from the 4 groups of Eucalyptus cneorifolia varied from 4.7 to 2.0% leaf oil and 2.1 to 0.56% cineole content by fresh weight, with the percentage of cineole within the total oil ranging from 27 - 75%. These results demonstrate the wide variation within species and the need to select the best germplasm for cultivation and improvement.

The small genetic samples at CCA are representative of the qualities of the parent genetics and can only be used as a gross indicator of a species wider performance. Site micro niches may also influence the performance of small samples of this kind by the creation of localised advantageous or detrimental conditions. Thus larger plantings of more diverse genetics chosen for their industrial feed stock quality would be recommended before utilising many of these species commercially. In some cases such as *Eucalyptus polybractea* much of that work has been done but for many of the species that performed well in this study little or no plant selection has been carried out.

Table 23. Oil yield and production values of oil mallee species from Currency Creek Arboretum site (sampled Autumn 2007).

Species [Provenance]	Age [yrs]	Plant Dens-ity [tph]	Green Biom-ass [t/ha/yr]	Biomass Fractions		Oil Yield [%gw]		Production [kg/ha/yr]		Commodity Value [$/ha/yr]		
				Wood & Twig [%gw]	Leaf [%gw]	Total	Cineole	Total Oil	Cineole	Energy @ $25/ green t	Total Oil @ $7/kg	Comb-ined Total
Eucalyptus porosa [Mt. Wudinna]	12.6	500	6.39	75%	25%	2.42	0.67	39.0	10.7	159	273	432
Eucalyptus odorata [Kangaroo Island]	11.6	500	8.88	73%	27%	1.14	0.33	27.7	8.0	221	194	415
Eucalyptus pulverulenta [Lithgow]	10.6	500	2.32	55%	45%	4.48	2.70	47.1	28.4	57	330	386
Eucalyptus angustissima ssp. *quaerenda* [Lake Chinocup]	13.6	625	3.37	71%	29%	3.93	3.08	38.4	30.2	83	269	352
Eucalyptus aspratilis [Mt. Day]	13.6	625	3.09	68%	32%	3.34	0.71	33.2	7.0	76	232	309
Eucalyptus angustissima ssp. *angustissima* [Upper Lort River]	13.6	625	3.09	69%	31%	3.41	2.33	32.8	22.5	76	229	306
Eucalyptus incrassata [Lochiel]	11.6	500	3.08	69%	31%	3.08	0.66	29.6	6.3	76	207	284
Eucalyptus loxophleba ssp. *lissophloia* [Norseman]	13.6	625	2.81	75%	25%	4.34	2.19	30.1	15.2	70	210	280
Eucalyptus hypochlamydea [Youanmi]	6.6	500	1.60	44%	56%	3.78	1.95	33.9	17.5	39	237	276
Eucalyptus bakeri [Mt. Moffit]	10.6	500	2.96	68%	32%	2.93	2.44	28.1	23.5	73	197	270
Eucalyptus sporadica [Needilup]	13.6	625	8.02	74%	26%	0.44	0.01	9.2	0.2	200	65	265
Eucalyptus viridis ssp. *wimmerensis* [Bordertown]	10.6	500	8.98	80%	20%	0.32	0.21	5.7	3.8	224	40	264
Eucalyptus loxophleba ssp. *gratiae* [Harris Nature Reserve]	13.6	625	2.15	66%	34%	3.74	2.47	27.2	18.0	53	191	244
Eucalyptus flocktoniae ssp. *flocktoniae* [Twertup]	9.6	500	2.05	57%	43%	3.03	0.76	26.6	6.7	51	186	237
Eucalyptus kochii ssp. *kochii* [Dalwallinu]	13.6	625	1.58	62%	38%	4.31	3.53	26.1	21.4	39	183	222
Eucalyptus cneorifolia [Wilson Hill]	12.6	500	2.02	58%	42%	2.73	2.05	23.2	17.4	50	162	212
Eucalyptus incrassata [Cape LeGrand]	9.6	500	3.53	65%	35%	1.39	0.36	17.1	4.4	88	120	208
Eucalyptus polybractea [West Wyalong]	12.6	500	2.92	67%	33%	1.87	0.71	18.0	6.8	73	126	199
Eucalyptus oleosa ssp. *cylindroidea* [Scadden]	9.6	444	2.51	63%	37%	1.80	0.25	16.7	2.3	62	117	180
Eucalyptus oleosa ssp. *oleosa* [Tarcoola]	6.6	500	1.21	68%	32%	5.08	0.57	19.6	2.2	30	137	167

Species [Provenance]	Age [yrs]	Plant Dens-ity [tph]	Green Biom-ass [t/ha/yr]	Biomass Fractions		Oil Yield [%gw]		Production [kg/ha/yr]		Commodity Value [$/ha/yr]		
				Wood & Twig [%gw]	Leaf [%gw]	Total	Cineole	Total Oil	Cineole	Energy @ $25/ green t	Total Oil @ $7/kg	Comb-ined Total
Eucalyptus oleosa ssp. *ampliata* [Toolinna Cove]	12.6	500	1.91	54%	46%	1.19	0.04	10.6	0.3	48	74	122
Eucalyptus brachycorys [Marchagee]	9.6	500	0.63	57%	43%	5.62	0.63	15.2	1.7	15	106	121
Eucalyptus canescens ssp. *canescens* [Cook]	12.6	444	0.93	62%	38%	3.84	0.56	13.7	2.0	23	96	119
Eucalyptus burracoppinensis [Burracoppin]	13.6	625	1.08	58%	42%	2.62	1.15	12.0	5.3	27	84	111
Eucalyptus horistes [Mullewa]	13.6	556	0.91	57%	43%	2.77	2.30	10.9	9.1	23	76	99
Eucalyptus erythronema var. *marginata* [Dalwallina]	13.6	365	0.93	73%	27%	4.28	1.27	10.8	3.2	23	75	98
Eucalyptus percostata [Devils Peak]	9.6	444	1.14	58%	42%	1.97	0.38	9.5	1.8	28	67	95
Eucalyptus oleosa ssp. *oleosa* [Great Victoria Desert]	6.6	500	0.91	44%	56%	1.82	0.16	9.2	0.8	22	64	87
Eucalyptus froggattii [Mitre]	6.6	500	1.57	57%	43%	0.73	0.13	4.9	0.8	39	34	73
Eucalyptus thamnoides [Kambellup]	4.6	500	0.86	38%	62%	1.19	0.25	6.3	1.3	21	44	65
Eucalyptus oleosa ssp. *ampliata* [Port Germein]	11.6	389	2.59	64%	36%	0.00	0.00	0.0	0.0	65	0	65
Eucalyptus gillii [Angepena]	9.6	500	0.43	52%	48%	3.26	0.41	6.8	0.8	11	47	58
Eucalyptus kochii ssp. *plenissima* [Lake Deborah]	4.6	389	0.35	76%	24%	7.47	3.92	6.3	3.3	9	44	53
Eucalyptus erythronema ssp. *erythronema* [Walgoolan]	5.6	444	0.32	64%	36%	5.33	2.66	6.3	3.1	8	44	52
Eucalyptus youngiana [Lake Minigwal]	12.6	500	0.43	45%	55%	1.68	0.59	4.0	1.4	11	28	38
Eucalyptus peeneri [Serpentine Lakes]	8.6	500	0.46	61%	39%	2.05	0.17	3.7	0.3	11	26	37
Eucalyptus leptopoda ssp. *arctata* [Mullewa]	13.6	556	0.30	72%	28%	1.67	1.22	1.4	1.0	7	10	17
Eucalyptus leptopoda ssp. *leptopoda* [Bonnie Rock]	13.6	365	0.10	51%	49%	1.75	1.14	0.9	0.6	3	6	9
Eucalyptus leptopoda ssp. *elevata* [Serpentine Lakes]	13.6	491	0.08	63%	37%	1.25	0.49	0.4	0.1	2	3	5
Eucalyptus leptopoda ssp. *subluta* [Menzies]	6.6	222	0.06	80%	20%	2.99	0.98	0.4	0.1	2	3	4

Fig. 18. Total freshweight leaf yields of cineole and other oils for a range Eucalypt species sampled at Currency Creek Arboretum, South Australia.

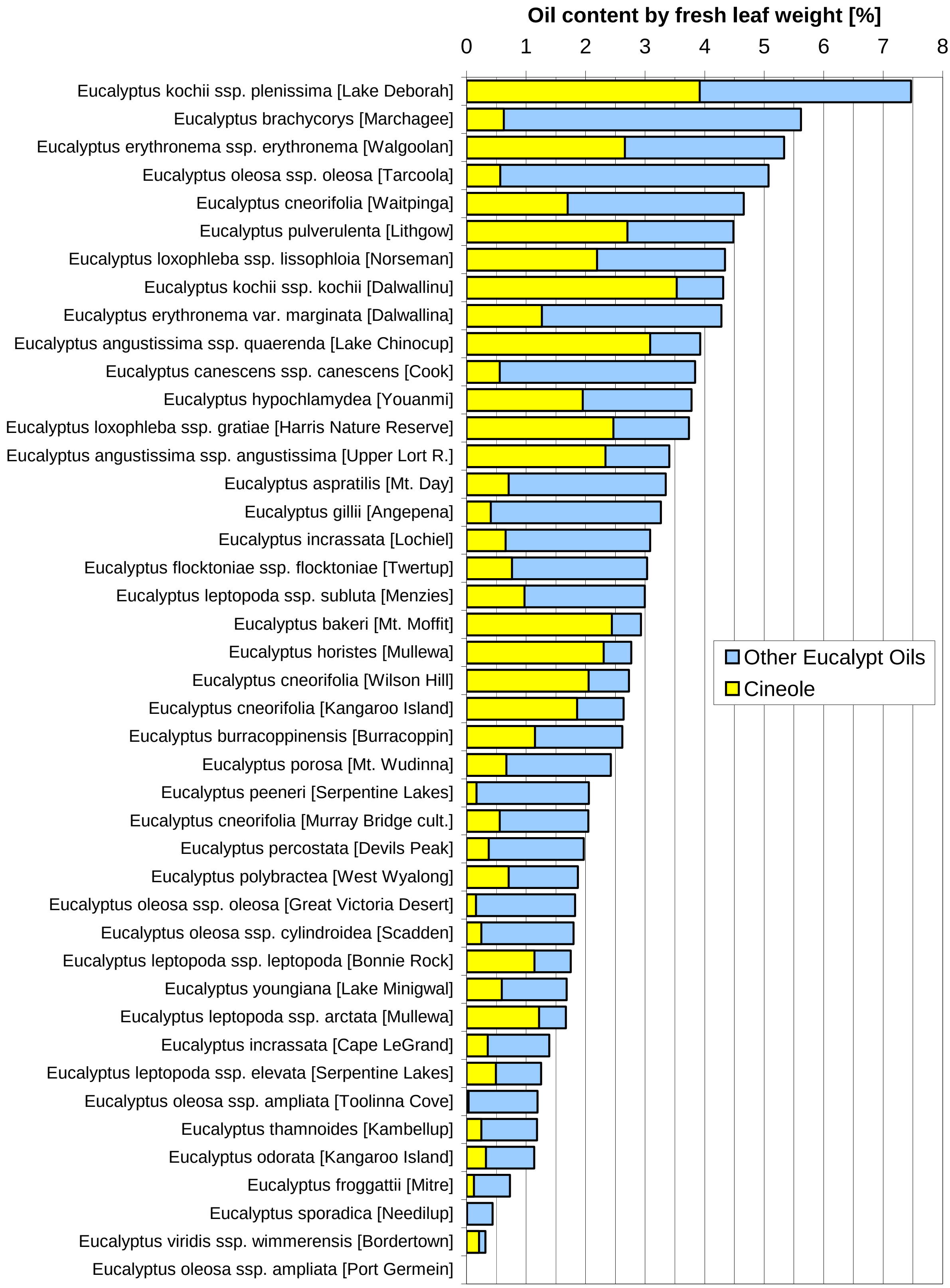
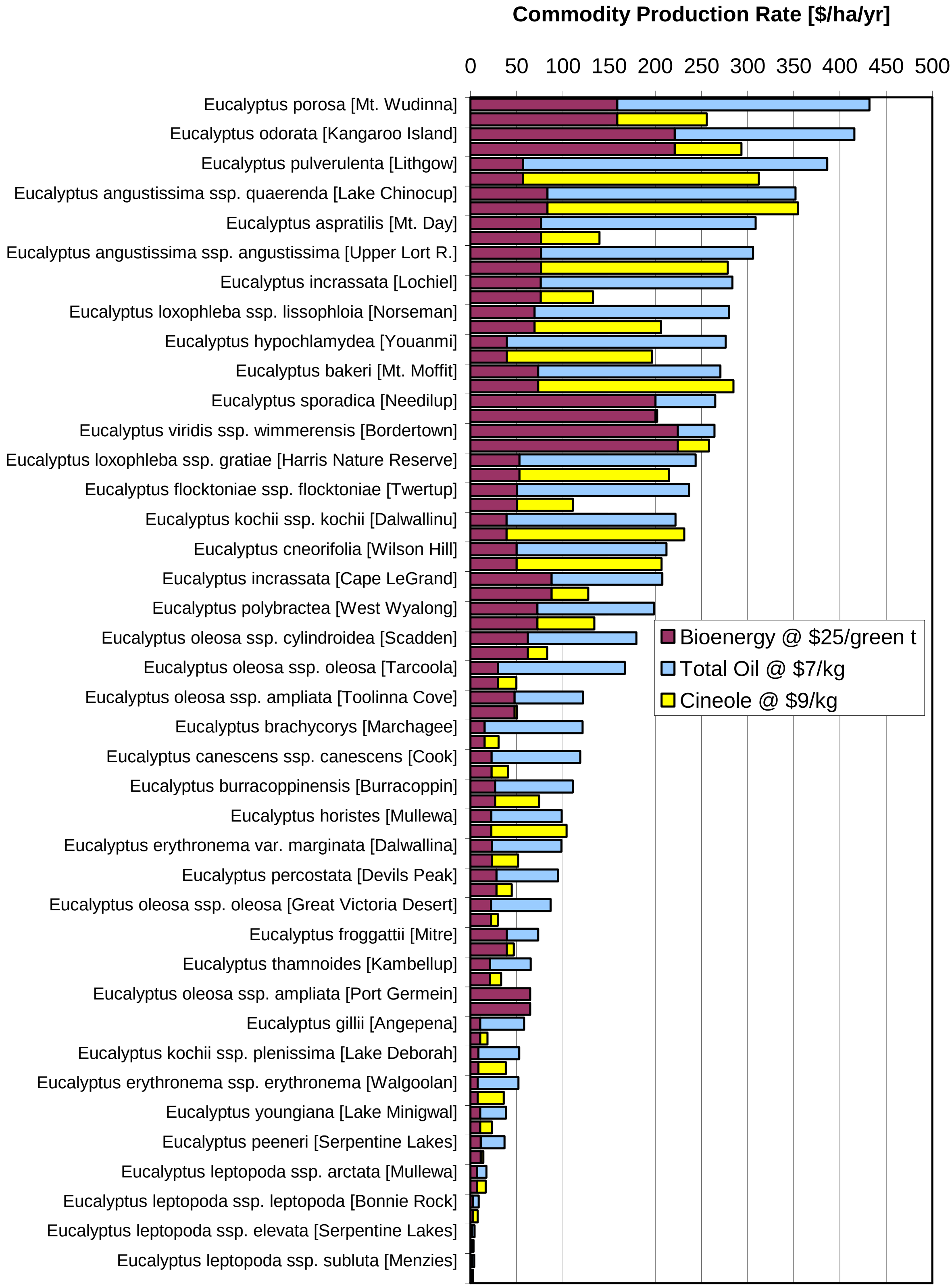


Fig. 19. Comparison of commodity values for oil mallee species, including influences of differing production rates, prices and yields of Eucalyptus oils.



Eucalyptus oil and annual fluctuations

While the constituents that make up the oil of any individual Eucalypt species vary little from season to season (Nicolle *et al.* 1998) for most species the total yield fluctuates. The amount and constituents within Eucalyptus oil vary not only from species to species but within the germplasm of individual species, as can be seen from our results for *Eucalyptus cneorifolia*. *Eucalyptus cneorifolia's* oil yield has been found to vary through out the year peaking between October and December being at it's lowest in May and June (Berry 1947, Steer 1995) these finding were repeated for a number of other mallee species tested in Western Australia (Wildy *et al.* 2000b). We chose to test in early autumn, when the yield of Eucalyptus oil is typically between the two extremes, in an attempt to responsibly report on oil yield from these species.

Species with other considerations/problems

The term 'mallee' applies to any Eucalypt species that has the potential to grow with multiple stems from underground lignotubers. However, the variation within this habit is far from uniform and some of those variations may prove an inhibition to the commercial use of an individual species. For example *Eucalyptus pulverulenta* performed extremely well by the metrics we applied in this study but rarely develops petiolate adult leaves and the juvenile leaves, being paired and sessile, may prove difficult to separate from the woody fraction in production processes.

Another consideration when selecting a species for integrated tree processing is the coppicing survival rate. Both subspecies of *Eucalyptus angustissima* performed well in this study but Wildy (*et al.* 2000a) found *Eucalyptus angustissima* showed low levels of survival after harvest, particularly if harvested over the summer months, and advocated longer harvesting cycles for this species than the very short rotations carried out in that study.

Opportunities and future research

Many of the species in this study have not been examined from an integrated tree processing plant (ITP) viewpoint in the past, particularly those from eastern Australia. The opportunity exists to select some of the better performers from this study and examine them more closely. Species like *Eucalyptus bakeri, Eucalyptus porosa* and *Eucalyptus odorata* could well prove outstanding candidates for ITP industries in the future producing both renewable energy and industrial solvents to replace the petroleum based solvents in use today. The limited gene pool for each species that was present at the Currency Creek Arboretum (CCA) cannot reflect the genetic variety of species like *Eucalyptus oleosa* or *Eucalyptus incrassata* that are found across large sections of southern Australia

Several questions need to be answered before any of these species can be used in an ITP process. We need to know how long we should grow any particular mallees species to maximise return on investment? If we need to grow the species longer to maximise the return from the woody fraction what extra costs might be involved in harvesting older mallees that could impact on profitability? Further, what impact would year round harvesting have on the coppicing and survival abilities of any species selected? Further research will be required to address some of these key issues, and to build on the lessons learnt from known oil mallee species such as *Eucalyptus polybractea* and *Eucalyptus cneorifolia*.

Agronomic Evaluations

Influence of agronomy and production systems on yields

The influence of agronomic designs and management greatly influence the productivity of woody biomass crops. The length of harvest cycles determines average production rates as species both mature and utilse soil moisture / nutrients. Biomass fractions also change with plant maturity and stocking density. Young plants are predominated by leaf and twig biomass fractions and grow into adults typically dominated by greater stemwood biomass. Each industry type, product stream and harvest technology have preferences for particular plant forms and yields of biomass fractions.

FloraSearch has started to evaluate some of these agronomic issues through specific studies aimed at exploring plant responses to sites, planting designs and spacing, establishment issues, harvest cycles, water interceptions, timing of harvests and coppicing. Preceding subsections, on field trials of short cycle systems, partially addresses some of the issues of site, species and provenance selections on productivity. The following subsections illustrate some of issues being investigated, some results to date, and highlight recent experiments and trials established to further understanding planting density/plant competition issues and coppicing influences on productivity.

Long cycle trials

SA-Vic 2004 Long cycle trials (3 sites, 3 years old)

In 2004, another 2272 individuals were planted over 3 trial sites (Murray Bridge, Roseworthy and Rutherglen) representing 5 different species (Table 41). At Murray Bridge and Roseworthy all 5 species were planted, while at Rutherglen available trial site space restricted the plantings to 2 species only. At each site 4 replicate plots for each species were planted at 3 x 3 m spacing, resulting in a planting density of 1111 trees per hectare to suit long-rotation forestry initial planting rates. The species chosen for these trials represented dry country forestry species that have been included in trials in the past with the view to produce sawlogs (Kiddle *et al.* 1987, Boland *et al.* 1992, Stackpole and Hamlet 1998, Bird 2000, Harwood *et al.* 2001). Final stocking rates (after thinnings) for long-cycle species may be as low as 200 stems per hectare in lower rainfall regions.

The same allometric relationships and green biomass calculations used in the short cycle trials were applied to assess the performance of the long cycle trials at 3 years of age ("FTWG plant volumes" see Table 8). Similar performance pattern can be observed between sites, with the Rutherglen plantings out performing the same species planted at the 2 South Australian sites (Table 41). *Eucalyptus cladocalyx* and *Eucalyptus occidentalis* were again amongst the best of the species planted and *Callitris gracilis* again survived well but grew slowly. It is interesting to note that some of the long cycle plantings performed less well than the same species in the short cycle trials at the same site, particularly at Murray Bridge. At half the planting density it was expected that the long cycle plantings would obtain green biomass results about half or better than that of the more densely planted short cycle trials, as was the case for *Eucalyptus camaldulensis*, *Eucalyptus cladocalyx*, and *Eucalyptus occidentalis* at Roseworthy. However, at Murray Bridge the 4 species included in both treatments performed better in the short cycle plots than in the long cycle and *Callitris gracilis* repeated this pattern at Roseworthy. The reason for these results is currently unclear, but may suggest site and microclimate variation influences on productivity.

NSW 2005 Long cycle trial (Thurloo, 2 years old)

Due to drought conditions in 2004 at Thurloo site the long cycle trial plantings were delayed. In 2005, 704 individuals were planted at this site representing 4 different species (*Eucalyptus occidentalis*, *Eucalyptus cladocalyx*, *Casuarina cunninghamiana* ssp. *cunninghamiana*, and *Eucalyptus camaldulensis* ssp. *camaldulensis*). These were planted at the same spacing and densities (1111 tph) as the 2004 long cycle trials at the other eastern states sites. *Eucalyptus occidentalis* and *Eucalyptus* *cladocalyx* were planted in 4 replicated plots of 4 x 6 plants, and *Casuarina cunninghamiana* and *Eucalyptus camaldulensis* were planted in 4 replicated plots of 8x8 plants. The same allometric equation (“FTWG plant volume”, Table 8) used for 2004 plantings was used estimate plant standing green biomass for long cycle trials planted in 2005. The product of annual plant growth, survival and planting density provides estimates of species productivity rates (Table 40). At half the planting density of neighbouring short cycle trials, the long cycle plots were expected produce slightly more than half the biomass than the more densely planted short cycle plots with the same germplasm. This was the case for *Eucalyptus cladocalyx* and *Eucalyptus occidentalis* but was surprisingly much lower in *Eucalyptus camaldulensis* (8 t/ha/year in short cycle cf. 2.1 t/ha/year in long cycle plots). The local native species *Casuarina cunninghamiana* was a poor performer on this site (0.5 t/ha/year).

Plant spacing trials

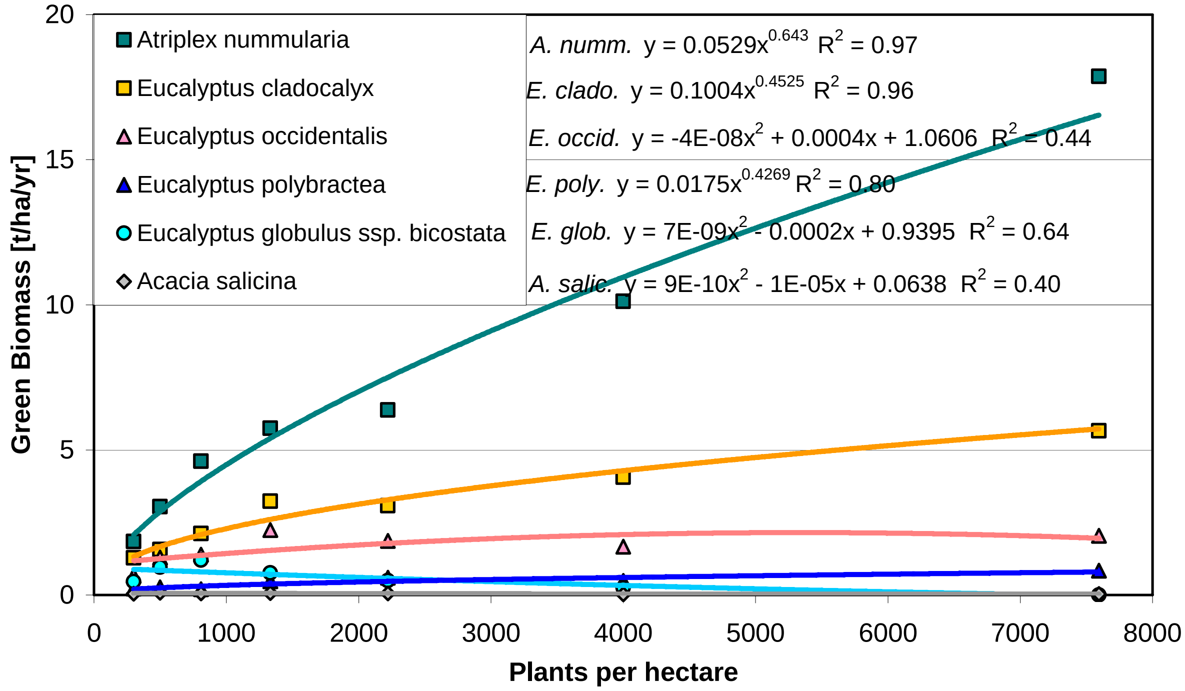
SA Nelder plant spacing trials (Murray Bridge, 3 years old)

Nelder-styled plant spacing trials (Nelder 1962) for 4 replicates of 6 species were established at Murray Bridge in 2004. Each of the 8 circular plots contains 3 species sections established in equal sized wedges of 49 plants with planting densities increasing toward the centre of each circle (ie. 300, 500, 808, 1332, 2222, 4000, 7595 tph). Six species were used that match those included in the short cycle trials to represent different plant forms and groupings, allowing 4 repetitions of each species (Table 41). In total, 1176 plants with an average planting density ~2400 plants per hectare were established. The object of this experiment is to examine the affect that competition between plants at different planting density may have on their productivity. This analysis has yet to be carried out but generally the species planted in the Nelders, like those in the long cycle trials, have not performed as well as those in the short cycle trials. The exceptions are *Atriplex nummularia* and *Eucalyptus globulus* ssp. *bicostata* which both have 8% greater average green biomass in the Nelder trials compared to the short cycle trials. But, where as *Atriplex nummularia* recorded 99% survival and was the best producer of green biomass in the Nelders, *Eucalyptus globulus* ssp. *bicostata* had the poorest survival (38%) and modest green biomass returns. The other 4 species planted in the Nelders all had 19 to 79% less green biomass on average than the same plants in the short cycle trials and lower survival rates.

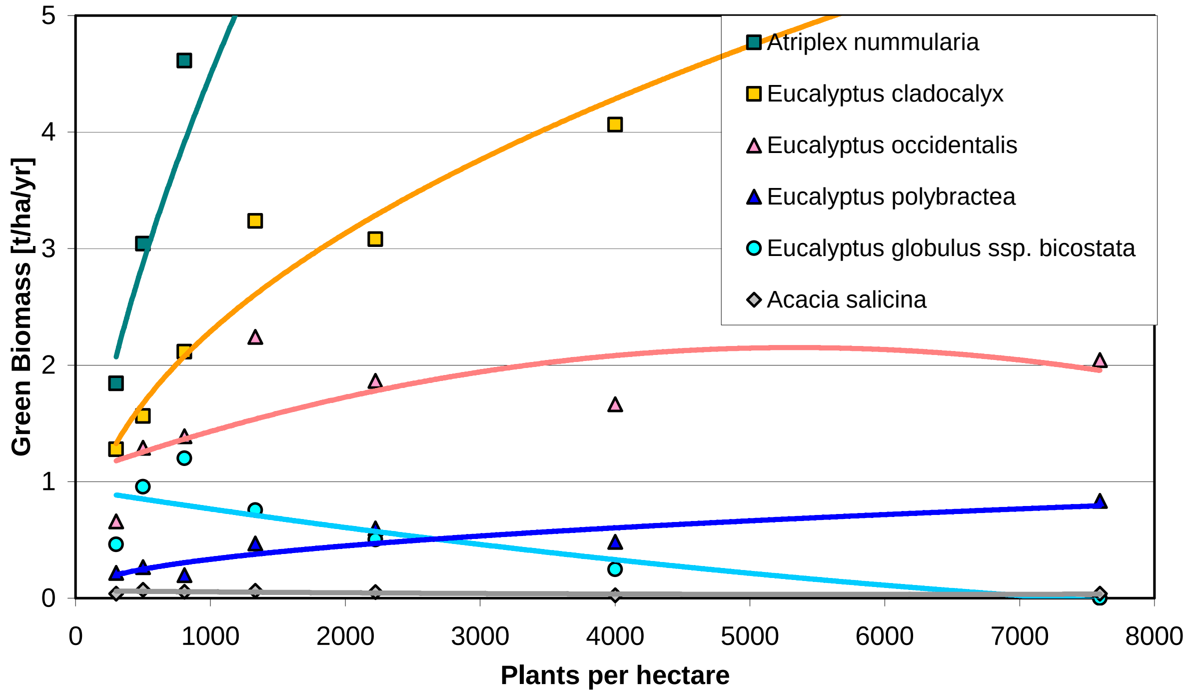
Due to some plant losses within the Nelder designs they have not been ideally analysed in terms of adjusted plant spacing resulting from missing plants. However, in Fig. 20 we present the results of this trial and are inclusive mortalities on annual productivity rates for each original planting density class and species. Fig. 20a shows that at 3 years of age competition effects on *Atriplex nummularia*, *Eucalyptus cladocalyx* and *Eucalyptus polybractea* are currently minimum or non existant. This suggests that higher planting densities (2000-4000+ tph) could be used to maximise young age (~3-5 year) productivity at this site and rainfall zone. Competion effects are very pronounced for *Eucalyptus globulus* ssp. *bicostata* and to a lesser extent for *Eucalyptus occidentalis*. We have noted on other lower rainfall sites that *Eucalyptus globulus* is more suceptable to drought and exhausted soil moisture profiles in very few years of growth. Our data suggests that on this site and under dry conditions (<400mm MAR) *Eucalyptus globulus* should not be planted at greater than ~700 trees per hectare. Similarly, our data suggests a planting density of <1500 trees per hectare for *Eucalyptus occidentalis* at this site without additonal water supplies. The very unproductive *Acacia salicina* on this site does not appear to suffer from any competition effect in this case but there may be a weak suggestion of suffering from exposure to the elements in wider spacings.

Fig. 20. Influence of plant spacing on productivity of 6 species planted at Nelder design at Murray Bridge in 2004 (3 years old).

a) Full range of data (Y axis scale 20 t/ha/yr)



b) Y axis scale 5 t/ha/yr, to illustrate trends in less productive species



WA Acacia saligna plant spacing trials (Lake Bryde, 2 years old)

There is very little published work investigating the impact of crop layout and density on the production of *Acacia saligna*. However, the pronounced edge effects seen in some trial plantings in

Western Australia demonstrate that trees in belt configurations will be substantially more productive than those in block configurations. In unpublished research on a variety of species in south western Australia including *A. saligna*, the authors have routinely measured edge rows with 150% to 300% more standing biomass than interior trees. The trade off created by the belt system is competition impacts on adjacent land uses.

The authors have established planting density trials on farmland in Western Australia. These trials are planted in blocks using a row/column design incorporating four planting density treatments, which are replicated four times. Interim results from one site, for two year old plants, showed that plant growth varies with planting density (Table 24). Estimated green biomass production has been determined from stem basal area measurements and allometric equations (Table 9), planting density and plot survival.

Table 24. The effect of planting density on *Acacia saligna* growth, 24 months since establishment on farmland at Lake Bryde in Western Australia.

Planting Density	Mean Plant Height [m]	Mean plant SBA[1] [cm^2]	Plot SBA [m^2/ha]	Green Biomass Productivity [green t/ha/yr]	Dry Biomass Productivity[2] [dry t/ha/yr]
1000	1.62	35.4	3.46	3.3	1.6
2000	1.41	22.7	4.27	3.7	1.8
4000	1.10	16.7	5.94	4.7	2.3
8000	1.24	11.6	8.74	6.4	3.2

[1] Stem Basal Area (SBA) is the sum of cross sectional areas of all stems 5-10cm above ground level

[2] Productivity of above ground biomass calculated assuming moisture content of 50%.

For two year old plants, higher planting densities corresponded with greater stem basal area per hectare and consequently greater standing biomass. Trees at lower planting densities grew larger than those at the highest planting density of 8000 stems per hectare (SPH); however the extra growth was not sufficient to match the biomass production per unit area of land observed in the 8000 SPH plots. This implies that lower density plantings have been unable to exploit site resources to the same extent as trees planted at 8000 SPH over the two year period. It remains to be seen whether this trend will be maintained as the plants age. The composition of *A. saligna* biomass has also been observed to vary with planting density and plant age (amount of wood, bark, twig and phyllode). It will be important to quantify these relationships in the future, given the expectation that different biomass components will have different values as product feed stocks.

WA mallee spacing and coppicing

WA DEC is currently conducting a separately study funded by the Joint Venture Agroforestry Program and other partners on “Productivity of mallee agroforestry systems under various competition management regimes”. They will measure biomass growth of unharvested oil mallees and the coppice productivity of mallees subject to four harvest regimes and root pruning. The project also explores the lateral extent of the competition zone adjacent to mallee belts and crop yield and estimated pasture production within the competition zones. Economic evaluations will be conducted on integrated mallee/agriculture systems with various harvest and competition management regimes. The project also plans to develop robust guidelines for managing integrated mallee/agriculture systems to maximise economic returns. The results of that study will be reported to JVAP in the future and it will provide significant guidance to future research issues and utilisation of oil mallee systems.

However, coppicing experiments have been conducted by WA DEC over several years from sites established in the 1990’s and with the WA Search project. These have focussed on the oil mallees, *Eucalyptus polybractea* and *Eucalyptus loxophleba* ssp. *lissophloia*. Representative results for 2 year old coppice growth at a few focus sites are presented in Table 25.

Table 25. Selected species coppicing productivity observations at trial sites in Western Australia.

Species (Trial Site)	Annual Rainfall [mm]	Age [years]	Plant Density * [plants/ha]	Green Biomass [t/ha/yr]	CO_2 Sequestration equiv. [t/ha/yr]
Eucalyptus loxophleba ssp. *lissophloia* (Highbury, coppice)	495	2	2015	5.5	5.0
Eucalyptus loxophleba ssp. *lissophloia* (Kulin, coppice)	375	2	1304	8.7	8.0
Eucalyptus loxophleba ssp. *liss.* (Dongolocking, coppice)	434	2	1795	2.9	2.7
Eucalyptus loxophleba ssp. *liss.* (Woodanilling, coppice)	450	2	2017	4.8	4.4
Eucalyptus polybractea (Tincurrin, coppice)	495	2	1905	6.5	6.0
Eucalyptus polybractea (Woodanilling, coppice)	450	2	2526	11.1	10.2

New coppicing experiments

Within the suite of field trials established by FloraSearch, and part of the Field Trials of Woody Germplasm project, several blocks of plantings have been established with the purpose of conducting coppicing experiment to evaluate plant mortality from harvesting and to measure and evaluate plant regrowth rates following coppicing. A list of the species/provenances and numbers planted are located in Table 26. At present, only Old Man Saltbush coppicing treatments have commenced, as the taller trees and shrubs have not yet reached their target first harvest/initial coppice age.

Table 26. Number of individuals planted by species and provenances for coppicing experiments in FloraSearch and Field Trials of Woody Germplasm sites across southern Australia.

Trial sites: MB=SA Murray Bridge; MN=SA Monarto; RW=SA Roseworthy; SE=SA Lucindale - South East; RG=Vic. Rutherglen; T1=NSW Thurloo; CR=WA Coorow; and TB=WA Toolibin.

Species [Provenance] - Table 25. Coppice Plants	Total	MB	MN	RW	SE	RG	T1	CR	TB
Acacia decurrens [Bungonia]	**96**		96						
Acacia decurrens [Picton]	**96**		96						
Acacia mearnsii [Tantanoola]	**96**		96						
Acacia retinodes var. retinodes (hill form) [Littlehampton]	**96**		96						
Acacia retinodes var. retinodes (swamp form) [Fryerstown]	**96**		96						
Acacia retinodes var. retinodes (swamp form) [Grampians/Lake Bellfield]	**96**		96						
Acacia retinodes var. retinodes (swamp form) [Kangaroo Island]	**96**		96						
Acacia retinodes var. retinodes (swamp form) [Kuitpo]	**96**		96						
Acacia retinodes var. uncifolia [Kangaroo Island BSC]	**96**		96						
Acacia salicina [Mambray Creek]	**584**	256		72			256		
Acacia saligna ssp. lindleyi [Parkeyerring]	**640**	256		96	96	96	96		
Agonis flexuosa [Esperance]	**144**								144
Atriplex nummularia [Eyres Green]	**256**	256							
Atriplex nummularia [Yando]	**96**				96				

Species [Provenance] - Table 25. Coppice Plants	**Total**	**MB**	**MN**	**RW**	**SE**	**RG**	**T1**	**CR**	**TB**
Eucalyptus aromaphloia ssp. sabulosa [Balmoral]	**96**		96						
Eucalyptus aromaphloia ssp. sabulosa [Little Desert]	**96**		96						
Eucalyptus camaldulensis var. camaldulensis [Lake Albacutya]	**800**	256		96	96	96	256		
Eucalyptus camaldulensis x globulus ssp. globulus [SG34]	**24**		24						
Eucalyptus camaldulensis x globulus ssp. globulus [SG35]	**24**		24						
Eucalyptus camaldulensis x globulus ssp. globulus [SG39]	**24**		24						
Eucalyptus camaldulensis x globulus ssp. globulus [SG40]	**24**		24						
Eucalyptus camaldulensis x grandis [SG06]	**24**		24						
Eucalyptus camaldulensis x grandis [SG13]	**24**		24						
Eucalyptus camaldulensis x grandis [SG18]	**24**		24						
Eucalyptus camaldulensis x grandis [SG21]	**24**		24						
Eucalyptus cladocalyx [Bundaleer cult.]	**96**		96						
Eucalyptus cladocalyx [Cape Border]	**96**		96						
Eucalyptus cladocalyx [Kersbrook cult.]	**96**		96						
Eucalyptus cladocalyx [Wail]	**96**		96						
Eucalyptus cladocalyx [Wirrabara CS]	**96**		96						
Eucalyptus cladocalyx [Wirrabara SFMB]	**640**	256		96	96	96	96		
Eucalyptus cneorifolia [Kangaroo Island CS]	**800**	256		96	96	256	96		
Eucalyptus cneorifolia [Kingscote]	**96**		96						
Eucalyptus globulus ssp. bicostata [Barkly]	**96**		96						
Eucalyptus globulus ssp. bicostata [Mt. Bryan CS]	**96**		96						
Eucalyptus globulus ssp. bicostata [Wee Jasper]	**96**		96						
Eucalyptus globulus ssp. globulus [Jeeralong]	**96**		96						
Eucalyptus globulus ssp. globulus [Ottway]	**96**		96						
Eucalyptus globulus ssp. globulus [WAFPC]	**96**		96						
Eucalyptus globulus ssp. globulus [Worrolong]	**96**		96						
Eucalyptus horistes [WA]	**96**		96						
Eucalyptus incrassata [Owen]	**800**	256		96	96	256	96		
Eucalyptus loxophleba ssp. lissophloia [Newdegate]	**1215**	256		96	96	256	256	255	
Eucalyptus loxophleba ssp. lissophloia [WA]	**96**		96						
Eucalyptus occidentalis [Jerdacuttup River]	**96**		96						
Eucalyptus occidentalis [Jerramungup area]	**96**		96						
Eucalyptus occidentalis [Kantanning]	**96**		96						
Eucalyptus occidentalis [Old Newgate Road]	**96**		96						
Eucalyptus occidentalis [Redhill cult.]	**728**	256		120	96		256		
Eucalyptus occidentalis [Truslove]	**96**		96						
Eucalyptus oleosa ssp. ampliata [Port Lincoln]	**96**		96						
Eucalyptus oleosa ssp. oleosa [Mallala]	**96**		96						
Eucalyptus oleosa ssp. oleosa [Menzies]	**96**		96						
Eucalyptus oleosa ssp. oleosa [Paruna]	**96**		96						
Eucalyptus ovata ssp. grandiflora [Mt. Gambier]	**96**		96						
Eucalyptus ovata ssp. ovata [Adelaide Hills]	**96**		96						
Eucalyptus ovata ssp. ovata [Crookwell]	**96**		96						
Eucalyptus ovata ssp. ovata [Strathdownie]	**96**		96						
Eucalyptus ovata ssp. ovata [Tasmania]	**96**		96						
Eucalyptus petiolaris [Cleve Hills]	**96**		96						
Eucalyptus petiolaris [Koppio Hills]	**96**		96						
Eucalyptus polybractea [CLM29]	**96**		96						
Eucalyptus polybractea [CLM31]	**96**		96						
Eucalyptus polybractea [CLM42]	**96**		96						
Eucalyptus polybractea [WA cult.]	**800**	256		96	96	96	256		

Species [Provenance] - Table 25. Coppice Plants	Total	MB	MN	RW	SE	RG	T1	CR	TB
Eucalyptus porosa [Fleurieu Penn]	**96**		96						
Eucalyptus porosa [Melton to Price]	**96**		96						
Eucalyptus porosa ssp. devestiva [Tintinara]	**96**		96						
Eucalyptus rudis [Narrogin]	**512**							256	256
Eucalyptus rudis [WA]	**96**		96						
Eucalyptus socialis [Chapman Bore]	**800**	256		96	96	256	96		
Eucalyptus viminalis (FSA hybrid) [Tintinara cult.]	**96**		96						
Eucalyptus viminalis ssp. cygnetensis [Flinders Chase]	**96**		96						
Eucalyptus viminalis ssp. cygnetensis [Frances]	**96**		96						
Eucalyptus viminalis ssp. cygnetensis [Mt. Gambier]	**96**		96						
Eucalyptus viminalis ssp. cygnetensis [Onkaparinga River]	**96**		96						
Eucalyptus viminalis ssp. cygnetensis [Port Lincoln]	**96**		96						
Eucalyptus viminalis ssp. cygnetensis [Williamstown]	**96**		96						
Indigofera australis [Scott Creek]	**256**	256							
Viminaria juncea [Gippsland]	**96**		96						
Viminaria juncea [Jervis Bay]	**96**		96						
Viminaria juncea [McLoughlins Beach]	**96**		96						
Viminaria juncea [Nangkita]	**96**		96						
Viminaria juncea [Perth]	**96**		96						
Viminaria juncea [Wimmera River]	**96**		96						

Old Man Saltbush coppice experiments

In Autumn 2007, we commenced a coppicing experiment on *Atriplex nummularia* aimed at determining standing plant biomass and the ability of the plants to regrow following a coppice or heavy grazing. We destructively sampled individuals that were planted in the "Field Trials of Woody Germplasm" trial sites at Murray Bridge and Roseworthy in South Australia in 2004 and 2005. At these two sites, there was a combination of *Atriplex nummularia* ssp. *nummularia* germplasm collected from near Yando in Victoria, and the commercial clone, Eyres Green. At Murray Bridge, each of these provenances was planted in 2004 as 4 replicated plots of 8 rows of 8 plants at 3m by 1.5m spacing.

The study commenced in late Autumn 2007, where we measured the height and width along and across the row for the 16 plants in the northwest quadrant of each plot. We then cut these plants back to a height and width of approximately 50cm and weighed the green biomass (leaf and stems combined) removed from each. For two of the 16 plants from each plot of Yando, and for all plants from each plot of Eyre's Green, we subdivided and weighed the edible (leaf and fine stem < 3mm) and woody (all material > 3mm) green biomass fractions. The 2005 plantings consisted of Eyres Green in 2 plots of 2 rows of 6 plants at 3m by 1.5m spacing. All of these plants were also cut back using the same protocol as for the 2004 plants.

The biomass of the remaining standing in-ground stems was estimated using the modified Adelaide technique of Andrew *et al.* (1979). This approach requires taking a branch unit of known weight that is representative of the branches within the plant to be measured. A count is then made of the number of representative branch equivalents on the plant, which is then multiplied by the weight of the branch unit to get the standing biomass. We then combined this with the weight of harvested material in order to calculate whole-plant biomass.

At the Roseworthy site, there were 4 plots of the Yando provenance planted in 2004 and 4 plots of Eyres Green planted in 2005, all containing 4 rows of 6 plants at 3m by 1.5m spacing. All of these plants were also sampled in the late autumn of 2007 using the same destructive sampling outlined above. Two plants from each plot were again separated into the edible and woody fractions and the remaining biomass was estimated using the Adelaide technique.

These destructive figures were used to create a predictive allometric model for green biomass based on the volume of a plant as an elliptical cylinder (Fig. 7). We used this model to estimate green biomass in the other three quadrants of each plot and combined this with the destructive data to get mean green biomass values. We then used these estimates to determine the green biomass productivity rate (t/ha/yr) based on a planting density of 2222 plants per hectare. We also calculated the standardised productivity rate at mean annual rainfall conditions of 500mm.

Initial growth and yield

Survival after planting was high at both sites ranging between 95.8% for the 2005 Eyres Green at Murray Bridge to 99.2% for Yando at Murray Bridge, with the Roseworthy survival intermediate to these values. The total green biomass per plant was highly variable at both sites, ranging from 2.8 kg to 63.0 kg per individual. Mean biomass values per individual ranged from 11.1 kg for the 2004 Yando plots at Murray Bridge up to 27.7 kg per plant for the 2005 Eyres Green plots at Roseworthy (Fig. 21). Plants located on the external edge of the plots were on average between 14% and 28% larger than those planted internally (Fig. 21). Because the Eyres Green 2005 plots only consisted of 2 rows, all plants were edge plants. Productivity differences were strongly evident at both the within and between site scales, with the Eyres Green cultivar consistently out producing the Yando provenance at both sites. Productivity at the Roseworthy site also outstripped that at Murray Bridge by a factor of 2.3 and 2.0 for the Yando 2004 and Eyres Green 2005 plant comparisons respectively (Fig. 21).

Partitioning of the destructively sampled plants into edible and woody biomass fractions revealed a slight trend of increased leaf biomass in the external plants, with the exception to this being the 2004 Yando plants from Roseworthy (Fig. 22). Mean percentage of the edible fraction for edge plants across sites was 66% and for internal plants was 64%. Examination of Fig. 22 also reveals a higher proportion of woody biomass at the higher rainfall Roseworthy site compared to Murray Bridge site for both *Atriplex nummularia* [Yando] and *Atriplex nummularia* c.v. Eyres Green**.**

The green biomass productivity rates (t/ha/yr) for both *Atriplex nummularia* [Yando] and *Atriplex nummularia* c.v. Eyres Green were substantial (Fig. 23). The lowest productivity rate was for the 2004 *Atriplex nummularia* [Yando] at Murray Bridge, with 10.3 t/ha/yr. The 2005 *Atriplex nummularia* Eyres Green showed the highest productivity rate at 30.4 t/ha/yr. This is the highest productivity rate of any of the tree and shrub species planted within the field trials of woody germplasm projects (see Table 12 & Table 15). Strong site differences were again evident with Roseworthy much more productive than Murray Bridge.

In the case of both the 2004 *Atriplex nummularia* [Yando] and 2004 *Atriplex nummularia* c.v. Eyres Green at Murray Bridge, the modelled estimates for the green biomass productivity rate differed from that predicted by using the destructive quarters only. We expect that these plants are the group generally clustered below the regression line at around 6m^3 volume (see Fig. 7) and are thus are over estimated by the model. This may be because the lower rainfall at this site results in more intense competition amongst internal plants, resulting in a reduced leaf biomass relative to the plant volume.

Fig. 21. Mean per plant green biomass recorded for internal plants, external plants and all plants combined of 3 year old (2004) and 2 year old (2005) *Atriplex nummularia* [Yando] and *Atriplex nummularia* c.v. Eyres Green at Murray Bridge (MB) and Roseworthy (RW).

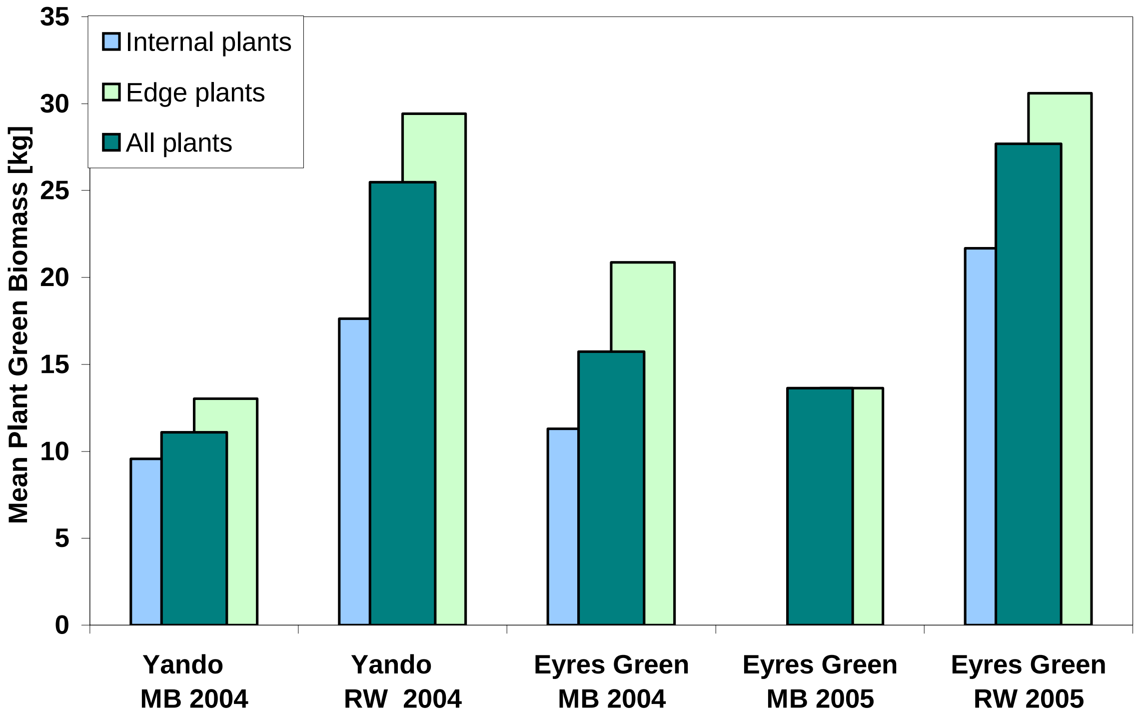


Fig. 22. Mean percentage of whole plant green biomass that was edible leaf and fine twig for 3 year old (2004) and 2 year old (2005) *Atriplex nummularia* [Yando] and *Atriplex nummularia* c.v. Eyres Green at Murray Bridge (MB) and Roseworthy (RW).

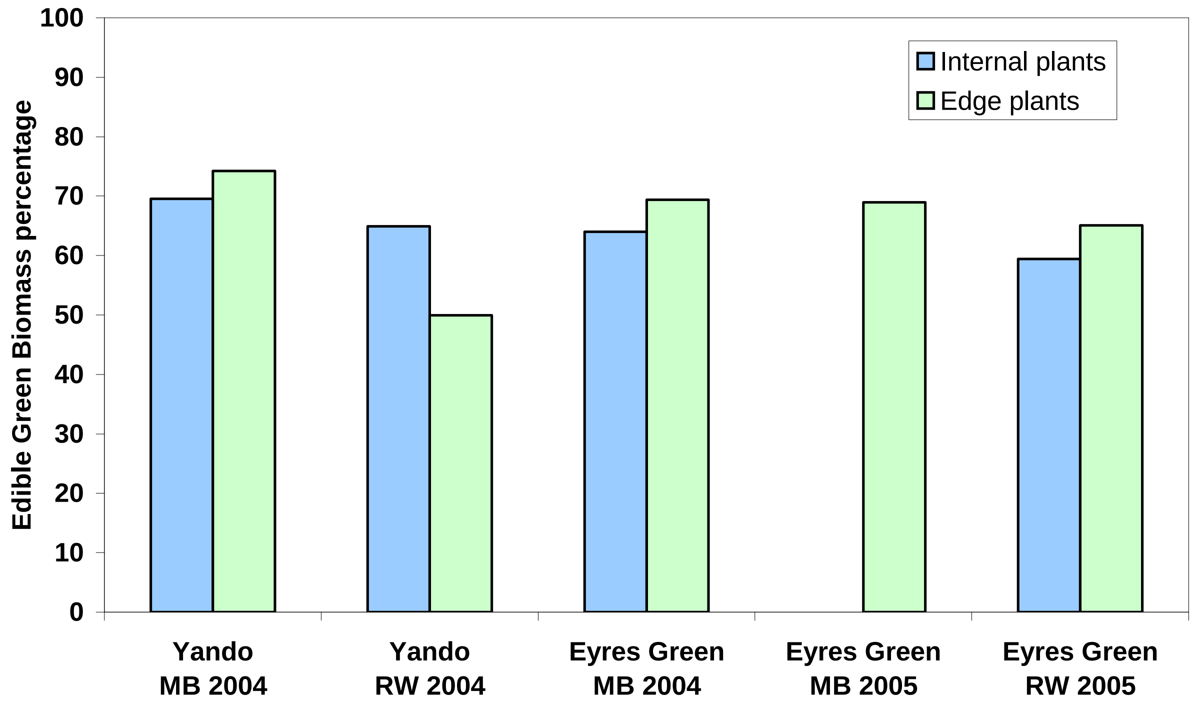
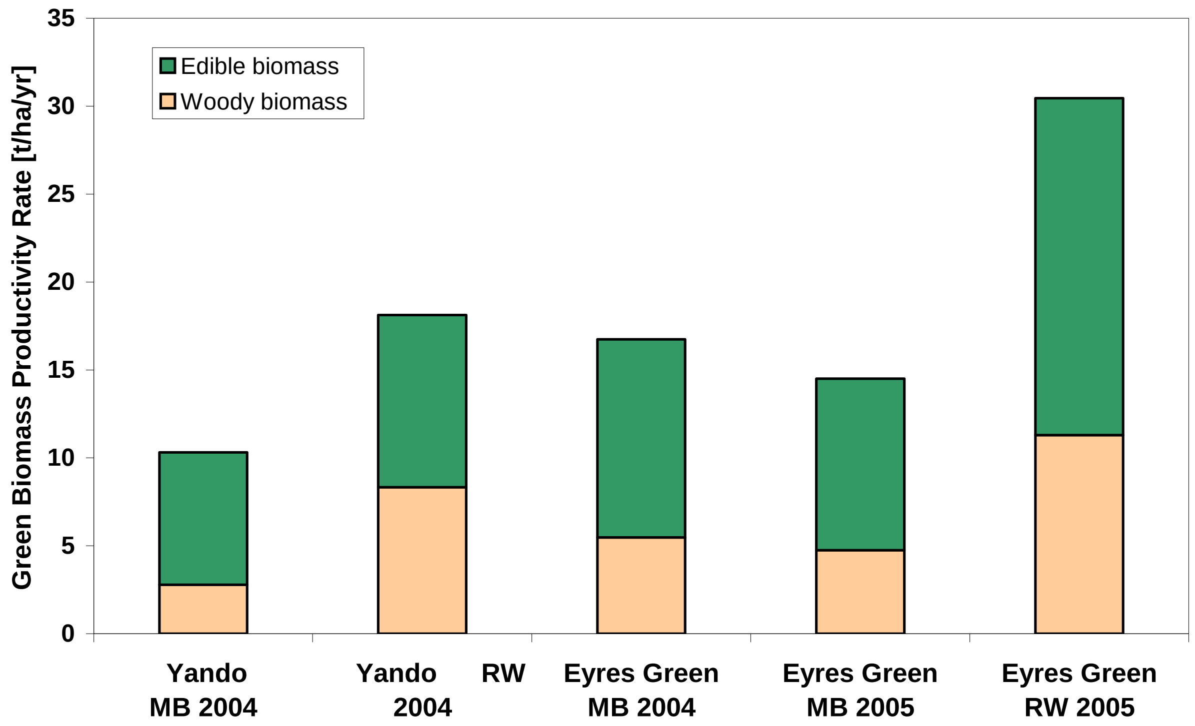


Fig. 23. Annual green biomass accumulation rates (t/ha/yr) of edible and woody biomass for 3 year old (2004) and 2 year old (2005) *Atriplex nummularia* [Yando] and *Atriplex nummularia* c.v. Eyres Green at Murray Bridge (MB) and Roseworthy (RW).



Regrowth studies

As well as the autumn coppice at Murray Bridge, we have also conducted coppices of the remaining three quarter plots in the winter and spring of 2007 and summer 2008, with the goal of examining seasonal variation in biomass allocation (Fig. 24). This data has still to be analysed. The next stage of the assessment will be to measure the 12 month regrowth from the plants that were coppiced in Autumn of 2007. Visual appraisal of the plants at 9 months post coppice suggests a good level of resprouting of edible green biomass when compared to the newly coppiced stems from the summer 2008 (Fig. 25).

Fig. 24. Seasonal coppice sampling of 3 year old (2004) *Atriplex nummularia* [Yando] at Murray Bridge.

Quarter plots were sampled clockwise from top left at 9, 6, 3 and 0 months before the photo was taken.

Fig. 25. Regrowth of *Atriplex nummularia* [Yando] 9 months after an Autumn 2007 coppice at Murray Bridge.

The two newly coppiced plants in the foreground indicate the plant size from which regrowth has occurred.

Regional Productivity

The development of regional productivity models has been focussed on each of the *Biomass Industry Group* of species (ie. *Pulpwood Species*, *Bioenergy Species*, *Oil Mallee Species*, *Saltbush Fodder Species*). The models have been based on relationships between our observations of plantation productivity in the region and soil-climate models. Raupach *et al.* (2001) developed the "*BiosEquil Model*" and created a national productivity surface coverage suitable for computer-based Geographic Information Systems (GIS). The *BiosEquil Model* coverage provides coarse resolution (~1km²) data for Australia. This productivity modelling metholodogy has been described previously in the FloraSearch Stage 2 report (Hobbs *et al.* 2008c) and we present the latest outputs of models for green biomass accumulation rates in Fig. 26 - Fig. 29.

In the SA Upper South East study the high quality of soil mapping in South Australia (SA DWLBC Soil and Land Program 2006, Hobbs *et al.* 2006) allows us to spatially refine the BiosEquil Model to a resolution less than one hectare (ie.100x100metres resolution). Relationships between BiosEquil Model data and SA maps of inherent fertility in the Upper South East (USE) region and average annual rainfall were identified. From these relationships and high quality soil and rainfall maps we have created a high resolution (1 ha scale) equivalent of the BiosEquil Model.

ArcGIS software was used to extract the corresponding productivity index coverage value for each field trial or survey site location used for our SA Upper South East productivity study. Site and species productivity data was restricted to those species within the Biomass Industry Species Groups and the Top 10% Species Plots dataset. Strong linear regressions between productivity index values and restricted productivity data for each of the Biomass Industry Species Groups has allowed us to predict industry specific plantation productivities and yields across the USE region. A selection of model outputs for annual rates of stemwood production and green biomass production are detailed in Hobbs *et al.* (2006). Fig. 30 illustrates this capacity to model woody crop productivity at finer resolutions than previously possible.

Fig. 26. Green biomass productivity of bioenergy species in southern Australia (at 1000 plants per ha).

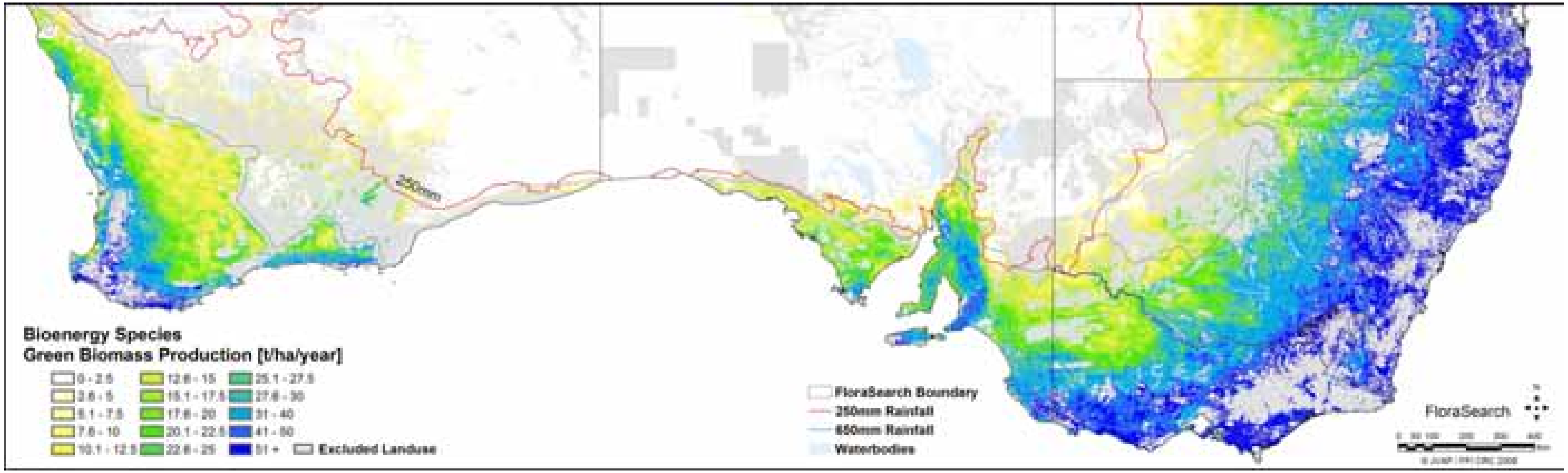


Fig. 27. Green biomass productivity of oil mallee species in southern Australia (at 1000 plants per ha).

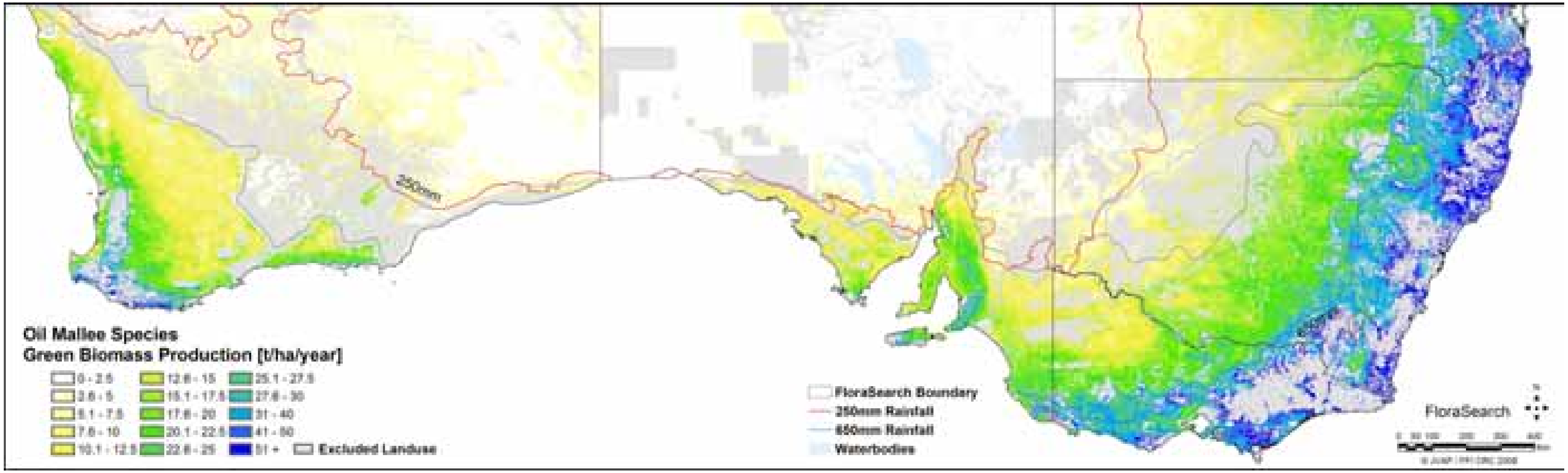


Fig. 28. Green biomass productivity of pulp and fibre species in southern Australia (at 1000 plants per ha).

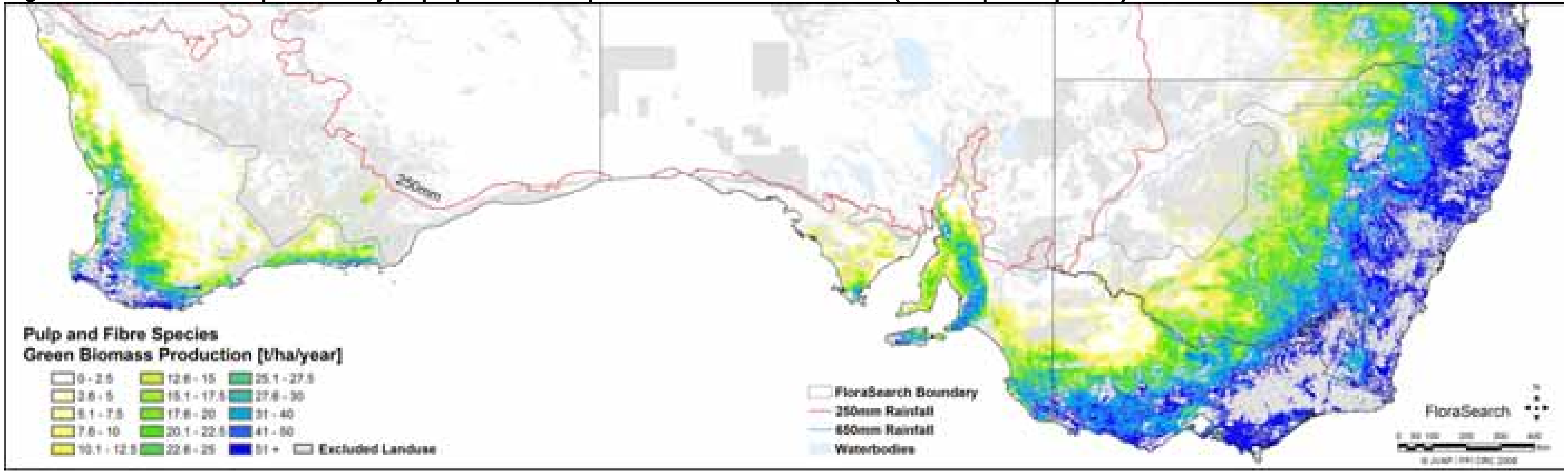


Fig. 29. Green biomass productivity of salbush fodder species in southern Australia (at 2000 plants per ha).

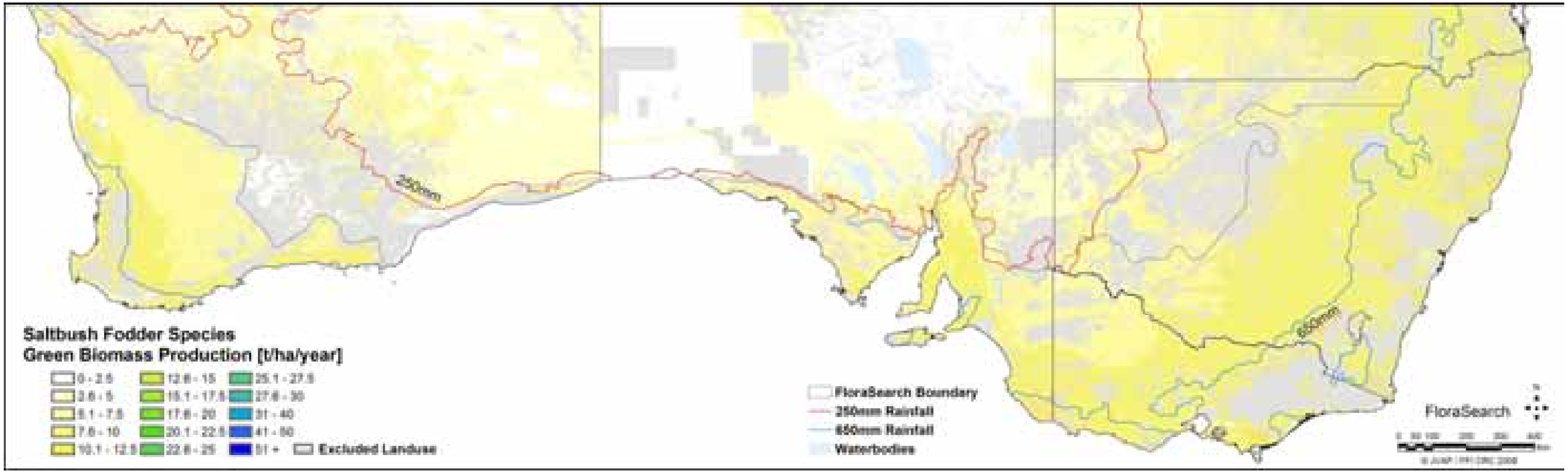
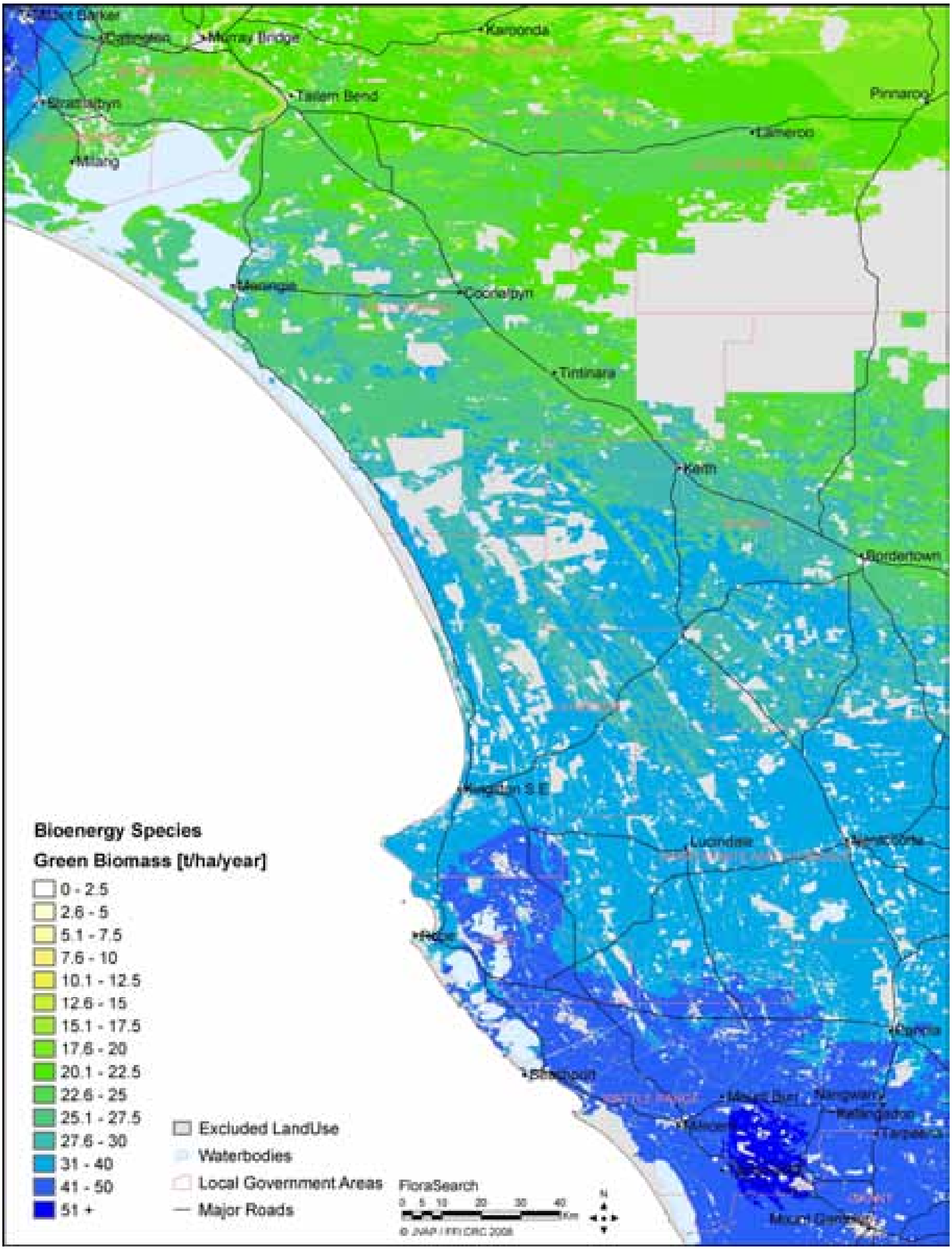


Fig. 30. Green biomass productivity for bioenergy species in the Upper South East region of South Australia (at 1000 plants per ha).



3. High Priority Species

Michael Bennell[1,2], Trevor J. Hobbs[1,2], Craig Neumann[1,2], Wayne O'Sullivan[2,3], David J. McKenna[1,2], John Bartle[2,3] and Richard Mazanec[2,3]
[1] Department of Water, Land and Biodiversity Conservation, Urrbrae SA 5064
[2] Future Farm Industries Cooperative Research Centre, Crawley WA 6009
[3] Department of Environment and Conservation, Bentley WA 6983

Introduction

Each species identifed in our list of 'Focus' and 'Development' species has physical or chemical properties that meet the product specifications of potentially significant industries that are, or could be developed further in the lower rainfall regions of southern Australia (Olsen *et al.* 2004, Bennell *et al.* 2008, Hobbs *et al.* 2008c). Our species choices are also strongly based on the capacity of each of these species to grow quickly and productively across significant portions of our target region, or be highly productive in modest areas of particluary high interest to current or future biomass industry groups.

The high priority species identified by FloraSearch all fall within one or more of 4 major Biomass Industry Groups:

1. **Pulpwood Species**
2. **Bioenergy Species**
3. **Oil Mallee Species**
4. **Fodder Species**

Where a particular species has attributes that make it suitable for more that one industry group it has the advantage of either servicing multiple product streams (and potentially greater profits from those combined streams) or the capacity to alter product directions to changing markets and prices to maximise profits in the future.

The following section outlines a revision of high priority species previously identified by the FloraSearch 2 report (Hobbs *et al.* 2008c) and takes into account of new knowledge gained from recent research on plant growth and product yield characteristics, the emergence of new opportunities to service renewable energy and carbon sequestration markets.

Review of Development and Focus Species List

Focus species

Early in 2005, two lists were drawn up in an effort to maximise the domestication rate for promising species. Focus species are those 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. The species chosen are 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 the productive potential that together suggest this species is worthy of ongoing evaluation as a commercial species (Hobbs *et al.* 2008c). The original focus species list contained 2 species (*Acacia saligna* and *Atriplex nummularia*) that were considered most promising and could be most quickly advanced towards a full breeding program. Family / provenance trials of *Atriplex nummularia* have been established across southern Australia and family / provenance trials of *Acacia saligna* have also been established in Western Australia. Due to weed control factors in the eastern states, family / provenance trials of *Acacia saligna* are not being established outside Western Australia. Both these species are the subject of continued efforts in genetic improvement, evaluation and agronomy.

Table 27. Revised FloraSearch 'Focus and Development Species' list (2008) for germplasm improvement and domestication as woody crops in lower rainfall regions of southern Australia

Focus Species	Development Species
Atriplex nummularia	*Acacia decurrens*
Acacia saligna	*Acacia lasiocalyx*
Eucalyptus polybractea	*Acacia mearnsii*
Eucalyptus rudis	*Acacia retinodes* var. *retinodes* (hill form)
	Acacia retinodes var. *retinodes* (swamp form)
	Casuarina obesa
	Eucalyptus aromaphloia ssp. *sabulosa*
	#*Eucalyptus camaldulensis*
	Eucalyptus cladocalyx
	Eucalyptus globulus ssp. *bicostata*
	#*Eucalyptus gomphocephala*
	Eucalyptus horistes
	Eucalyptus loxophleba ssp. *lissophloia*
	Eucalyptus occidentalis
	Eucalyptus oleosa
	Eucalyptus ovata
	Eucalyptus petiolaris
	Eucalyptus porosa
	#*Eucalyptus sideroxylon*
	Eucalyptus viminalis ssp. *cygnetensis*
	Demoted from 2007 Development List
	Anthocercis littorea
	Codonocarpus cotinifolius
	Taxandria juniperina
	Viminaria juncea

\# New additions to the development list

Eucalyptus polybractea has been the subject of much interest for development within oil mallee production systems of WA, NSW and Vic. over several years. It is a species well recognised by the Australian Low Rainfall Tree Improvement Group (ALRTIG), NSW Department of Primary Industries and WA Department of Environment and Conservation. Significant progress has been made in the selection of high oil-yielding germplasm for crops development, especially from work conducted by the WA Department of Environment and Conservation. It is the most developed oil mallee species in Australia, with several existing improved plant breeding lines currently available. It has therefore been rightly promoted to our list of 'focus' species and will continue to be a species worthy of greater development.

More recently *Eucalyptus rudis* from Western Australia (a close relative to *Eucalyptus camaldulensis*) has emerged as a 'focus species' candidate from strong interest and investment by the WA Department of Environment and Conservation. The development of *Eucalyptus rudis* (like *Acacia saligna*) is strongly oriented towards Western Australia regions where it is typically very productive and is intended for wood fibre (panelboard) and woody biomass production. Results from trials in eastern

Australia suggest lower productivity rates than those in WA and suggest this species has preferences for climates and soils closer to its origins.

Development species

The selection of development and focus species was a major objective of FloraSearch Stage 2 (Hobbs *et al.* 2008c) and the western node also undertook this process for WA species as part of the Search project (Olsen *et al.* 2004). The development list contained species with the same characteristics as the focus species but with a reduced confidence level. As such, further testing and field trials have been required to ensure these species perform to the standards required. Ongoing evaluation and observation of species characteristics has led to 4 of the original list being omitted from the current development effort.

Codonocarpus cotinifolius proved to be difficult to propagate and even more difficult to establish in the field. While this species continues to have excellent industrial properties, the near total failure to establish this species in trials over several seasons has lead to its removal from the development list (Tables 2004 and 2005 ss trials). *Taxandria juniperina* and *Anthocercis littorea* were both less problematic in the propagation phase but failed in trials at Murray Bridge and Lucindale. While *Taxandria juniperina* did better in the WA trials its results were modest and could not warrant its continued inclusion in the development list at this stage. *Viminaria juncea* initially grew well at most trial sites and is currently performing well in the 2006 trials at Monarto (Table 43). However it has failed to maintain its early vigour in the 2004 and 2005 trials, succumbing to drought at some sites and frost at others.

The rank of each of the original development species was dependant on specific industry requirements, distribution potential and growth potential. In summary, those species with high pulp yields, low density and high paper scores (good yields and paper testing qualities) were the most highly ranked for pulp, fiberboard and particleboard manufacturing. At that time these species received the most attention as they were seen as the most likely species to provide the highest return for investment by the growers. However, with increasing interest in biomass fuels and carbon sequestration we have revisited those rankings and reevaluated many of the species. Species with high growth rates and wood densities are best for bioenergy related industries and carbon sequestration as they tend to have higher calorific values and more carbon stored per unit of stemwood volume. The reexamination of Search, FloraSearch, Australian Low Rainfall Tree Improvement Group (ALRTIG), Treedat and other data, has lead to 4 extra species being added to the development species.

The ALRTIG data is most compatible with our own as both have a low rainfall focus and similarities in candidate species selections can be seen (Table 28) even though the ALRTIG focus was on saw log production. *Eucalyptus camaldulensis* for instance has ranked well in both ALRTIG and FloraSearch estimations and was amongst the most productive species on many of our trial sites (Table 39, Table 41). The *Eucalyptus sideroxylon* group (including *E. sideroxylon* ssp. *tricarpa*) was not included in any current FloraSearch trials but had solid performance results in many other dryland trials in zones under 700 mm annual rainfall. *Eucalyptus sideroxylon* ssp. *sideroxylon* has averaged growth of around 1 metre a year across 3 year old trials in NSW and Vic, recording about 2.6 tonnes of green biomass per hectare per year on modelled results. *Eucalyptus sideroxylon* ssp. *tricarpa* had similar results based on 2.3 year old Victorian data of 1.1 metres a year average height and, based on older age data, about 3.5 t/ha/yr green biomass results. These species along with *Eucalyptus camaldulensis* have been added to the development list. The other key species from ALRTIG, *Corymbia maculata* failed in all FloraSearch trials in which it was included (Table 41). *Eucalyptus gomphocephala* did not rank as highly as the key species in the ALRTIG program but has been outstanding in the 2005 Murray Bridge FloraSearch trials. *Eucalyptus gomphocephala* was also found to be one of the best biomass producers in the Woody Biomass Productivity and Potential Biomass Industries in the Upper South East study (Hobbs *et al.* 2006). At several trials measured in that study *Eucalyptus gomphocephala* was the best producer of woody biomass (Fig. 17) and has been included in the development list because of its trial site performances.

Several other development species performed well in trials examined as part of the Upper South East study (Hobbs *et al.* 2006). These include *Eucalyptus camaldulensis, Eucalyptus occidentalis, Eucalyptus cladocalyx, Eucalyptus globulus* and *Eucalyptus viminalis* (Fig. 17). Another of the best performers on those trial sites was *Eucalyptus leucoxylon*, a close relative of *Eucalyptus petiolaris. Eucalyptus petiolaris* is currently in the development list and has performed consistently across most FloraSearch trials (Table 43, Table 39, Table 41). These development and focus lists continue to be subject to up date as outstanding results and failures are recorded.

Other species of interest

Eucalyptus leucoxylon and its sub-species are not currently within the development list however they are part of a group of species that we have an ongoing interest in for future development, and further updates may occur as more knowledge is gained. *Eucalyptus leucoxylon* has potential for the renewable energy and carbon markets in many parts of southern Australia.

Acacia bartleana, Acacia microbotrya, Acacia lasiocalyx, and *Acacia conniana* are all members of the '*Acacia microbotrya* Group', which also includes *Acacia lasiocalyx*, *Acacia retinodes* and *Acacia saligna* listed in the FloraSearch development and focus lists. All these species are fast growing accumulators of biomass and low energy fodder suitable for phase cropping and dewatering purposes. Both *Acacia bartleana* and *Acacia lasiocalyx* have performed well in our trials in Western Australia, with *Acacia lasiocalyx* being the most productive species at both the Coorow and Toolibin sites. *Paraserianthes lophantha* is another species that performed well at Coorow and Toolibin and could be used in a similar fashion to the Acacias mentioned here.

Eucalyptus astringens and *Eucalyptus urna* are both mallets from Western Australia that could be used in phase crop situations to dewater areas prior to a return to conventional cropping. Being good biomass producers in drier areas they are suitable for bioenergy purposes because of their high wood density. Low leaf oil content and their lack of a lignotuber, which inhibits coppicing, has consequently seen them given a lower priority.

Species with high oil contents are prized for oil extraction and integrated wood processing. *Eucalyptus angustissima* ssp. *angustissima, Eucalyptus angustissima* ssp. *quaerenda, Eucalyptus kochii* ssp. *kochi, Eucalyptus kochii* ssp. *plenissima, Eucalyptus pulverulenta, Eucalyptus bakeri,* and *Eucalyptus cneorifolia,* represent a group of oil mallees that have potential in restricted regions or are yet to be researched extensively. All have records of excellent oil yields and all but *Eucalyptus kochii* ssp. *plenissima* returned reasonable combined productivity results in the Currency Creek Arboretum study mentioned in Chapter 3. The five oil mallee species present in the development and focus lists have application over larger areas and in some cases have had extensive research carried out into their productivity (*Eucalyptus polybractea, Eucalyptus horistes, and Eucalyptus loxophleba ssp. lissophloia). Eucalyptus odorata* and *Eucalyptus viridis* ssp. *wimmerensis* are also promising species but more for the woody biomass component of their combined productivity results than the oil component.

Atriplex amnicola, Atriplex rhagodioides and *Atriplex cinerea* head a list of chenopods with good fodder potential. In the 2005 plantings at Murray Bridge these species produced more biomass in the first 2 years of growth than most of the tree species planted at the same time. These, and many of the other fodder shrubs established at the Murray Bridge site, now form part of the knowledge base for the Enrich program within the Future Farm Industries Cooperative Research Centre, which has trials plots based at the FloraSearch trial site at Monarto SA.

Table 28. List of candidate hardwood species from the Australian Low Rainfall Tree Improvement Group (ALRTIG) program and matching with FloraSearch list (FS).

ALRTIG Candidate Species	Common name	Growth Rate Assessment	Class	Key Species	FS Product Group	In FS Trials?
Acacia dealbata	silver wattle	High	US			Y
Acacia falciformis	hickory wattle	Unknown				
Acacia mearnsii	late black wattle	High	SS		B,F	Y
Acacia melanoxylon	blackwood	Medium	US		ST,B	Y
Allocasuarina luehmannii	bull-oak	Low	SS		ST	
Allocasuarina verticillata	drooping she-oak	Medium				Y
Casuarina cunninghamiana	river she-oak	Medium	US		ST	Y
Casuarina glauca	grey she-oak	Medium			ST	
Casuarina obesa	swamp she-oak	Medium			ST,B	Y
Corymbia citriodora	lemon scented gum	med. High	SS		ST,O	Y
Corymbia henryi	spotted gum	med. High	VS		ST	
Corymbia maculata	spotted gum	med. High	VS	Y	ST	Y
Corymbia variegata	spotted gum	med. High	VS	Y	ST	
Eucalyptus angustissima			VS		O,B	
Eucalyptus astringens	brown mallet	Low	S			
Eucalyptus baxteri	brown stringybark	Medium	SS			Y
Eucalyptus benthamii	Camden white gum	med-High	US		ST	
Eucalyptus bosistoana	Gippsland grey box	Medium	S		ST	
Eucalyptus botryoides	southern mahogany	med-High			ST	Y
Eucalyptus brookerana			US			
Eucalyptus camaldulensis	river red gum	Medium	VS	Y	ST,O,B	Y
Eucalyptus cladocalyx	sugar gum	Medium	VS	Y	P,B	Y
Eucalyptus cornuta	yate	Medium			ST	Y
Eucalyptus cypellocarpa	mountain grey gum	Med.-High	SS		ST	
Eucalyptus dunnii	Dunn's white gum	High-v. high	SS			
Eucalyptus fastigata	brown barrel	High	US		ST	
Eucalyptus globulus ssp. *bicostata*	southern blue gum	V. high	US		ST	Y
Eucalyptus globulus ssp. *globulus*	Tasmanian blue gum	V. high	US		ST,O	Y
Eucalyptus gomphocephala	tuart	High	SS		B	Y
Eucalyptus grandis	flooded gum	V. high	VS		ST,P,B	Y
Eucalyptus horistes	oil mallee		VS	Y	O,B	Y
Eucalyptus kochii ssp. *kochii*			VS		O,B	
Eucalyptus kochii ssp. *plenissima*			VS		O,B	
Eucalyptus largiflorens	black box	Low	SS			Y
Eucalyptus leucoxylon ssp. *leucoxylon*	SA bluegum/ yellow gum	Med.-high	S			Y
Eucalyptus leucoxylon ssp. *megalocarpa*	red flowering yellow gum	Medium	SS			
Eucalyptus leucoxylon ssp. *pauperita*	SA bluegum/ yellow gum	Low-medium	SS			Y
Eucalyptus leucoxylon ssp. *pruinosa*	SA bluegum/ yellow gum	Low-medium	SS			Y
Eucalyptus loxophleba ssp. *lissophloia*			VS		O,B	Y
Eucalyptus macrorhyncha	red stringybark	Medium	SS			Y
Eucalyptus melliodora	yellow box	Medium	SS			Y
Eucalyptus microcarpa	grey box	Medium	SS			Y
Eucalyptus muelleriana	yellow stringybark	Med.-high	US			
Eucalyptus nitens	shining gum	V. high	US		P	
Eucalyptus obliqua	messmate stringybark	High	SS		ST	Y
Eucalyptus occidentalis	swamp yate	Med.-high	VS	Y	ST,P,B	Y
Eucalyptus ovata	swamp gum	Medium	US		P,B	Y
Eucalyptus paniculata	grey ironbark	Medium	SS		ST	
Eucalyptus polyanthemos	red box	Medium				Y
Eucalyptus polybractea	blue mallee		VS	Y	O,B	Y
Eucalyptus porosa	black mallee box	Medium			O,P,B	Y
Eucalyptus punctata	grey gum	Medium				
Eucalyptus saligna	Sydney blue gum	High	S		ST,B	Y
Eucalyptus sideroxylon/tricarpa	red ironbark	Medium	VS	Y	B	
Eucalyptus tereticornis	forest red gum	High	SS		B	Y
Eucalyptus viminalis	manna gum	High	SS		ST,P,B	Y

Key to Class codes: US= Unsuitable; SS= Somewhat suitable; S= Suitable; VS= Very Suitable; Key to Product category codes: ST= Sawn timber; P= Pulp; F= Fodder; O= Oil., B= Bioenergy.(Adapted from Harwood *et al.* 2001 & Harwood and Bush 2002)

Domestication of Development Species

Oil mallee breeding in WA

In Western Australia, the Department of Environment and Conservation (DEC) recognised oil mallee eucalypts as having strong potential as an alternative crop for wheatbelt agriculture in the early 1990s. Work on several oil mallee species including *E. polybractea* was initiated in 1992, with several collections undertaken from the two disjunct areas of natural occurrence in the West Wyalong (NSW) and Bendigo (Victoria) regions. In total, over 450 wild trees were screened for percentage fresh weight leaf cineole, and of these, 99 trees exhibiting high leaf cineole concentration were included in the breeding program. In 1993, three small progeny trials of 28 high cineole yielding families from West Wyalong were established on three sites in Western Australia. Since then a further nine progeny trials have been established. The two latest trials included mixtures of selections from both West Wyalong and the Bendigo region.

Development of *Eucalyptus loxophleba* ssp *lissophloia* was initiated in 1994 following a similar pattern of screening wild trees for percentage fresh weight leaf cineole. This led to the establishment of the first progeny trials for this species 1995. A total of 2006 trees were screened in the field from across the species distribution, with one hundred chosen for inclusion in the breeding program. To date, eleven progeny trials have been established.

The progeny trials were designed to be thinned down to production seed orchards to provide a quick source of improved seed. Economic analysis of prospective industries indicated that improving cineole concentration in the leaves of oil mallees allows for higher profits than selecting on biomass alone. Accordingly, every tree in a trial is screened for leaf cineole concentration and measured for biomass production. Using a selection index weighted towards leaf cineole concentration, trees in the trials are ranked on their genetic merit and the worst individuals are culled. The resulting Open Pollinated Seedling Seed Orchards (OPSSO's) contain the best germplasm which is then allowed to openly cross pollinate to produce seed for production. Gain trials were established in 2006 and 2007 to enable the effectiveness of selection to be evaluated.

Reviews of Key Species for Domestication

FloraSearch has continued development of an efficient process of species evaluation to provide the perennial plant germplasm 'building blocks' for future agroforestry systems. FloraSearch Stage 2 concluded with identification of groups of development species suited to western and eastern Australia that included some common species broadly suited to southern Australia and some with more limited, node-specific suitability. More detailed species development was undertaken on Old Man Saltbush (*Atriplex nummularia*), Koojong Wattle (*Acacia saligna*) and Flooded Gum (*Eucalyptus rudis*). Knowledge of these species has expanded greatly through field trials, further data collection of growth attributes, refinement of allometric and growth modelling of key species, agronomic evaluations, and continued evaluation of economic and market potentials.

In most cases the early choices have been confirmed but there have been some changes in view point. The product focus has shifted, with a suite of products (carbon sequestration, biofuels) more aligned to climate change adaptation and mitigation taking a higher priority. This has resulted in some changes from the strong focus on wood products that predominated in Stages 1 and 2. Although still valuable options, general biomass is now more important and this will be refined as the attributes for new products, such as those derived using lignocellulosics, become clearly defined. This culminated in a review of the Development and Focus species list and has provided a team consensus on the continuing process of selection and development of woody germplasm on the national scale. Additional species, including Sugar Gum (*Eucalyptus cladocalyx*), Flat-top Yate (*E. occidentalis*) and Blue Mallee (*E. polybractea*), will be the next rank of focus species, but more general biomass producing species such as *E. porosa* and *E. gomphocephala* have been included as development species. This work is being undertaken alongside mallee plant improvement work by the WA Department of Environment and Conservation.

FloraSearch 3b report (Hobbs *et al.* 2009b) presents in-depth reviews of three focus species earmarked for further development. Koojong Wattle has been the subject of many prior studies and is recognised as a productive and adaptable species with the potential to supply woody biomass and forage, but only in WA as it presents a high weed risk in eastern Australia. The review of Old Man Saltbush reflects the long standing interest in the species in rangeland livestock industries, the remediation of dryland salinity affected land, and as a drought tolerant species providing an important source of livestock feed when annual feed sources are stressed. Similarly, Flooded Gum is an adaptable productive species suited to WA conditions, however it has not been widely recognised as a potential commercial species in the past and there is a smaller amount of background information.

Species selection is just the first stage of the genetic improvement process, especially where the species are genetically diverse and have been subject to little prior selection or breeding. This is the case for many of the species identified as prospective development candidates by the FloraSearch Project. There is therefore opportunity to commence genetic improvement for these species and to expect rapid genetic advance. Investment in genetic improvement and availability of superior planting material would be seen as a major attraction towards adoption by growers and an excellent opportunity for research investors to become the holder of potentially valuable plant breeder's rights in a new set of industries.

This section provides a shortened summary of the main points from the reviews of the focus species as a means of providing the reader with an understanding of the main characteristics and background issues with these key species.

Koojong Wattle (Acacia saligna)

Acacia saligna is a woody shrub native to Australia and endemic to SW Australia that has been selected as a candidate for domestication in the SW of Western Australia (WA). It has a long history of use for a wide variety of purposes in Australia and other parts of the world. It is easy to propagate and establish, is capable of rapid growth and can adapt to a wide range of environments.

Acacia is a large genus comprising over 1500 species occurring on five continents, with approximately 950 from Australia. (Orchard and Wilson 2001) where SE Western Australia has the world's highest diversity of *Acacia* (Hopper and Maslin 1978). Internationally, Acacia are widely utilised for fuel wood, timber, tannins, livestock feed, livestock shelter and land rehabilitation (El-Lakany 1987; Fox 1986; New 1984. There has been minimal development of *Acacia* species as crop plants for temperate zones in Australia.

Taxonomy and biology

Species description

Acacia saligna exhibits highly variable morphology and it was suspected that the variation within *A. saligna* might have been the result of unresolved taxonomic complexity or differentiation between provenances. Four subspecies are now formally recognised following a recently completed taxonomic revision by McDonald and Maslin (in review). These are *Acacia saligna* subspecies *saligna* (formerly 'cyanophylla'), *Acacia saligna* subspecies *lindleyi* (formerly 'typical'), *Acacia saligna* subspecies *stolonifera* (formerly 'forest'), and *Acacia saligna* subspecies *pruinescens* (formerly 'Tweed Blue'). Traits that are potentially important in the domestication process, such as growth form and suckering propensity, vary between these newly described subspecies (Maslin and McDonald 2004; McDonald and Maslin, in review).

The species has a widespread but discontinuous distribution in the south western part of WA and it is often common in areas where it occurs (Maslin 2001). In WA the species grows in a variety of habitats, tending to favour areas that accumulate moisture in excess of rainfall. It is common in riparian and depositional zones, with lesser occurrences proximal to large granite outcrops in the wheat-sheep agricultural zone (Maslin 2001). It is an early succession species, and even within its endemic range it is most common on disturbed sites, particularly on road verges. The subspecies with habitat details are:

Acacia saligna subspecies *saligna* is most common on geologically recent coastal and sub coastal plains, associated with deep calcareous and silicaceous sands of the Swan Coastal Plain and the south east region around Esperance. It also extends to recent alluvial soils, and ancient laterites and loams. It has a strong affiliation with watercourses and wetlands, and when close to the coast occurs in interdunal swales.

Acacia saligna subspecies *lindleyi* occurs along seasonal watercourses, the fringes of saline and non saline wetlands, below granite outcrops and in the swales of dunal systems. It is common as a roadside disturbance species.

Acacia saligna subspecies *pruinescens* has disjunct and highly varied occurrences. In the area where it is most frequent, scattered through the forest region of the south west, it is most commonly associated with yellow duplexes with loamy, clay loam or loamy clay soils that experience winter water-logging and frequently have shallow hardpans.

Acacia saligna subspecies *stolonifera* is associated with laterite-derived alluvium or colluvium gradational soils in the eastern and southern part of its range. Close to the coast in the western part of its range, it occurs on calcareous and silicaceous sands and sandy loams, overlying limestone. It most commonly occurs low in the landscape around wetter areas.

Acacia saligna grows in a Mediterranean climate in areas with a mean minimum temperature of 12°C, with a range of 9°C to 16°C and mean maximum temperature of 24°C, with a range of 20°C to 30°C. The long-term average rainfall is 580 mm, with a range of 240 to 1160 mm, falling mostly in the winter months. It is an adaptable species, able to grow throughout most of the wheat-sheep agricultural zone region of Western Australia. It does not grow in areas that regularly experience temperatures below freezing as severe frosts (-6°C) kill phyllodes and stems (Pollock *et al.* 1986)

Biology

The recent taxonomy revision highlights differences in root architecture between the subspecies. Most notable of these is subspecies *stolonifera*, which has a shallow, spreading root system that suckers aggressively. The other subspecies appear to sucker occasionally, usually in response to some degree of disturbance. The species can send out lateral roots a considerable distance (over 10 meters) towards sources of water. Roots that penetrate the soil vertically arise both from the base of trunk as well as from lateral roots. In Egypt, on deep coarse sandy soils, the roots of 6 to 7 year-old *A. saligna* plants were found to penetrate to a depth of 2.5 to 3.5 meters, and to have a lateral extent of 11 to 12 meters (El-Lakany and Mohamed 1993a; El-Lakany and Mohamed 1993b.

Acacia saligna can reproduce via seed or sucker growth. Suckering propensity varies between subspecies and may also be provenance dependant within subspecies. Plants have been observed to flower when 15 months old (Ryan and Bell 1989) and flower heavily after 2 to 3 years (Maslin *et al.* 1998). In WA flower buds form in May and grow for three to four months, with flowers opening between August and October (late winter to early spring). Pods grow for three to four months, and dehisce between November and January (Fox 1995). Field observations confirm that flowering phenology varies between subspecies. Flowering times generally overlap to some extent and it is therefore possible for pollen-mediated gene transfer or hybridisation between subspecies where they co-occur.

In SW Australia *Acacia saligna* is reported to put on new growth during the spring months of September to November (Majer 1979). Ongoing growth measurements in trials established by the authors show a period of rapid growth during spring, slowing during the remainder of the year. In Israel a flush of leaf and shoot development was observed in spring coinciding with maximum cambial activity, although the wood cambium was found to display some activity year-round (Fahn 1959). In SW Australia plants are reported to live for nearly twenty years under favourable conditions (Fox 1995) but a five to twelve year lifespan is believed to be more typical. In contrast with observations in Australia, trees in Chile are reported to have reached 30 years of age and still be in good health (W. O'Sullivan pers. obs.).

Utilisation

Wood fibres

Unpublished research (WA DEC) at a 4 year old trial site at Narrogin, Western Australia, determined that the dry above ground biomass consisted of 16 % foliage and 84% woody matter (wood and bark). Bark accounted for 20-25% of the woody matter fraction. These proportions could be expected to vary with plant age, growing conditions, subspecies and possibly provenance. Moisture content of green biomass also varied with, whole plant above ground biomass 50-52%, wood 40-44%, bark 54-61% and phyllodes 61-66%. The wood of *A. saligna* is classified as diffuse-porous with no growth rings, the result of year-round cambial activity (Fahn 1959). The basic density of the wood ranged from 469-735 kg/m^3, with a mean of about 600 kg/m^3 based on core sampling from wild and planted stands in WA.

Preliminary tests, including laboratory scale panel manufacture, have shown that *A. saligna* wood can be used to make medium density fibreboard (MDF) and particleboard (Olsen *et al.* 2004). The physical and mechanical properties of the wood, particularly strength, are comparable to the industry requirements for these products (CPA 2006).

Key traits impacting on paper production are wood density, fibre length, fibre coarseness and pulp yield (Downes *et al.* 1997; Via *et al.* 2004). An ideal density range for paper production is considered to be 400-600 kg/m3 (Downes *et al.* 1997), with a density of about 460 kg/m3 optimum for strength (Whiteman *et al.* 1996). Pulp yields for *A. saligna* were 45.2% with a Kappa number of 14.9, which is lower than for other species commonly used for production of pulp (Cotterill and Brolin 1997; Pot *et al.* 2002). The paper produced had good density, but bleaching and strength characters were poor (Olsen *et al.* 2004). As for the panel boards, *A. saligna* wood density encompasses the ideal range for paper manufacturing.

Bioenergy

Factors affecting the quality of biomass for use in energy conversion processes include its moisture content and ash fraction, a measure of inorganic elements. The Gross Calorific Value (GCV) of *A. saligna* biomass samples; consisting of ⅓ wood, ⅓ bark and ⅓ leaves and twigs; was determined to be 19.2 MJ/kg (dry basis) (Olsen *et al.* 2004). The same biomass samples had a relatively low ash content of 3.3% (dry basis) and were found to have a low propensity to cause fouling and corrosion when combusted. Compliance with fuel pellet standards may prevent some components of *A. saligna* biomass, such as bark and phyllodes, from being suitable pellet feed stocks but the wood was considered to be suitable. Ethanol synthesis processes prefer feed stocks with high cellulose to lignin ratio (Dinus 2000; Wyman 1999). The cellulose content of *A. saligna* wood chips was measured to be about 40% by Olsen *et al.* (2004), a relatively low proportion compared with other energy crop species such as switchgrass and poplar (Dinus 2000).

Fodder

A. saligna is already utilized for grazing to a limited extent in south-western Australia, as well as elsewhere in the world. As a perennial, it has the advantage of being able to provide feed when annual pastures are not available (Doran and Turnbull 1997; Stringi *et al.* 1991). Acacia species in general do not meet the forage requirements for maintenance of sheep. This may be due to high lignin content reducing the dry matter digestibility (Lefroy *et al.*1992), and/or the presence of tannins decreasing palatability, digestion and absorption of nitrogen (Reed *et al.*1989; Reed 1995; Woodward and Reed 1989). In general, the species is low in energy, as measured by dry matter digestibility, but sufficient in protein and most of the essential minerals (George *et al.* 2007). Krebs *et al.* (2003) examined changes in feed quality due to differences in season and plant maturity in *A. saligna* and found the nutritive value was affected by the season in which it was pruned and the age of the subsequent regrowth. The nutritive value decreased as the plant material aged, however the season in which foliage was pruned confounded the effect. Regrowth from spring pruned *A. saligna* generally had higher digestibility and protein content than regrowth from plants pruned in autumn or winter, although the difference became less pronounced as the plants aged.

Tannins

Acacia saligna contains high levels of tannins that also compromise its suitability as food source for livestock. Tannins reduce voluntary intake of the plant through reduced palatability or through reduced digestion (Reed 1995) although low levels in stock feeds can be beneficial. They may improve protein use efficiency in ruminant animals through protection of proteins from microbial action in the rumen, increased efficiency in urea recycling, and increased yield of beneficial microbes (Reed 1995).

Productivity and yields

Growth

Acacia saligna has a demonstrated capacity for rapid growth rates under optimal conditions and in WA performs strongly compared with other species across a range of site types (Olsen *et al.* 2004). The authors have observed four year old stands with growth rates exceeding 20 dry tonnes of above ground biomass/ha/yr, however growth rates can vary markedly between and even within sites, and are more frequently in the range of 3-12 dry tonnes of above ground biomass/ha/yr. The study by Zegada-Lizarazu *et al.* (2007) provides a powerful demonstration of the responsiveness of *A. saligna* to water availability; in their trial of varying irrigation treatments in the Negev desert, the reported growth of 5 year old plants ranged from 14.4 to 126.2 tonnes/ha dry above ground biomass. The range of growth was proportional to the amount of water supplied to the plants.

A number of studies have demonstrated that it is possible to accurately predict the biomass productivity of *Acacia saligna* using non-destructive measurements of stem cross sectional area which can provide a rapid and non-destructive estimate of yields from *A. saligna* crops. Studies conducted in North and South Africa were able to accurately predict biomass productivity ($r^2 > 0.9$) using allometric relationships with stem basal diameter as the independent variable (Zegada-Lizarazu *et al.* 2007; Laamouri *et al.* 2002; Milton and Siegfried 1981). The same variables have been used to develop similar allometric relationships in WA in unpublished research by the authors.

Several pot trials have shown that young *A. saligna* plants respond strongly to additional macro-nutrients. In one study in which a treatment of nitrogen, phosphorus and potassium fertilizer (0.33, 0.05 and 0.05 g/kg) was applied, after approximately nine months growth the mean dry weight of fertilized plants was 20 g whilst non-fertilized plants was 10 g (El-Baha *et al.* 2003). At phosphorous application rates of approximately 0, 5 and 40 mg/kg soil the dry mass of 2 month old shoots of *A. saligna* was 0.6, 0.9 and 1.5 g/plant respectively (Jasper *et al.* 1989). No known studies have specifically addressed, or tried to quantify, the impact of nutrient additions on the productivity of *A. saligna* in field trials.

Crop layout and density

There is very little published work investigating the impact of crop layout and density on the production of *Acacia saligna*. The authors have established planting density trials on farmland in WA.

Interim results from one site, for two year old plants, showed that plant growth varies with planting density. For two year old plants, higher planting densities corresponded with greater stem basal area per hectare and consequently greater standing biomass. Trees at lower planting densities grew larger than those at the highest planting density of 8000 stems per hectare (SPH), however the extra growth was not sufficient to match the biomass production per unit area of land observed in the 8000 SPH plots. This implies that lower density plantings have been unable to exploit site resources to the same extent as trees planted at 8000 SPH over the two year period. It remains to be seen whether this trend will be maintained as the plants age.

The productivity of *Acacia saligna* as a coppice crop is affected by harvest factors such as frequency, cutting height, plant age and time of year. Work from North Africa suggests that *A. saligna* will coppice after cutting even if cut several years in succession (Tiedeman and Johnson 1992). Wide variation in coppicing ability in WA has been observed with some provenances failing to coppice if cut near ground level. Coppicing ability will affect the future production systems *A. saligna* is suited to, and developing a thorough understanding of how it responds to harvesting is important for its future use as a crop plant.

Only a limited number of studies have examined aspects of *A. saligna* harvesting. The study of Droppelmann and Berliner (2000) measured relative growth rates of unpruned plants and plants where the foliage and small branches were removed, they recommended pruning intervals of 6-8 months to optimise growth rates under the site conditions in north west Kenya. Other research has shown that regular cutting of *A. saligna* results in lower yields than if plants are cut less frequently. For example, the harvest of two year old *A. saligna* yielded 4.2 kg DM of wood and 1.6 kg DM foliage, while the combined yield from plants harvested twice in the same period was 1.8 kg DM wood and 1.6 kg DM foliage (Tiedeman and Johnson 1992). In a study which examined the effect of cutting height in Chile, it was found that trees cut 50 cm above ground level were significantly more productive than those cut at 5 cm or 100 cm (Bratti *et al.* 1998).

As a leguminous plant, *Acacia saligna* can fix atmospheric nitrogen by forming symbiotic relationships with bacteria in root nodules and a number of studies have found that the presence or absence of root-nodule bacteria can impact substantially on productivity. Plants inoculated with isolates of the nitrogen fixing microbes *Bradyrhizobium* sp. and *Rhizobium* sp. from different coastal dunes in Morocco were found to have a mean shoot dry weight of 5.6 to 9.8 g/plant, compared with 4.1 g/plant for the un-inoculated treatments (Hatimi 1999). Work in south-eastern Australia using other *Acacia* species has found that plants inoculated with root-nodule bacteria grew 10 to 58% faster than un-inoculated controls during the critical early phase of establishment, although this varied among species and sites (Thrall *et al.* 2005).

Wild populations of *A. saligna* are known to be susceptible to a number of insect and fungal pathogens. The most significant of these is Gall Rust fungus (*Uromycladium tepperianum* (Sacc.) McAlp.). This fungus has been observed on plants of all ages, but typically affects older trees. It is common on trees growing in poor conditions, and heavy infestation can lead to the death of the trees (Fox 1995; Gathe 1971). *Acacia saligna* is also reported to be susceptible to anthracnose fungus (Barnard and Schroeder 1984). A number of phytophagous insect species appear to have the potential to cause damage to *A. saligna* (Van Den Berg 1980a; Van Den Berg 1980b; Van Den Berg 1980c). Sap-sucking insects and also mites are known to damage *A. saligna* (Angell and Glencross 1993; Old *et al.* 2002).

Propagation

Acacia saligna can be readily propagated using seed. In good growing conditions the species produces large quantities of seed that is relatively easy to collect and clean. Once sorted to remove seeds that are damaged, undeveloped or aborted, the seed typically has over 70% viability (Doran and Turnbull 1997; Fox 1995). The seed coat of *A. saligna* is impervious to water, which restricts imbibition and functions as a physical barrier to germination (Fox 1995). To facilitate germination, the seed must be physically scarified or exposed to boiling water. The ideal germination temperature for *A. saligna* seed is reported to be 15ºC (Shaybany and Rouhani 1976).

Acacia saligna can be propagated vegetatively via root-sucker growth (Angell and Glencross 1993) and tissue culture (Barakat and El-Lakany 1992). Use of vegetative propagation may be appropriate under some circumstances; for example as part of a breeding improvement program.

Weediness and geneflow

Acacia saligna has become a weed in many areas where it has been introduced (Blood 2001; Muyt 2001; Swarbrick and Skarratt 1994). It has many characteristics that predispose it to weediness: including the production of large volumes of seed, persistence of seed-bank, high germination rates, aggressive growth, extensive root system, suckering, coppicing, and tolerance of poor environmental conditions (Morris 1999; Witkowski 1991). The species is naturalised in all states of Australia, and all regions of the world that experience a Mediterranean climate (Fox 1995; Muyt 2001).

Until the mid 1990's, *A. saligna* was recognised as 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 species was introduced into South Africa as early as the 1830's, where it was widely planted for sand dune stabilization and as a source of wood and tannins (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). Virtue and Melland (2003), completed a weed risk assessment for *A. saligna* in South Australia, and concluded that the species poses a high weed risk in the southern part of the State. They noted that infestations of *A. saligna* are difficult to control because trees readily sucker and coppice, requiring cut stumps to be treated with herbicide. The longevity of the seed-bank means sites must be re-treated. If the species is used as a crop it may interfere with farming activities. The report recommended that any attempt to produce cultivars for South Australia should focus on reduced reproductive ability.

Within its natural range there is little risk of *A. saligna* becoming weedy, especially if utilisation is based on subspecies boundaries. It is for this reason that FloraSearch only proposes to develop the species as a commercial crop in WA

Selection and genetic modifications to improve *A. saligna* crop performance could threaten the genetic integrity of wild populations where they are in proximity to planted cultivars, based on experience with other crop species (Ellstrand *et al.* 1999). Widely distributed species are likely to have locally specific adaptations (Hufford and Mazer 2003), and prolonged selection and breeding are also likely to result in cultivars that that are genetically differentiated and less genetically diverse than wild populations (Adams and Burczyk 2000; Allard 1999). Gene flow between plantings and natural populations could therefore lead to the introduction of adaptive or maladaptive genes.

A formal weed risk assessment for this species has been conducted as part of our Cooperative Research Centre obligations. This evaluation can be found in Appendix C - Weed Risk Assessments section of this report.

Conclusions

As a candidate for domestication in WA, *Acacia saligna* has many desirable attributes. A sizable body of knowledge for the species, both locally and globally, has been accumulated over a period of several decades. This includes applied experience in local dryland farming systems. The seed is relatively easy to collect, purify, store and use for mass propagation. It is easy to establish in the field and has the potential for rapid growth rates. The reproductive biology of the species is suited to breeding improvement, and extensive wild populations provide a large and diverse genetic base to underpin this task.

There is a risk that an *A. saligna* industry could succumb to locally occurring pests and diseases, in particular Gall rust. A systematic assessment of the extent and manageability of this risk is strongly advisable. The relatively short lifespan of *A. saligna* also presents a challenge for industry development; development of a planting resource on farmland will need to be will synchronised with the construction of biomass processing facilities.

The authors conclude that the domestication of *A. saligna* for western Australian dryland farming systems remains a valid objective; given the inherently favourable characteristics of *A. saligna* for crop development and the scope for overcoming the challenges that remain.

Old Man Saltbush (Atriplex nummlaria)

Old Man Saltbush *(Atriplex nummularia*) is a native chenopod shrub species with a wide distribution through the arid lands of Australia. It is a summer active C4 photosynthesis plant with the primary growth period in the spring and summer months. It is a productive and adaptable shrub widely utilised for forage on saline and non-saline land systems for over 150 years. Interest in Old Man Saltbush has increased as new perennial crop options are sought for regions in the southern Australian agricultural zone that have been affected by salinity and the projected changes in climatic conditions linked to climate change. It is currently the most important shrub species used for remediation of saltland.

The development of commercially viable perennial-based farming systems for the lower rainfall wheat-sheep zone is the priority outcome of the Future Farm Industries CRC and there is considerable research focused on grazing systems development on saline and non-saline land. Old Man Saltbush has been identified as a key species in these systems. There is little history of domestication apart from some work undertaken in South Africa based on limited germplasm and a clonally propagated chance seedling with good growth characteristics that is marketed as 'Eyres Green'. Significant gains in productivity, palatability and feed value are expected through a scientific approach to plant improvement. An extensive germplasm collection has been established as part of the FloraSearch project that has the potential to underpin advances in the availability of superior planting material that can overcome the current limitations of Old Man Saltbush (palatability and feed value) and enable its more widespread application to farming systems of the wheat-sheep zone of southern Australia.

Challenges and opportunities for development

The potential of perennial shrub based forage systems is gaining acceptance as a means of providing options that:

- Provide a feed base made up of a functional mixture of plant species including shrub options that are resilient to prolonged dry periods and provide feed in periods of seasonal shortfall

- Integrate into a productive livestock enterprise based on current pasture options but are of a sufficient scale to have a positive impact on land management issues, and

- Provide the opportunity to include plants in a mixed assemblage that provide compounds of medicinal value, or compounds that have favourable effects on gut health through manipulating the microflora and fauna of the digestive tract.

Rogers *et al.* (2005) suggested that a key opportunity for the development of perennial fodder systems is to select appropriate species of *Atriplex* based on their ability to lower water tables, favourable habit, nutritive value, palatability, and ease of establishment. Old Man Saltbush has a long history of utilisation in rangelands and pastoral systems being used as a fodder resource in Australia since the mid 1800's (Williams 1961; Williams and Oxley 1979). The hardiness and adaptability of Old Man Saltbush in arid environments has also seen its export to many arid and semi-arid parts of the world for use in land reclamation and fodder (Le Houérou 2000b).

Whilst Old Man Saltbush has a long history of use there has been limited data gathered on the genetic variation in natural stands of Old Man Saltbush and how this is expressed in the parameters important for acceptance and performance by livestock. The extent to which unmanaged grazing of natural stands of Old Man Saltbush has resulted in the eradication of the most favourable genotypes (i.e. those with high palatability and nutritive value) is also unknown. For example, the long history of grazing in the riverine plains in western New South Wales (NSW) has resulted in the loss of much of the dominant Old Man Saltbush community, leading to a recent nomination as a threatened ecological community under the NSW Threatened Species Conservation Act (TSCA 1995). Recent research indicates however, that there may be sufficient genetic variability in saltbush to be able to select and breed cultivars that have high growth, palatability and nutritive value (Rogers *et al.* 2005). If sufficient genotype variability is present it will prove important for selecting genotypes best adapted for the environments and fodder traits of interest and suggests that examination of traits at the family level is warranted.

Taxonomy and biology

Species description

Atriplex nummularia Lindley is a large grey-green, scaly perennial shrub in the family Chenopodiaceae and is the largest of the Australian saltbushes (Cunningham *et al.* 1981). The lower branches are decumbent and the woody stems are generally brittle. Three different subspecies are currently recognised and can be differentiated primarily by the morphology of the bracteoles (Parr-Smith 1984).

Atriplex nummularia* ssp. *nummularia is the largest of the three subspecies, growing to a height of 2 – 3 m and can be 4 – 5 m across (Cunningham *et al.* 1981). It has thickened, woody orbicular bracteoles. The leaves are petiolate, broadly elliptic to ovate and 3 – 3.5 cm across (Parr-Smith 1984).

Atriplex nummularia* ssp. *omissa has thickened woody, rhomboidal bracteoles and grows to 2 m high. The leaves are elliptic, rhomboidal, or orbicular, and are up to 3 cm across (Parr-Smith 1984).

Atriplex nummularia* ssp. *spathulata has unthickened, reflexed bracteoles and is the smallest of the three subspecies, growing to 1.5 m. The leaf petiole is indistinct in this subspecies with the leaves elliptic to obovate in shape and up to 2 cm across (Parr-Smith 1984).

A. nummularia ssp. *nummularia* and ssp. *omissa* can be found on a variety of soil types but primarily on the heavier clay and clay loam soils on alluvial plains and on drainage depressions and sand dune swales (Cunningham *et al.* 1981; Leigh 1972). Subspecies *omissa* occurs on clay soils but more on the stony gibber plains and tablelands in drainage lines (Kutsche and Lay 2003).

Atriplex nummularia is endemic to the low – medium rainfall regions (150 – 650 mm) of Australia. Both *A. nummularia* ssp. *nummularia* and *A. nummularia* ssp. *omissa* have a sympatric distribution through the more arid parts of eastern and central Australia. *A. nummularia* ssp. *nummularia* extends further towards the eastern edge of the range into the higher rainfall areas. In contrast, *A. nummularia* ssp. *spathulata* has a disjunct distribution from the other two subspecies, occurring primarily in the arid parts of WA from the Nullarbor Plain in the east to the region around Shark Bay on the west coast.

Old Man Saltbush has the ability to withstand moderate low temperature periods but sustained low temperature periods can be detrimental. Maiden (1894) noted that Old Man Saltbush was able to withstand minimum temperatures of -10^{0}C in western NSW and Russell (1996) measured 90% survival of *A. nummularia* following severe frosts in the Southern Tablelands near Yass, New South Wales with temperatures ranging from -3°C to -10°C. Le Houérou (1992) also reports Old Man Saltbush being able to withstand temperatures as low as -10°C to -12°C for at least a few hours but cold spells of greater intensity and duration can be detrimental to survival. Old Man Saltbush is well known for its tolerance of drought conditions and high temperatures which are experienced throughout much of its range (Leigh 1972). Physiological adaptations that enable the species to cope with drought include a deep tap root system, an ability to shed leaves in dry periods, a C4 photosynthesis system with photosynthetic tissue concentrated around vascular bundles in the semi succulent leaves, and bladder like hairs on the leaf surface that act as protection from insolation and moderate transpiration (Leigh 1972). Old Man Saltbush has the ability to synthesise compounds such as oxalates, betaines and prolines that assist in osmoregulation by increasing salt concentration in the cell sap (Leigh 1972). It also has a high tolerance of saline conditions and low – moderate levels of sodium have been shown to enhance growth.

Biology

Previous descriptions suggest that Old Man Saltbush is predominantly dioecious (having separate male or female plants) although it has long been recognised that there are also monoecious (both sexes present on a single plant) individuals (Maiden 1894). *A. nummularia* ssp. *nummularia* and *A. nummularia* ssp. *omissa* flower most of the year (Costermans 1984; Kutsche and Lay 2003) and *A. nummularia* ssp. *spathulata* flowers through winter and sets fruits in September and October (Mitchell and Wilcox 1994). The male flowers are produced at the ends of the branches in globular heads forming interrupted or continuous spikes or panicles. The female flowers occur in dense clusters or singularly in leaf axils at the end of branchlets. Monoecious plants have a terminal inflorescence of male flowers and a variable number of female flowers in leaf axils lower down the stem. The fruit consists of two paper-like bracteoles that are pressed close together and house the seed at the base when present (Leigh 1972). Fruit production can be so prolific that branches may be bent to the ground or break under the weight. The presence of sexual labiality and the level of monoecy in Old Man Saltbush has not been established but may have important implications for selections within a breeding program.

Chenopods in general are considered to be infrequent hosts to arbuscular micorrhizal (AM) fungi (Asghari *et al.* 2005). However, within the genus AM fungi has been found in natural stands and successful inoculation has been achieved in pot trials for a range of *Atriplex* species including *Atriplex halimus* (He *et al.* 2002) and 8 *Atriplex* species endemic to Chile in South America (Aguilera *et al.* 1998). As well as these 8 species, Aguilera *et al.* (1998) also examined the AM fungi status of two populations of Old Man Saltbush growing in non-saline soils. In South Australia, Ashgari *et al.* (2005) tested the roots and soil of A. *nummularia* plants in natural stands at Monarto and found 10 – 30 % of the root length colonised by AM fungi. In subsequent experimental pot trials where they inoculated seedlings grown in the glasshouse at two salinities (2.2 and 12 dS/m) they found a lower uptake of AM fungi than in the field at only 1 – 2 % of root length, but there was increased growth and nutrient uptake compared to the control seedlings, primarily in the first 6 weeks. In a similar pot experiment, Plenchette and Duponnois (2005) found a significant increase in root and shoot biomass in 6-month old plants that had been inoculated with AM fungi.

The type of utilisation of Old Man Saltbush will be a strong determinant of lifespan (Guevara *et al.* 2005). Le Houerou (1994) discusses a 5 ha plantation of Old Man Saltbush that was established in 1921 that was still productive in 1993 under a management regime of browsing for only 1 month per year. Well managed stands in Tunisia have been consistent producers for over 40 years, although poorly managed stands that are grazed hard each year may only live for 10 – 12 years (Le Houérou 1986).

Much has been touted about the ability of deep-rooted perennial shrubs to tap into and lower the level of the water table but to date there has not been a significant investment into researching this aspect of Old Man Saltbush. Slavich *et al.* (1999) investigated the water use of grazed plantations above shallow water tables in southern NSW and found that the transpiration rate was small and for much of the year it was derived from shallower rainfall sources rather than deeper groundwater. In the hotter months there was greater utilisation of the groundwater that accounted for about half of the transpiration. Their conclusion was that annually grazed Old Man Saltbush plantations were not likely to have significant hydrological impact on saline groundwater areas due to reduction in leaf area and hence transpiration, in plants already stressed by the saline conditions. Ashby and Beadle (1957) looked at water use at a range of salinities in the glasshouse and found that daily water use was appreciably less in the saline treatments than the non saline, although these had the higher biomass dry weight.

In south eastern Australia there has been some investigation into the effective water use and competition of shrub belts amidst annual crops. The water use of Old Man Saltbush belts integrated with annual crops has been investigated at a number of other sites in SE Australia by (Knight *et al.* 2002). Living roots were found at 16m depth below the belts, confirming the deep-rooted nature of this species, and in 4 years the belts were found to have used an accumulated leakage of 600 mm from deep in the profile. This water was only removed from very close to the belt so that alley farming only controls a small percentage of the potential leakage. The authors recommend using larger scale block plantings for more efficient water use (Knight *et al.* 2002). A water use of 401 mm/yr has been recorded at Deniliquin in NSW for *A. nummularia* planted on heavy soils at 1100 stems/ha (Raper 1998). These figures are similar to those for *Atriplex vesicaria* that have also been recorded at between 0.7 and 2.0 mm per day (255.5 – 730 mm per year) (Greenwood and Beresford 1980; Sharma 1976b).

Utilisation

Fodder

The value of Old Man Saltbush to the livestock industry as a fodder plant has been recognised since the mid 1800’s in the western areas of NSW. Early reports suggest that the natural distribution was more widespread than is currently recognised. A combination of a limited number of water points, severe drought, the spread of rabbit populations, and high sheep stocking rates, have all been listed as contributing factors for the decline in extent and condition of chenopod shrublands (Williams and Oxley 1979). In many areas these populations were reduced to scattered plants due to overstocking and continued decline was observed over time (Maiden 1894). Kelly (1902) noted that the best varieties had been eaten out in this period, with the grazing pressure also eradicating saltbush populations in regions of the Upper Bogan and western Queensland (Holdsworth 1903). It was recognised that stands of Old Man Saltbush provides shelter for animals and had a stabilising influence on the soil, thus providing a range of ancillary benefits on top of the fodder applications (Peacock 1904). From a fodder perspective, it was discovered that Old Man Saltbush was not sufficient as a stand alone feed but was best used in combination with a range of other fodder options (Peacock 1901), which could be planted between rows in the early stages of establishment if rows are planted 3m or more apart (Kelly 1902).

Overseas usage

The ability of Old Man Saltbush to grow in low rainfall and saline conditions has seen its application to a whole range of both dryland and irrigated systems throughout the world. Germplasm was being exported to northern Africa, the Middle East and West Asia by the late 1800s (Le Houérou 1986; 2000b) and there has been a concerted effort to integrate fodder shrubs throughout this region in the latter part of the 20th century (Le Houérou 2000b). This has resulted excess of 100, 000 hectares being planted to *Atriplex*, with Old Man Saltbush plantations comprising by far the biggest proportion of this area (Le Houérou 1992). Fodder is the primary use in this region but it is also used extensively for reclamation of degraded lands (Le Houérou 2000a). Old Man Saltbush has also been used to reclaim large areas of arid land in South America, particularly Chile where an excess of 40,000 ha have been planted (Alonso 1990).

Fodder values and desirable traits

The fodder value of a crop is difficult to determine as it involves a number of interacting factors such as digestibility, nutrient composition, palatability, absorption of nutrients, secondary compounds and toxins and voluntary feed intake (Warren and Casson 1996).

Digestibility is an important determinant of the intake of forage by livestock. Ruminants require above 55% DMD of feed to maintain live weight and a DMD greater than 60 – 65%, in combination with other nutrients to enable growth (Warren and Casson 1996). Levels lower than 50% are unable to provide enough metabolisable energy because the limits inherent to rumen capacity mean livestock cannot physically consume and process enough feed to satisfy requirements. The documented measures of the *in vitro* digestibility of Old Man Saltbush provided by these techniques range from 52.9 –77.8% with leaf material having about twice the digestibility of the stems (Warren and Casson 1996). Taken on face value, these figures suggest that Old Man Saltbush should be able to supply sufficient energy requirements for weight gain in livestock, however, there is not always a direct relationship between measured attributes and their value to stock (Islam and Adams 2000). To date, few native Australian shrub samples have been through both the animal and laboratory calibrations of digestibility. Consequently, real figures for digestibility have generally been found to be less than the corresponding *in vitro* values and are often below 50% DMD (Warren *et al.* 1995). Currently there is considerable confusion in industry due to variation in prediction of saltbush digestibility (thus energy) by commercial laboratories using methodologies that are not calibrated for shrubs.

One of the major indicators of the nutritive value of a fodder is it's protein concentration (Islam and Adams 2000) which is conventionally calculated by multiplying the total nitrogen concentration by a factor of 6.25. Protein values in Old Man Saltbush range from 8.3% to 27.0% with an average of 15.4%, placing it favourably against other more traditional forage species. In reality, only about 50 % of the nitrogen in the saltbush is readily usable soluble protein-N, amino acid-N, nucleic acid-N and nitrate-N and the remaining proportion of nitrogen is non-soluble protein-N and other N associated with cell walls and membranes (Islam and Adams 2000). Because of the low digestible energy in saltbush, much of the rumen degradable non-protein N compounds will not be converted into microbial protein in the rumen without an additional energy source (Masters *et al.* 2001). Consequently, when saltbush is fed as a sole ration, the sheep are unable to utilise the full component of the N in the feed.

In general, the way in which salt tolerant plants accumulate other elements and the level of variation between individuals and populations remains largely untested (Masters *et al.* 2001). Old Man Saltbush is known to have high concentrations of phosphorous, calcium, sulphur, selenium and magnesium. A more recent discovery is that Old Man Saltbush is high in Vitamin E which may help to protect browsing animals from nutritional myopathy and also improve the colour and shelf life of the meat (Pearce and Jacob 2004).

Feed value can vary throughout the year and Islam and Adams (2000) found seasonal variation in nitrogen, phosphorous and cations in Old Man Saltbush in WA. El-Shatenawi and Abdullah (2003) examined the seasonal variation in nutritive and mineral content in a winter dominant rainfall area of Jordan and found significant variation in the dry matter content of the leaves and twigs with the highest values (48%) occurring in near the middle of the summer period and the lowest near the wettest winter period (25%). There was also significantly less crude protein, P and K in the summer period.

The ash content of Old Man Saltbush can be up to 30% and is predominantly composed of sodium, potassium and chloride (Masters *et al.* 2005a). The potential effect of this accrued ash content in saltbush on the diets of livestock has long been of interest. Early feeding trials conducted by Wilson (1966) found that higher sodium intake suppressed dry matter intake of sheep but they were able to compensate to some extent by increasing their intake of fresh water where available. However, when saltbush was fed in conjunction with drinking water containing above 0.6% sodium the dry matter intake was reduced by up to 50%. If available, sheep selected low salt rations to compensate for salty water or diets (Wilson 1968). A recent study on the effects of high sodium and potassium in the diet found organic matter intake, digestibility, live weight gain, and wool growth were depressed at high levels (Masters *et al.* 2005b). They suggest that the restricted organic matter intake (reduced by almost 50% from lowest to highest salt levels) as a result of physiological limitations of the rumen was the likely causal factor of this depressed wool growth. Interestingly, despite the depressed growth, the efficiency of wool growth per kg of organic matter intake increased by approximately 50% when comparing the lowest and highest levels of sodium and potassium.

Saltbushes have the ability to accumulate inorganic ions such as betaine and oxalate as the basic mechanism by which they adjust the osmotic potential of their internal tissues to the external salinity (Khan *et al.* 2000). In this way they can counteract the negative water potential resulting from saline soils or as a result of water stress. Oxalates have the potential to be toxic to ruminants at concentrations above 10%. It appears that concentrations of oxalates can differ with age of the respective plants. Oxalates were highest in young Old Man Saltbush seedlings (up to 8.8%) but dropped strongly with increasing plant age to a point considered non-toxic between 1.3% and 2.1% (Davis 1981). Abu-Zanat *et al.* (2003) examined seasonal and age related oxalate levels and found that mean levels for the spring were 7.6% and for the fall were 4.7%. Once again the levels were highest in young seedlings compared to 5 – 10 year old plants. These concentrations suggest the potential for toxicity but because they have the potential to suppress intake, toxicity seems to be rare, particularly where mixed forage systems are being utilised.

Livestock utilisation

Prior selection of saltbush for commercial planting in Australia has been conducted with little thought for nutritive value or palatability in mind (Norman *et al.* 2004b). However, in a plant improvement program aimed at selecting improved fodder lines, palatability will be an important trait to consider. In general, most chenopods are considered of moderate to low palatability with livestock preferring other grasses and forbs. An understanding of palatability is complex, as it involves factors relating to the plant, animal and environment (Kaitho *et al.* 1996). There are a number of reports that suggest that sheep that have not previously grazed saltbush require an introduction and preconditioning period, in essence allowing the rumen flora time to adapt to the new feed source (Kaitho *et al.* 1996; Mirreh *et al.* 1996; Norman *et al.* 2004b). Anecdotal and experimental evidence suggests that once conditioned there are specific preferences displayed by sheep for certain individual plants over others (Kessler 1990; Leigh 1972; Norman *et al.* 2004b).

A study by Norman *et al.* (2004b), is one of the few that looks at variation in palatability at the within population level. They found that river saltbush (*A. amnicola*) was eaten in preference to Old Man Saltbush in a feeding trial in WA. Digestibility and levels of minerals and secondary compounds did not adequately explain the differences in preference, suggesting that our current knowledge of sheep preference is too limited for us to be able to make selections of individual plants based on these characters alone.

Old Man Saltbush is suggested to be more useful as a component in a fodder system, perhaps in the summer autumn feed gap (Tiong *et al.* 1994; Warren *et al.* 1991). A number of subsequent experimental feeding trials have provided a quantitative basis to this notion and have highlighted the efficiencies to be gained by the addition of supplementary energy feeds. Franklin-McEvoy *et al.* (2007) suggested that this could be achieved through the use of readily fermentable carbohydrates as an energy source for rumen microbes, and by providing increased fibrous roughage that slows the flow of digesta, thus increasing digestion. There is now a growing body of literature on the use of saltbushes with supplementation from other energy sources. A feeding trial with 4 other *Atriplex* species found that sheep consumed 500-1200g/day less saltbush than required to maintain weight when fed on saltbush alone. With a mixed diet of hay and saltbush (50:50) the sheep consumed twice as much feed and increased weight over the trial (Warren *et al.* 1991). Norman *et al.* (2004a) showed a trend of enhanced performance with the addition of supplements of barley straw and barley grain but this was not significant in their study in WA. Sheep in this trial performed significantly better on Old Man Saltbush than on *Atriplex amnicola.* More recently in South Australia, Franklin-McEvoy *et al.* (2007) conducted a feeding trial with Old Man Saltbush only, Old Man Saltbush + 250g/day barley straw, Old Man Saltbush + 250g/day barley grain, and Old Man Saltbush + 250g/day of both barley straw and barley grain. Old Man Saltbush plus grain resulted in significantly heavier sheep than the other treatments. Grain supplements also increased wool growth by 16% and improved energy balance to enhance rumen protein capture.

Productivity and yields

Growth and edible biomass

The amount of edible biomass achievable from stands of Old Man Saltbush appears to vary depending on a number of factors including rainfall, planting density, soils, and wether it is to be grown in a dryland or irrigated setting. It has been reported that irrigated stands have the potential for producing 10 – 15 t/ha/yr of edible dry fodder mass (Le Houérou 1986). Some of these studies have extremely high planting densities in the range of 15,000 to 28,000 plants/ ha which is beyond what is desirable for a standing fodder crop. In dryland settings, the realised yield from plantations of saltbush is much more modest than that indicated by these irrigated trials. Much of the work from WA describes yields for other species of saltbush, often grown on saline land. Most of these saltbush plantations produce about 0.8 – 1.2 t/DM/ha/yr (Warren and Casson 1993). In comparative studies where Old Man Saltbush has been planted with other Atriplex species it has been found to be the larger biomass producer (Benjamin *et al.* 1995; Hyder 1981).

Abu-zanat *et al.* (2004) investigated the benefits to biomass production from harvesting extra water with the use of furrows. In 80 – 200 mm rainfall conditions browse production averaged 380 and 1151 kg DM ha^{-1} for the natural and harvested rainfall treatments. They also found that the intensity of pruning for management had a significant effect on shrub regrowth, with cutting at 45cm above ground level better than 15 and 30cm. High survival irrespective of the cutting regime suggests that Old Man Saltbush is highly tolerant to browsing or cutting.

One of the recognised issues with the use of woody halophyte shrubs is that a large proportion of the biomass is woody material of limited nutritional value (Masters *et al.* 2006; Masters *et al.* 2005a). Browse to total biomass ratio decreased from 0.63 to 0.40 and 0.29 for the first three growing seasons in the trial by Guevara *et al.* (2005). The browse to total biomass ratio of green matter was 0.33 in 3year old uncut plants but 1.0 for regrowth after 1 year (Le Houérou 1986) but was 34% higher for 3yr old plants in a study by Guevara *et al.* 2005). Mean basic density of the woody fraction of Old Man Saltbush is high, averaging between 610 and 724 kg/m^3. Significant differences have been found between two different provenances grown on a site with the highest density corresponding to the slowest growing provenance and vice versa (McKenna unpublished data).

Grazing response

Old Man Saltbush has the ability to periodically withstand complete defoliation (Leigh 1972) but it can be sensitive to overgrazing and may be destroyed by overstocking (Barnard *et al.* 1992; Le Houérou 1986). Milthorpe *et al.* (2001) recommend that at least 10% of the leaf biomass be left on the plants and up to 20% if grazing occurs in the winter. Benjamin *et al.* (1995) grazed shrubs annually till 100% leaf removal in the summer feed gap but the shrubs never regained their initial biomass. Edible green biomass was highest at the pre grazing period, ranging from 1t/ha to 3.7 t/ha for the highest and lowest planting densities respectively. This equates to approximately 0.22 t/ha and 0.81 t/ha dry matter. Available biomass of edible regrowth reduced with each successive year of grazing, significantly so in the last two of the 5 years. By the 5^{th} year the edible biomass production was reduced to approximately 0.2 t/ha and 1.1 t/ha respectively for the lowest and highest densities. Stem regrowth was more variable than that of leaves and was primarily responsible for the differences among treatments. The leaf biomass removed was initially higher than that of fine twig material but in two years it was significantly less. Variation in the quality of regrowth has been recorded by Watson *et al.* (1987) and by Guevara *et al.* (2005) who found that the crude protein content of the regrowth was generally higher than that of similarly aged ungrazed plants (at 33 months of age). This suggests that grazing management will be important.

Propagation and establishment

Germination of seed can be extremely low when the bracts are left intact (Beadle 1952; (Abu-Zanat and Samarah 2005; Peluc and Parera 2000; Stevens *et al.* 2006). Beadle (1952) concluded that the chloride build up in the bracteoles was responsible for retarding germination and reapplication of an abstract derived from the bracts has also been shown to inhibit germination (Campbell and Matthewson 1992). Seeds within the bracts have either a soft or a hard coating (Beadle 1952) with the harder seeds having a lifespan of at least 8 years but germination with the bracts removed reduced from 92% when fresh to 10% over this time. The optimum temperature for germination was 20 – 25^{0}C with little effect of photoperiod, with higher temperatures being detrimental (Beadle 1952; Sharma 1976a). Providing successful germination can be achieved, the most cost effective way of establishing Old Man Saltbush plantations would be through direct seeding however, slow germination and poor seedling establishment following direct seeding has been a limiting factor to more widespread use by farmers (Donaldson 1990).

Currently, direct field sowing of seed can lead to as little as 5% successful germination (Stevens *et al.* 2006). In their trials, removal of the bracteole significantly enhanced germination but it was still low at 40%. Inclusion of light increased germination by 12%. Field emergence with water priming was low at 20% but was higher for the intact fruits than the naked seed. In contrast, under laboratory conditions bracteole removal and light had minor positive effects on germination of *A. nummularia*, but this did not translate into improved emergence in soil or in the field. Application of salicylic acid and kinetin improved emergence at the different levels of salinity examined. Increasing salinity levels in either the ground water or soil can have detrimental affects on germination (Sharma 1973). Bajji *et al.* (2002) found low levels of salt stress delayed germination and higher levels of salt stress reduced germination percentages in *A. halimus*. Malcolm *et al.* (2003) also found a progressive reduction in germination as salinity increased to 250 m*M* NaCl, beyond which it was generally inhibited altogether. They argued that a low salinity niche could provide a greater chance of germination and persistence and therefore applied a coating of the seed/vermiculite mixture with paint or bitumen (creating a favorable germination niche) before planting and germination was significantly enhanced using this method. Verschoor and Rethman (1992) similarly tested the use of a water absorbent polymer applied around roots of seedlings. They found it to be useful for water stress situations but not under unlimited water availability particularly in heavier soils.

Once seedlings have been transplanted in the field they can rapidly establish a root system and root growth observations in root boxes for Old Man Saltbush showed the roots growing to a depth of 1.60 m in 4 weeks. Shrub roots in another trial were recorded reaching the water table at 1.1m depth in 12 to 15 months after planting (Guevara *et al.* 2005).

Stands can be established either by direct seeding or by the planting of nursery grown seedlings or cuttings but Old Man Saltbush is a poor competitor in the seedling stage and it is important that correct weed management is adhered to in the establishment phase. The traditional approach for establishing Old Man Saltbush is to rip to a depth 400 – 600 mm at 6-12 months prior to planting and conduct spraying at this time. The use of a pre emergent herbicide just prior to planting will help to reduce competition effects in the establishment phase (Milthorpe *et al.* 2001). Plantations should be ready for an initial graze at 12 – 24 months of age depending on the prevailing conditions (Milthorpe *et al.* 2001).

Planting configurations

Internationally there have been a number of studies that have examined the effects of planting density on yield. Benjamin *et al.* (1995) examined the edible biomass of Old Man Saltbush shrubs planted at 625, 1111, 2500, 4444, and 10000 plants per hectare. Old Man Saltbush proved superior to *A. canescens* and *Cassia sturtii* in terms of biomass production. Per shrub standing biomass was higher at lower planting density but the per hectare biomass followed the opposite trend, being greatest at higher density planting configurations. Similar density related effects were found by Van Heerden *et* *al.* (2000) who planted 10 saltbush species at a range of densities (from 2x2m down to 1x1m spacing) to examine the effect on productivity. Yield per plant decreased with increased planting density with Old Man Saltbush the most strongly affected. Like Benjamin *et al.* (1995), they found that yield per hectare increased with increasing planting density. In India, Old Man Saltbush planted at 2500, 3333, and 5000 plants per hectare produced significantly more biomass from the high density plantation although, there was still 13 and 12 t green biomass and 5.2 and 4.8 t dry biomass at 2 lower densities respectively. They tested a range of heights for cutting for harvesting and management and found that cutting at 80cm produced largest amount of regrowth (Lal 2001).

Grazing management

The management of livestock will depend to some degree on the how the saltbush is integrated in the farming system. The use of Old Man Saltbush as a drought reserve is now not advocated as the plants become too large and woody to be effectively utilised and annual grazing is the recommended practice. Higher density stocking rates (grazing for 3-4 weeks) will allow the longest period for recovery (Milthorpe *et al.* 2001). Because Old Man Saltbush is susceptible to overgrazing (Barnard *et al.* 1992; Le Houérou 1986) it is important to allow enough time for the plants to recover before reintroducing the stock.

Optimising productivity and economic returns

An evaluation of the economic value of saltland pastures in WA (O,Connell *et al.* 2006) show that saltland pastures suited to moderately saline environments offers twin advantages of improved profit and reduced recharge. A sensitivity analysis conducted as part of this study indicated that quality of summer/autumn feed quality (digestibility) would have the greatest single impact on profitability with improved biomass on offer leading to profit gains but at a much-reduced level. Improved quality through plant improvement would well fit this option. MIDAS modelling for the WA wheat belt suggests that the highest returns for whole of farm profit would be generated by the planting of 10% of the farm with saltbush.

Weed risk and gene flow

Within Eastern Australia the weed risk for ssp. *nummularia* has been determined as negligible (Virtue and Melland 2003) largely because it has been planted within its own range. Anecdotal information cited by Virtue and Melland (2003) suggest that spread of *A. nummularia* ssp. *nummularia* from plantations in Australia is fairly rare. *A. nummularia* ssp *nummularia* has already been introduced and planted widely in WA. Where such plantations are located in close proximity to natural stands of *A. nummularia* ssp. *spathulata* there may be the potential for significant genetic pollution if hybridisation occurs.

A formal weed risk assessment for this species has been conducted as part of our Cooperative Research Centre obligations. The determination of this assessment is that Old man Saltbush is a medium weed risk in all southern Australian states. This evaluation can be found in Appendix C - Weed Risk Assessments section of this report.

Conclusions and future directions

The review suggests that there is significant potential for improved germplasm as a fodder source. Old Man Saltbush is moderately productive, is moderately palatable, has a high crude protein content, is easy to establish, is drought and salt tolerant, contains a range of beneficial nutritional compounds, provides year round feed, and provides a range of environmental and financial benefits when incorporated into agricultural systems. The wide geographic distribution and results of genetic investigations elsewhere suggest that there is a good likelihood of improvement of many of these aspects through selection and breeding if the traits of interest can be correctly quantified. Old Man Saltbush does have limitations that need to be considered if it is to be most effectively utilised for this purpose including the high cost of establishment and deficiencies in our understanding of the nutritional aspects and beneficial compounds.

There are still a number of unknowns in relation to the assessment of nutritional value of fodder that need to be addressed if we are to be able to select for desirable nutritional traits. One of the main problems at present is that the rapid cost-effective methods available for determination of energy value are not reliable. What is now needed is a range of *in vitro* measures of energy that have been calibrated with the same samples put through *in vivo* tests. Ultimately the goal will be to derive rapid assessment techniques using near infra-red scanning (NIR) that will allow assessment of nutritional and energy components of native fodder shrubs such as Old Man Saltbush. Our current understanding of why livestock select certain plant combinations to ensure correct nutrients and mineral intake is still limited. Consequently, there is still much to learn about livestock preference and the integration of Old Man Saltbush into mixed species forage systems and the range of beneficial compounds that this may provide.

Despite there being potential for good woody biomass accumulation, bioenergy applications have not been considered in this review as one of the primary outcomes for a development program for a fodder shrub such as Old Man Saltbush.

FloraSearch trials

The genetic variation among populations is currently being assessed through collection of germplasm across a number of different sites and establishment of evaluation trials in order to examine the genotype by environment interactions. This resulted in collections from 17 provenances of *Atriplex nummularia* ssp. *nummularia* and 11 provenances of *Atriplex nummularia* ssp. *spathulata*. These provenances have been incorporated into 4 different field trials across southern Australia at Monarto (SA), Tammin (x2 WA) and Condobolin (NSW). Data on morphological characteristics and edible biomass have been collected from 12-month old individuals at two of these sites (Monarto and Tammin). Preliminary biomass data suggests very good potential for making improvements in this trait through selection of strongly performing individuals. These data, along with upcoming data from sheep preference grazing trials and leaf nutritional analyses, will be used to make the first round of selections, ultimately leading to the application of a breeding strategy. A complete outline of the trial site design, a description of the breeding strategy, and a summary of the preliminary results are presented by Mazanec *et al.* in chapter 5 of this report.

Research priorities

We recommend a number of future research priorities that will enhance the uptake and utilisation of Old Man Saltbush and allow the selection and development of new improved cultivars and breeding populations. These are:

- Estimation of the natural variation in a number of traits relating to nutrition and productivity
- Development of more effective direct seeding techniques in order to reduce the cost of establishment
- Gaining a better understanding of nutritional components and how they relate to animal well being
- Gaining a better understanding of livestock preference in single and mixed species systems
- Developing more reliable rapid assessment techniques for nutritional assessment of native shrub species
- Examination of the complementary benefits of mixed species grazing systems in which Old Man Saltbush is an integral part

- A plant improvement program utilising selection and breeding to develop improved cultivars and breeding populations

Advancements in these areas will go a long way to allowing the development of very useful landuse management changes through the full utilisation of Old Man Saltbush in dryland agricultural systems.

Flooded Gum (Eucalyptus rudis)

Eucalyptus rudis is a medium sized tree that has been selected as a candidate for domestication in the south-west of Western Australia (WA). The NHT Search Project (Olsen *et al.* 2004) screened the flora of WA and delivered a list of over two hundred woody species endemic to the low-medium rainfall (300mm-600mm mean annual rainfall) zone of south western Australia worthy of more detailed testing. *Eucalyptus rudis* was one of the few eucalypt species with suitability as a feedstock for panel board products. It is easy to propagate and establish, is capable of rapid growth and can adapt to a wide range of environments including those subject to seasonal waterlogging and moderate salinity. There is strong potential to exploit the wide genetic variability within the species to develop improved crop cultivars.

Taxonomy and biology

Species description

Eucalyptus rudis belongs to *Eucalyptus* subgenus *Symphyomyrtus* section *Exsertaria* (the red gums) (Brooker *et al.* 2002). It is a tree form eucalypt which attains a height of 15-20m in natural stands. *E. rudis* occurs in the SW corner of Western Australia, west of a line running approximately from Dongara to Albany. Currently there are two subspecies: *E. rudis* ssp. *rudis* and *E. rudis* ssp. *cratyantha* (Brooker and Hopper 1993). The *E .rudis* ssp. *rudis* is of greater interest to this work, as *E. rudis* ssp. *cratyantha* is a declared rare taxon restricted to coastal and subcoastal areas of the southwest corner of the state.

The climate in the region of occurrence is Mediterranean-with cool wet winters and hot dry summers. The species extends from the relatively wet south west corner of Western Australia northwards and eastwards to the edge of the agricultural zone. This region has a mean annual rainfall ranging from approximately 400-1200mm. The annual evaporation range is from approximately 200mm in the south west to more than 2000mm in the northern part of the range.

The species is closely related to *Eucalyptus camaldulensis*. 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. Emmott (2002) describes the trees as intergrades, giving them the common name ‘moorditj’, and says they occur naturally around the swamps of the Bolgart/Calingiri area. In fact, the occurrence of trees with intermediate characteristics is extensive around the northern and north eastern part of the distribution, from York to at least Cockleshell Gully north of Jurien. The status of these ‘intergrade’ populations is unclear at this stage.

Eucalyptus rudis is a dominant species of the riparian zone of rivers and water courses of south-western Western Australia (Pettit and Froend 2001a). It almost invariably grows on moisture gaining sites, to the extent that it survives in areas where inundation excludes other species (Pettit and Froend 2001b). Although normally restricted to water courses and valley floors, in the central part of its distribution the tree can also be seen high in the landscape, generally associated with granite structures and heavy soils, which may have a high frequency of winter waterlogging. In its natural range *Eucalyptus rudis* is recorded as growing on red, grey and brown clays; brown loamy clays; red, brown and grey clay loams; grey, brown and black sandy loams; grey loamy sands and brown, grey, yellow and white sands (Western Australian Herbarium 1998).

Biology

Seed is wind dispersed (Young and Young 1992; Pettit and Froend 2001b). Experimental work by Cremer (1977) suggests that although wind is probably the most important dispersal mechanism for eucalypts, the bulk of the seed will fall within one tree height of the parent.

Brooker and Kleinig (2001) record the flowering season to be between July and November. Seed matures over summer, but Pettit and Froend (2001b) say that seed is retained in the canopy for at least twelve months with maximum seed release the following summer, with some release at other times throughout the year. Peak fall was shown to be late spring into early summer. The continual seeding ability is enabled by the species having a degree of serotiny (canopy seedbank) (Pettit and Froend 2001a). Pettit and Froend (2001b) showed the seed to be somewhat buoyant, with an average floating time of 5.6 days. This was less than other riverine species under investigation, and half the time recorded for *E. camaldulensis*. The seed began to germinate while floating, and then subsequently sank. In experiments where seed was buried at 1cm depth for various lengths of time, *E. rudis* seed had a viability of 75% +/- 10% after one month, 19% +/- 12% after six months, and zero after 12 months. Seedlings will often emerge in very dense clusters in preferred niches and then self thin as summer progresses.

Insect pests

Significant areas of naturally occurring *Eucalyptus rudis* are conspicuously degraded by insect damage. A good, brief summary of the significant insect pests attacking *E. rudis* is given in Clay and Majer (2001). The research literature identifies a number of pest and disease species that are likely to impact *Eucalyptus rudis* but the impact of these species on the productivity of commercial plantations is unknown.

Psillids are sap sucking insects most conspicuous in the nymph to young adult stage when they build and feed beneath a sugary cover, the 'lerp'. Feeding causes patches of leaf to discolour and die, and if insect numbers are high leaf drop and defoliation can occur. Curry (1981), cited in Clay and Majer (2001) suggests that the psyllid attacks flooded gum in winter and spring, causing defoliation, but seldom in consecutive years, allowing recovery. Morgan and Bungey (1981, cited in Clay and Majer 2001), suggest that trees will usually recover from psyllid attack and death will not occur unless the trees are subsequently attacked by other insects. Clay and Majer (2001) report the strongest correlation of tree decline with the presence of large numbers of these insects, but say that there is no consensus as to the cause of outbreaks of psyllids. Paine *et al.* (nd) list a range of control measures, both biological (predatory and parasitic insects, birds and spiders) and cultural (supplementary watering in dry periods, avoidance of excessive fertilizer, minimising physical damage), to reduce damage.

Leaf miner insects are conspicuously present in all populations of *Eucalyptus rudis*. Abbott (1999) attributes *E. rudis* decline to this insect, but Yeomans (1999) found no correlation between leafminer attack and tree decline in her study area. The damage is done by larva which feed between the surfaces of the leaf, and then cut a neat oval hole in the leaf and drop to the ground to aestivate over summer until emerging in April-May. Maximum feeding damage is caused in late September-October (Mazanec 1980).

Hall (1992) showed that a paropsine beetle (*Chrysophtharta debilis*) had a distinct preference for *E. rudis* over the other species with which it co-occurred, marri (*Corymbia calophylla*) and jarrah (*Eucalyptus marginata*). The wood borer, *Phoracantha semipunctata* attacks *E. rudis*, as well as being a problem in stressed *E. globulus*, and attacking dry millable jarrah logs and jarrah logging trash (Allan Wills, pers. comm. 2007). Citing literature, Hanks *et al.* (1999) show that drought stress effects host plant resistance to insect attack in physical ways (as opposed to chemical or nutritional effects), such as control of feeding due to reduced turgor pressure and increased cell sap viscosity, or sensitivities of particular species to specific moisture contents for certain life stage development.

Utilisation in south-western Australia

There has been little use of *Eucalyptus rudis* historically in Western Australia. Although sometimes used for fuel wood, it is regarded as being inferior to other widely available species such as Jarrah (*Eucalyptus marginata*) or Wandoo (*Eucalyptus wandoo*). The species is commonly used in revegetation work in areas within its natural range, valued for its fast growth rates, and tolerance of inundation and low levels of salinity. It is reportedly used as an amenity tree in south-western USA.

Paper and panel boards

Work carried out for the Search Project (Olsen *et al.* 2004) to investigate paper making properties showed young (estimated to be in the age class of 4-6 years) *Eucalyptus rudis* to have very good pulp yield, and bleaching and freeness properties. Density, tear index and tensile strength properties were poor. It was among a group of low density species (density range 468-494 kg/m3) recommended for revisiting for MDF production, with a view to quantifying fines content and fibre furnish geometry (Olsen *et al.* 2004). Older trees are reported to have much higher wood density than the figures from juvenile material presented in the Search report (Olsen *et al.* 2004).

Solid timber

The Forest Products Commission (FPC) assessed the value adding potential of the timber of a single tree described, as a hybrid *E. rudis* x *E. camaldulensis* (Murphy and Beel 2001). The timber was described as attractively coloured, and testing showed it to have suitable sawing and finishing properties. The wood was dense, (1005 kg/m3), and considered suitable for value adding for furniture, flooring and building uses. The tree was reckoned to be 40-50 years old, and the report advises caution in making generalisations based on a single tree sample. An undated poster publication issued by the (then) Department of Conservation and Land Management lists the density of sawn timber from E. rudis as 585 kg/m^3. The heartwood is described as pale brown to reddish. This sample and data was derived from another single log collection, from a roadside windfall tree, the origin of which was not recorded (G. Seimon pers. comm. November 2007).

Bioenergy

Combustion properties of *E. rudis* biomass for energy production were reported by Olsen *et al.* (2004), in their study of a selection of woody species. Factors affecting the quality of biomass for use in energy conversion processes include its moisture content and ash fraction, a measure of inorganic elements. The Gross Calorific Value (GCV) of *E. rudis* biomass samples; consisting of ⅓ wood, ⅓ bark and ⅓ leaves and twigs; was determined to be 19.4 MJ/kg (dry basis). The same biomass samples had a relatively low ash content of 3.4% (dry basis) and were found to have a low propensity to cause fouling and corrosion when combusted. Less is known about the prospect for using *E. rudis* biomass as a feedstock for pellets or ethanol production. The marketability of wood pellets is affected by their ash content, with very low ash content preferred (Urbanowski 2005). Compliance with fuel pellet standards may prevent some components of *E. rudis* biomass, such as bark and leaves, from being suitable pellet feed stocks. Ethanol synthesis processes prefer feed stocks with a high cellulose to lignin ratio (Dinus 2000; Wyman 1999). The cellulose content of *E. rudis* wood chips was measured to be about 38 % by Olsen *et al.* (2004), a relatively low proportion compared with other energy crop species such as switchgrass and poplar (Dinus 2000). The proportion of lignin in *E. rudis* wood has not been measured, however it is likely to be high relative to herbaceous and softwood plant species.

Eucalyptus oil is currently used for low volume specialty uses but has potential for large scale industrial use (Coppen 2002). Leaf oil from eucalypts consists of a variety of compounds, but for many species is dominated by monoterpenoids. Cineole is the most commercially interesting compound. Collections from over three hundred individual *E. rudis* trees were made across the range of the species, and screened by the Department of Environment and Conservation laboratory for cineole content. Cineole content was found to be relatively low: in the range of 0.5-1.5% of green leaf mass (Peter Grayling pers. comm. 2007). Cineole was also a relatively low proportion of the total leaf oil. Based on this finding, it is unlikely that *E. rudis* would be a competitive source of leaf oil; given that other species of eucalypts (for example the mallee species under development in WA) can have up to 4% oil in the green leaf mass with >90% cineole content.

Productivity and yields

Growth

There is little published information on the growth performance of *Eucalyptus rudis*. Limited trial data has been gathered, and this is reviewed below. Additional to this, a body of observational experience exists to suggest that the species is capable of relatively rapid growth on appropriate site types.

Two trials were established by (the then) Department of Conservation and Land Management in WA in 2005, of families selected for greater than average resistance to the common insect pests of the species. These selections were from the eastern and central part of the species range, and as such cannot be presented as representative of the whole distribution. Despite this limitation, significant differences are apparent between families, and some families have performed well at both sites, despite a separation of some 220 km and different climatic and edaphic conditions.

The trees in the Gillingara trial site were measured at 1.5 m above ground (diameter at breast height), but this was not practical at the Crossman trial site due to excessive branching, resulting from parrot damage. Although the trees were maintaining a more or less erect form, the variable incidence of heavy branching meant that more consistent results were to be obtained by measuring at 10cm height.

Additional measurements were made at a P2003 trial site in Katanning, which had three replicates of each of two provenances. Trees in the core of each plot were measures (height and stem basal area at 10cm), and then some destructive sampling was performed with 36 trees being cut and weighed. Good correlations were found between stem basal area and whole tree biomass. Additional data was gathered by measuring a search project plot at Corrigin, and a known age and seedlot planting by Greening WA at Bolgart.

In other work, Biddiscombe *et al.* (1989) researching growth of tree species in saline site revegetation work, describe growth in *E. rudis* as surpassed only by *E. occidentalis*. The *E. rudis* obtained a maximum height of 6.43m, with a crown index (hd^2) of 80.4 by age six. Increments of tree growth were recorded, averaged over the first five years of the trial for the cool wet season (April-October) and the warm dry season (November-March). The *E. rudis* showed a cool season average of 2.1 mm/day (range of means of 0.8-3.9mm), and a warm season average of 4.3 mm/day (1.7-6.8).

Emmott (2002) presents early data from trial plantings of *E. rudis*, *E. camaldulensis*, and an *E. rudis /E. camaldulensis* intergrade (see comments about the status of this intergrade in the Taxonomy section of this report). The intergrade is described as “showing promising early results, judged by survival, height and diameter growth. Stem form and branching results are however less favourable.”

In commenting on the Bolgart-Calingiri ‘intergrade’ population, Nathan McQuoid, (a researcher with long experience of field observation) noted that the trees were showing “unusual” salt tolerance and good form (McQuoid 2001).

Biomass partitioning

Little work has been done on this species in Western Australia to date. Four plots of four year old *E. rudis* in a mixed species trial at east Katanning were assessed by the authors in October 2007. After weighing the whole tree, a selection of 36 trees of different size classes was reduced to woody material greater than 2cm diameter over bark. A very strong allometric regression resulted. A summary of data appears below). In other work, Grieve *et al.* (1999) showed that in young *E. camaldulensis* clones, and one *E. rudis* clone (>50cm tall) foliage accounted for 56-66% of the above ground biomass under controlled conditions, whereas under saline conditions this percentage increased to 66-73%. The *E.*

rudis clone, and one of the *E. camaldulensis* clones (which physiologically resembled the *E. rudis*, rather than the other *E. camaldulensis*), showed greater within-clone variation in biomass productivity, than within-salinity treatments variation.

Coppicing ability

The authors know of no research conducted specifically on this subject, but have observed mature plants to recover from cutting at a range of heights and to reshoot from the root system after fire. Grieve *et al.* (1999) showed that a clonal selection of *E. rudis* had lower survival rate from coppicing compared to a range of *E. camaldulensis* clones. The work was performed on young plants.

Propagation and establishment

Seed germinates readily, and seedlings grow rapidly in the nursery, so much so that unless they are sown late in the nursery program they can be difficult to manage (Peter White pers. comm. 2007). Growth after transplantation to the field is also rapid, with growth rates frequently equalling or surpassing other species in mixed plantings.

In south-western Australia the use of containerised seedlings is the most common means of establishing *E. rudis,* due to its reliability across soil types and erratic seasonal conditions. The seedlings are typically grown in multiple cell container trays with a cell size of 40-90cm^3. When planted in the field they range from 150-300mm in height with a basal stem diameter of 2-3mm. For a comprehensive discussion of recommended nursery practices for seedling production, the reader is referred to Mullan and White (2002b).

Site preparation tasks prior to planting or sowing include soil cultivation and weed control. In Western Australia, soil cultivation methods have been developed to facilitate ease of planting, increase survival and growth, and overcome site constraints. Planting lines can be mounded, scalped or furrow lined as appropriate for particular sites to avoid seasonal waterlogging, reduce weed competition, improve soil characteristics and/or collect moisture. Any soil disturbance can alter the suite of weeds on a site, and typically increases weed germination and growth. Inadequate weed control can cause partial or complete establishment failure, primarily due to competition for moisture. Good weed control in the first two years of field establishment is normally recommended to improve survival and growth.

Stand management and harvesting

The foliage of *Eucalyptus rudis* is not resistant to grazing from stock, but the trees are fast growing and have an erect form which quickly gets them above grazing height. The bark does not appear to be attractive to grazing animals, either in planted stands or natural populations. Standard protocols of stock exclusion for a period of time after planting will apply. This period is determined by the growth of the tree, a product of season and site conditions, but will not normally exceed two years post planting.

This preliminary assessment indicates that *E. rudis* has good potential for integration into farming systems. Its strong coppicing ability indicates it should perform satisfactorily as short cycle coppice crop, and its potential as a phase crop, based on its capacity to perform well on wet or waterlogged duplex soils is also worthy of investigation.

Weed risk and geneflow

No published record has been found of *Eucalyptus rudis* becoming a weed species within its range in southwestern Australia, or elsewhere. The species is not widely planted and there is little material in the literature, but it is possible to provide a preliminary assessment based on anecdotal reports, the behaviour of eucalypts in general, and where possible on the specific behaviour of *Eucalyptus camaldulensis*, to which *Eucalyptus rudis* is closely related, and interbreeds.

Eucalyptus rudis has been observed spreading on farmland, including into areas away from its natural habitat (Andrew Thamo, pers. comm. 2007). It has been seen invading cleared land adjacent to pine plantations (Andrew Thamo, pers. comm. 2007), and self seeding to dominate planted eucalypts in revegetation areas (Peter White, pers. comm., 2007). It has been observed expanding its range within its preferred natural environment (Bob Gretton, pers. comm. 2007).

Eucalyptus rudis is a variable species. There are nominally two subspecies (*Eucalyptus rudis* subspecies *rudis* and *E. rudis* subsp *cratyantha*), but this may not represent the entire diversity within the species. There appears to be a naturally occurring intergrade with *Eucalyptus camaldulensis* in the northeast part of the range (Maurice McDonald, pers. comm. 2007). Egerton-Warberton (1995) states that genetic diversity measures for *E. rudis* (both subspecies) were comparable to other eucalypt species with similar geographic distributions. Estimates for outcrossing (*t*) were close to the average value seen in a number of other eucalypts. *Eucalyptus rudis* shows mixed types of mating (self fertilization and outcrossing), with "post-zygotic selection against homozygous (possibly selfed) progeny" (Egerton-Warberton 1995 p.343). Egerton-Warberton (1995) also observed high levels of gene flow in this species in natural populations.

The species is recorded as producing natural hybrids with *E. camaldulensis, E. drummondii, E. gomphocephala, E. loxophleba, E. occidentalis* and *E. wandoo* (Western Australian Herbarium). *Eucalyptus rudis* x *Eucalyptus camaldulensis* hybrid trees, a product of natural *E. rudis* populations crossing with garden *E. camaldulensis* plants, are showing greater vigor than the native *Eucalyptus rudis* around wetlands south of Perth (David Bright, pers. comm. 2007) Having discussed the potentially commercial value of the 'intergrade' populations around the Bolgart-Calingiri area, Emmott (2002) says that Greening Western Australia are concerned about genetic pollution resulting from the recent introduction of *E. camaldulensis* material into the range of a naturally occurring *E. rudis/E. camaldulensis* intergrade in the Bolgart area of the WA Wheat-sheep agricultural zone before the implications of such planting, or potential of the existing natural diversity is better understood.

The limited investigation of the genetics of the two recognised subspecies undertaken by Egerton-Warburton (1995) showed discernable difference, and suggests that it would be prudent to extend such investigation to better understand the extent of the genetic variation within the species, prior to any extensive revegetation with this species. The morphological differences between the subspecies are slight compared to those exhibited among populations in the northern and north-eastern parts of the species distribution (the 'smooth barked form' and the extensive 'intergrade' populations).

A formal weed risk assessment for this species has been conducted as part of our Cooperative Research Centre obligations. This evaluation can be found in Appendix C - Weed Risk Assessments section of this report.

Conclusions and recommendations

As a candidate for domestication, *Eucalyptus rudis* has many desirable attributes. Key among these are its ease of establishment, potential for rapid growth rates and (what we assume from its distribution), a wide genetic base to underpin breeding selection. It has a form that is amenable to efficient harvesting systems. The reproductive biology of the species does not preclude the use of breeding selection methods to develop improved cultivars. From an agronomic standpoint, *E. rudis* appears to be well suited for integration into dryland farming systems in Western Australia; where it could make a substantial contribution to salinity management by reducing groundwater recharge.

As a means of reducing recharge, it is desirable for perennial crops to occupy the smallest fraction of land required to remove excess water from the whole landscape. This assertion is based on the plausible assumption that annual crops will be more profitable than perennial crops per unit of land area occupied. Perennial crops also represent a significant change in land use, which will, at least initially, constrain their acceptance by farmers. This further increases the imperative to maximise results from the areas planted. Traits that characterise the ideal perennial crop plant include the ability to remove soil water in a zone greater than the projected canopy area, minimal negative effects on adjacent land use and rapid response to episodic inputs from lateral water movement. *Eucalyptus rudis* appears to have the potential to better emulate this ideal than many other woody plant species endemic to south-western Australia.

The heritability of economically important traits in *E. rudis* is poorly understood, so the potential for producing improved cultivars is unknown. Similarly, the level of variation in these traits between subspecies and provenances is unknown but may be important. As a result, the potential for the selection and breeding of plants with improved agronomic and feed stock qualities remains to be determined. To explore the potential further, seed collections representing a comprehensive sample of the variation in *E. rudis* have been made to allow the establishment of major family provenance trials.

Based on the synthesis of information contained in this knowledge review, recommendations for progressing the domestication of *E. rudis* have been developed. These address the three over-arching developmental challenges seen as critical for the future success of *E. rudis* as a crop in south western Australia: namely improving the utility of the biomass, improving biomass productivity of planted stands and improving agronomic practices to allow economically viable biomass production to be integrated into sustainable, multifaceted farming systems.

The authors conclude that the domestication of *E. rudis* for western Australian dryland farming systems remains a valid objective; given the inherently favourable characteristics of *E. rudis* for crop development and the scope for overcoming the challenges that remain.

4. Plant Improvement Strategies

Richard Mazanec[1,2]

[1] Department of Environment and Conservation, Bentley WA 6983
[2] Future Farm Industries Cooperative Research Centre, Crawley WA 6009

Introduction

Profitable integration of woody perennials into farm practice is an essential component in the use of perennial plant systems and their adoption by farmers (Bathgate and Pannell 2002). At present tagasaste (*Chamaecytisus palmensis* (H.Christ) F.A.Bisby & K.W.Nicholls) is the only woody perennial profitably integrated into farm systems, however its use is restricted to deep infertile soils with poor water holding capacity. New woody perennial crops are needed to make it possible for extensive use of woody crops integrated into crop or pasture systems (Pannell *et al.* 2004).

Investigations by the Search, FloraSearch and Acacia Search projects produced a shortlist of native Australian woody perennials suitable for further development. Species were screened on the basis of their suitability for end products such as paper, panel feedstock, particle boards, medium density fibre boards and livestock fodder. *Acacia saligna* ranked highly in both the Search and Acacia Search projects as a prospective species (Olsen *et al.* 2004, Maslin and McDonald 2004) whilst the FloraSearch (Hobbs *et al.* 2008c) project yielded Old Man Saltbush (*Atriplex nummularia*) as the top contender for further development.

Selection of species is just the beginning. Successful development of any new plant crop for commercial production requires optimisation of agronomy or silviculture together with genetic improvement in traits of commercial interest. Integration of woody perennials such as *A. saligna* and *A. nummularia* into farming systems is no exception. Despite being used extensively in Australia and other parts of the world for many years, little is known about genetic variation in traits of commercial interest for either species. No formal improvement efforts have been conducted for *A. saligna.*

Genetic improvement of *A. nummularia* has been restricted to two cultivars and a clone which are available on the open market. The two cultivars “De Kock” and “van Holt” were developed from a land race in South Africa. The commercial clone known as ‘Eyres Green’ (Topline Plant Company, Uraidla 2003) was selected from a plantation of *A. nummularia* growing near Rudall South Australia. Both De Kock and Eyres Green are available commercially within Australia.

This report provides a brief review of tree breeding concepts and proposes breeding strategies for both *A. saligna* and *A. nummularia*.

Tree Breeding Concepts

Effective breeding programs maintain four general types of population (Eldridge *et al.* 1994):

The natural or base population

Includes forests and wild populations in general from which parental selection is conducted;

Breeding population

Consists of the selected parent trees and their progeny - which may be established in a range of progeny or family/provenance trials in which the cycle of mating and selection will be repeated;

Propagation population

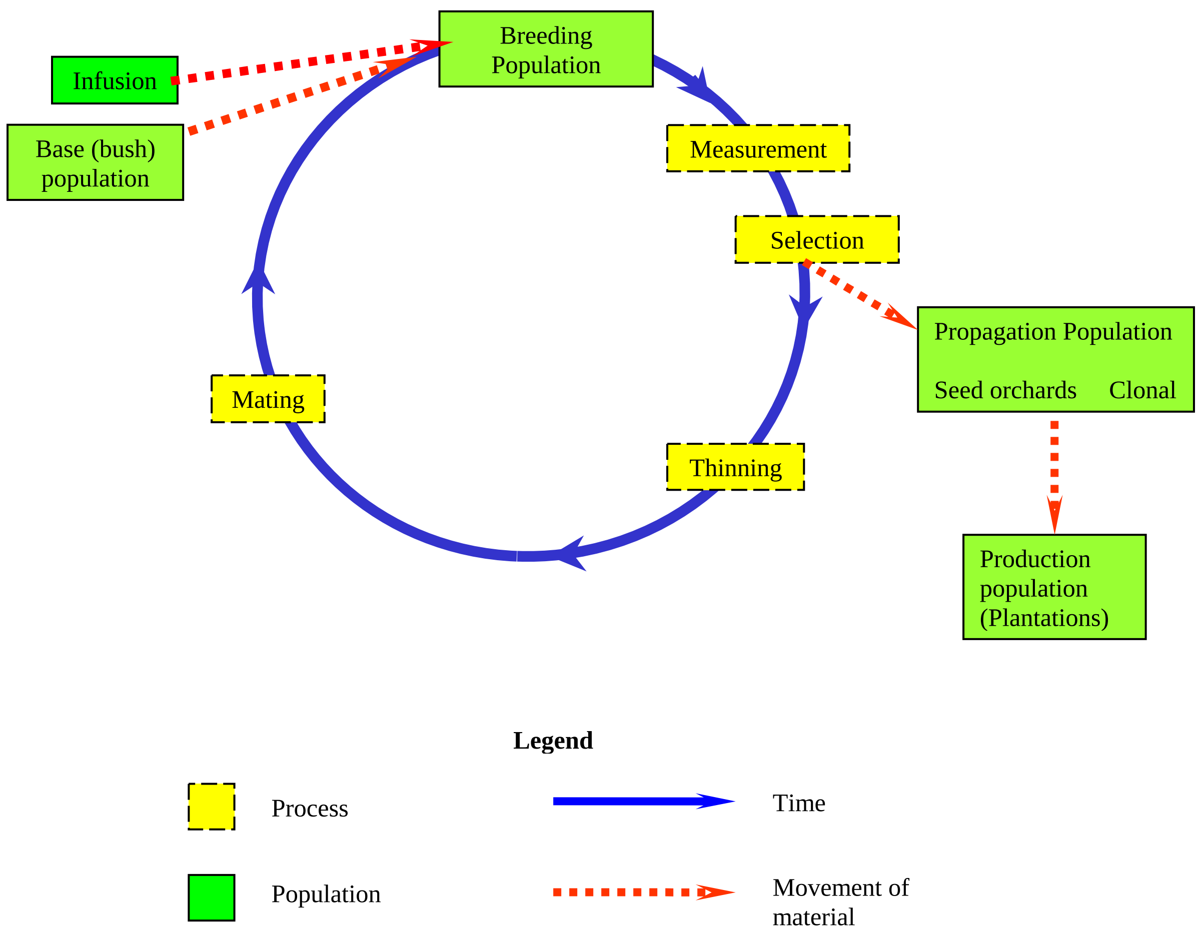
Consists of the best genotypes selected from the breeding population in the form of seedling seed orchards, clonal seed orchards or cuttings multiplication areas. These populations are managed to produce large quantities of genetically superior propagules for deployment in plantations;

Production Population

The fourth population which the breeding program feeds into is the production population and consists of operational plantations;

Infusions of new material from other sources can be brought into the breeding population in second and later generations as required to offset the effects of inbreeding. How the populations relate can be seen in Fig. 31.

Fig. 31. General breeding cycle adapted from Harwood *et al.* (2001).



The success of a breeding program depends entirely on the cumulative improvement of the breeding population in the desired traits. This in turn is dependant on clear definition of breeding objective traits and selection criteria, their heritability and genetic and phenotypic correlations amongst the traits involved. Control of inbreeding in advance generations of the breeding population and ultimately in the resulting production populations is a primary concern facing tree breeders. Rapid improvement can be achieved by high selection pressure effected by intense selection and elimination of inferior families. This can result in quick short term gain but decreases genetic diversity which in turn reduces opportunity for making long term gains (White 2001). Through the use of large breeding populations, careful structuring of the breeding population and control over related mating, breeding strategies should aim to optimise both short term gains and long term gains. Studies in conifers have shown that breeding programs can maintain similar or higher levels of genetic diversity in their breeding and production populations than that found in wild populations (El-Kassaby 2000).

Estimates of the number of individuals required to maintain a diverse breeding population vary. Burdon and Shelbourne (1971), Burdon (1995), Cotterill (1986), Kang and Nienstaedt (1987), Libby (1973), White (1992, 1995, 2001), Zobel and Talbert (1984) suggest numbers ranging from 200 unrelated genotypes as a minimum, up to 2000 effective breeding individuals. Cotterill (1986) and White (1992, 1995) suggest that a breeding population of 300 effective breeding individuals should sustain an entire breeding program for many generations

Advance generation breeding populations will require approximately 100 offspring per parent (Cotterill 1986) to generate useful selection intensities, for example 35 offspring on each of three different sites. The process by which these various populations are manipulated and deployed is called a breeding strategy, as opposed to a breeding plan which schedules the sequence of steps required to execute the strategy. There are a diverse range of breeding strategies which have been developed over time to manage breeding populations and maintain some control over rates of inbreeding. Simple strategies focus on the maintenance of a single large breeding population that is cycled through generations. Still others split the breeding population into two or more sub populations in an effort to exert greater control over the risk of accumulated inbreeding. Some of these variations are described by Eldridge *et al.* (1994). Examples of the more important strategies include mass selection, recurrent selection for general combining ability, sublining, multiple populations (Burdon and Namkoong 1983), Nucleus breeding (Cotteril 1989) and Rolling Front (Borralho and Dutkowski 1996). These are briefly outlined below.

Simple mass selection

In this scenario open pollinated seed is collected from the wild and bulked so that no family identity is retained. The seed is then used to establish plantations that are subsequently thinned heavily to retain the best trees for use as a seed production area (SPA). Seed is collected from the best trees in the SPA for establishment of the next generation. This process is repeated for several generations.

Potentially large gains can be made in the first generation for traits of high heritability and where neighborhood effects (Hardner *et al.* 1998) existing in the wild populations are broken. Gain in subsequent generations is likely to be smaller and with intense selection, inbreeding will build up quite rapidly unless new germplasm is introduced to the population.

Recurrent selection with open pollination and maintenance of family identity

This strategy was used successfully on *Eucalyptus grandis* in Florida and yielded gains of 66% in height and 160% in volume (Meskimen 1983) over four generations at minimal cost (Meskimen 1983). The basic process is as follows. Seed is collected from about 300 or more parent trees and established in a progeny test of about sixty seedlings per parent tree. The progeny test is measured and culled at the earliest opportunity. About a third of the worst families are dropped and the remainder culled to the best individuals in each family. The best families may contribute four individuals whilst the other families will only contribute one or two individuals. Open pollinated seed is then collected and used to establish the next generation. Based on results of the second generation progeny test, the first generation is culled (backward selection) for seed production, removing families and individuals with poor breeding values. The process is repeated in the second generation. The first generation trial is used for commercial seed production until it is superseded by the second generation orchard. Introductions of new genetic material are required each generation to retard the rate of inbreeding.

This strategy represents a refinement of more conventional recurrent selection where separate progeny tests of select individuals were established, and used to backwards select the elite individuals for clonal propagation into seed orchards. Once this was achieved seed was collected from the forwards selected parents to regenerate the next breeding population. Combining the second generation breeding population and progeny test of the first generation into one population represents a highly significant reduction in the time and cost involved in completing a breeding cycle and greatly increases gains per unit time.

Shelbourne (1992) estimated potential gains from different combinations of breeding populations composed of open pollinated progeny or clones and production populations of various kinds. As an example, using open pollinated breeding populations. In ascending order, good gains were expected from clonal orchards from forwards selection, both pedigreed and unpedigreed seedling orchards from forward selection and clonal orchards from backwards selection. Of these four options clonal orchards from backwards selection gave the greatest yields, but have the disadvantage of requiring data from the second generation trials to enable rogueing of the poorest clones.

Sublining

Structuring a breeding population for sublining requires division of the main population into small, well separated groups or sublines of equal size and requires control-pollinated crossing to advance the breeding population, especially with wind-pollinated species. For example, a breeding population consisting of 300 unrelated clones may be divided into 10 sublines of 30 clones each. No outcrossing is permitted between sublines. All outcrossing to regenerate the next generation occurs within a subline. Inbreeding within sublines can occur quite quickly – particularly with open pollinated matings (McKeanal and Beineke 1980). All families within each subline are progeny tested at a common site. Backward selection is used to select the best clone in each subline for incorporation into the new seed orchard and forward selection is used to select the best material to be carried forward into the second generation. The best individuals from each of the remaining families in each subline are then cloned into the second or advance generation sublines for further breeding. In the propagation population only the best single clone from each subline is incorporated into the seed orchard in any given generation. This ensures that only unrelated mating occurs and therefore maximum genetic gain is achieved.

Establishment of the sublines may take place initially with the random allocation of families from a seed collection to sublines. The disadvantage of this approach is that there is no ability to check genetic equality of the sublines prior to establishment. For example if sublines consist of two provenances each and there has been no prior provenance testing then some sublines may be much poorer than others. Alternatively if families from multiple provenances are randomly allocated to different sublines, and provenances are poorly or variably represented amongst sublines then estimation of provenance effects within a subline may be compromised. This in turn may bias estimates of breeding values. A better approach is to establish a large progeny trial, replicated across three sites to test the individual provenances and families within provenances. The best individuals from the best families are identified, cloned and established into sublines of roughly equal genetic value. Care must be taken to ensure that related males and females in dioecious plants are not allocated to different sublines. This eliminates problems estimating genetic parameters in the first generation because of poor representation of provenances within sublines.

The advantages conferred by sublining include: good control of inbreeding in production populations, maintenance of pedigree is not required **-** this is an advantage in wind pollinated species, inbreeding and selection within sublines purges deleterious alleles, poor-perfoming sublines can be removed or enriched with better genetic material and it works well for hybridization – e.g. sublines of *Atriplex nummularia* ssp. *nummularia* and or ssp. *spathulata.*

Potential disadvantages include:

- The high levels of inbreeding within a subline may present problems with selection, particularly in the third and later breeding populations since some individuals or families may be more inbred than others and could be unfairly penalized i.e. some genotypes will produce poorer offspring when mated with close relatives than they would in unrelated matings. Hence true breeding values may be difficult to obtain. One solution is to conduct polycross testing in separate progeny trials to enable accurate estimation of the true breeding value of potential parents.
- A co-operative structure involving several institutions may be required to efficiently manage multiple sublines. Sublining was rejected as an option for structuring the breeding population for *Eucalyptus pilularis* in New South Wales on this basis (Johnson and Nikles 1997). Breeding programs may require fifteen or more sublines (White 2001, White *et al.* 1993, Lowe and van Buijtenen 1986, Mckeanal and Beineke 1980) in order to provide sufficient numbers of selections to create a clonal seed orchard.

Multiple populations

A variation on sublining, this can be used when there is a need to produce trees for different, possibly conflicting objectives e.g. adaptation to saline or acidic soil conditions. Negative correlations between desirable traits for different requirements may leave no option other than to use multiple populations (Cotterill 1984). In this instance allocation of families to sublines may be based on criteria such as disease resistance or salt tolerance etc.

Nucleus breeding

Nucleus breeding reorganizes the main breeding population into two tiers including a large, “Main”, breeding population and a smaller, “Elite” or “Nucleus” breeding population which may constitute the top ten percent of genotypes. (Cotterill 1989, Cotterill *et al.* 1989, White *et al.* 1999). The objective here is to concentrate resources on the best ranking individuals in the breeding population. Selections from the elite population form the propagation population, which produce seed or other propagules for operational plantations. In terms of crossing this may mean that controlled pollination is conducted in the nucleus whilst for the main population open pollination is relied on to produce seed for the next generation. The open pollinated main population may be a constant 300 parents in each generation which are allowed to cross pollinate to produce say 22500-30000 progeny (i.e. 75-100 progeny each, planted across three or more trials).

The nucleus is initiated by screening the main population for outstanding trees. The nucleus may have say 40 parents each generation which are control pollinated to produce 250 progeny each –i.e. total of 10 000 full sib progeny. The nucleus provides a formal population structure for cumulatively capturing gains made from intensive selection and assortative mating from generation to generation.

With the establishment of each new nucleus population new material is injected by the transfer of highly productive breeding individuals from the main population (or from other populations). Outstanding selections from both the nucleus and the main population would therefore be mated (via controlled pollination) to produce the next nucleus population. Similarly, seed or pollen from the nucleus may be transferred to the main population with each turn of the cycle.

Elite populations may also be a useul way of managing different breeding objectives. Jayawickrama and Carson (2000) outline the use of multiple elite populations for *P. radiata* each with a different breeding objective, whilst maintaining an unspecialised main breeding population.

Rolling front strategy

Traditionally mating strategies have been implemented using discrete cycles or generations with all crosses, whether open pollination or controlled pollination, occurring prior to the establishment of the next generation. Often however, delays are experienced due to problems with lack of flowering synchrony, modifications to the original plan, failure of flowering etc. When such problems arise it leads to extended generation intervals.

An alternative pathway which theoretical studies (Borralho and Dutkowski 1996, 1998) suggest should give greater gains per unit time, is known as the rolling front breeding strategy. In this scenario progeny testing is carried out as crosses become available rather than waiting for all crosses to be made as in discrete generations. There is no distinction made between generations. Rather, all trees in all generations are compared directly using individual tree Best Linear Unbiased Prediction (BLUP) to estimate breeding values. Trials need to have sufficient linkage to enable efficient comparisons and ranking across trials. As each trial is measured, breeding values are updated and new selections can be made.

The rolling front strategy is applicable in schemes where controlled crossing is used and relies heavily on database management and the ability to generate unbiased estimates of breeding values. Management of inbreeding is achieved through control of the crosses that are made in each generation. The method is also applicable to sublining. In this scenario, sublines are managed on a rolling front basis.

Mating designs for advanced generations

Various mating designs for the production of the next generation are in general use. The first of these is open pollination. Based on theoretical calculations (Cotterill 1986) it is possible to achieve good gains per unit time using open pollinated matings when used together with index selection, owing to rapid turnover of breeding cycles. Meskimen (1983) and Rockwood *et al.* (1989) reported strong genetic gains in a *Eucalyptus grandis* breeding program over four generations using open pollination. This method is often employed in species where controlled pollination is difficult and / or expensive to conduct.

Control pollination is used in species that are easy to pollinate manually. The advantages over open pollination (White 2001) include full control over the pedigree, which facilitates management of co-ancestry and inbreeding. In addition, selection for both the maternal and paternal parents results in higher genetic gain. White (2001), points out that it is often necessary to propagate selections into some kind of breeding orchard prior to control pollination e.g. a clonal orchard. The time required to achieve this can introduce some delay in initiating the crossing program.

Various full-sib mating designs fall into two general categories: balanced and unbalanced. Balanced designs are those in which each selection in the breeding population is crossed the same number of times. This means that all selections make an equal contribution to the next generation breeding population. Unbalanced designs are sometimes used in which better parents are crossed more often that others. This ensures that the better parents contribute more progeny to the next generation breeding population and increases the probability of concentrating their superior alleles in future selections. Conversely this kind of approach will tend to reduce genetic diversity more rapidly. Examples of mating designs include single pair mating, full diallel, half diallel, partial diallel and polycross each of which has different applications (Bridgewater 1992).

Seed Collection and Trial Design Rationale

The objective was to provide a resource which would enable examination of genetic variation in *Acacia saligna* and *Atriplex nummularia* at the subspecies, provenance, family and within family levels. The trials established would then provide the basis for a breeding program. The question arose as to how to structure the collection.

Sampling to represent an individual provenance

Historically there have been a number of approaches to determining how many seed trees should be used to sample a local population or provenance. The use of traditional sample size formulae is suggested by Eldridge *et al.* (1994).

Eldridge *et al.* (1994) suggest the use of sample size formulae for estimation of a mean within chosen confidence limits as an indicator of the number of seed trees required to represent a stand.

As an example, if preliminary data on traits of interest for a species is available, variances may be calculated and from these the number of trees required to calculate the provenance mean with a 95% confidence interval can be estimated. Implicit in this method is the assumption that the seed collected from the seed trees is sufficient to adequately represent the gene pool of the provenance using the formula:

$$n = 4\sigma^2/L^2$$ **(Snedecor 1956)**

Where,

n = the number of trees required to calculate the mean of a provenance,

σ^2= variance and

L = the acceptable error in the estimate e.g. ± 5% of the mean

This formula makes a relatively crude approximation for the probabilities of committing Type I and Type II Errors. Other formulae accounting for Type I and Type II errors may be found in Zar (1984)

A potential problem with this approach is that it assumes that the variance is the same across all populations for a particular trait – and that the variance is similar for all potential traits which may be assessed in the future. Where data from multiple populations are available, other formulae exist to refine estimates.

The FAO Panel of Experts on Forest Gene Resources (1969) recommended sampling from a minimum of 10 trees but preferably between 25 to 50 trees. Eldridge *et al.* (1994) suggest that 10 to 15 trees per stand (or provenance) separated by about 100m represents a reasonable compromise between precision in estimating means and enabling as many populations as possible to be sampled.

There is growing evidence that gene flow via pollen dispersal can occur over hundreds of meters or more in eucalypts (Potts *et al.* 2001). In *Acacia saligna*, inter-subspecific pollen dispersal of over 1500m has been detected (Millar and Byrne 2007a; Millar *et al.* 2007). Hence seed from one maternal parent, depending on the biology and breeding system of the species, may contain gene contributions from a diverse range of pollen parents occurring over large areas.

There is some evidence that for locally abundant species such as *E. sieberi* (Moran *et al.* 2000) a collection of as low as 4-5 individuals may capture a large proportion of the alleles in the population (owing to diverse opportunities for cross pollination with other individuals) whereas for species of lower abundance such as *E. consideniana* (Glaubitz *et al.* 2003) there may be much lower opportunity for outcrossing and therefore small samples of 4 – 5 trees will be less likely to capture the genetic diversity that exists in the population as a whole. Theoretical estimates by Brown and Hardner (2000) suggests that where large amounts of seed per parent (>30 seeds) are available, collection of a minimum of 15 maternal plants should be sampled for outbreeding forest trees from about 50 sites for gene conservation purposes.

Based on the above information it was considered that seed from a minimum of 15 female parents per provenance should be collected, and as many as resources will permit after that, say 20-25 parents per provenance.

Trial design

A fundamental question in progeny testing is how many progeny per family to establish in order to accurately rank provenances and families. Cotterill (1990) suggested that for poorly heritable (e.g. $h^2 < 0.1$) traits, some 200 individuals from five to ten families should be sampled whereas in traits with high heritability (e.g. $h^2 > 0.4$) 100 progeny from five to ten families may be adequate to estimate provenance means. Cotterill (1990) also comments that for progeny tests which are to be used as base populations for future breeding, breeders may prefer to plant as many progeny and families per provenance as resources will permit.

Cotterill and James (1984) and Cotterill and Dean (1990) recommend that for traits of low heritability it is necessary to measure at least twenty individuals per family to determine reliable family means. Where the trial serves as a breeding population from which to make selections within families, as many individuals as possible should be planted in order to maximise selection intensity and hence genetic gain from individual selection within families. In addition to improved opportunity for selection, extra seedlings per family provide insurance against mortality within the site. The estimates by Brown and Hardner (2000) above suggest that it may be useful to include at least thirty progeny per family for selection purposes. Cotterill and James (1984) also recommend that for progeny testing across multiple sites, each trial should stand alone. This provides insurance against loss of a trial and where family x site interactions are important the existence of stand alone trials allows for accurate selection of the best genotypes for each site.

Trials need to be established at a number of sites, depending on the scale and range of sites for plantation establishment. Three to four sites may be adequate for this purpose if they are well matched to anticipated plantation environments. Carson (1992) in a study of genotype by environment interactions amongst eleven progeny test sites in *Pinus radiata*, found that far fewer sites were necessary for assessment of G x E and selection.

Williams *et al.* (2002) suggest that a minimum of four replicates should be used for provenance/ progeny trials in order to provide adequate degrees of freedom for the error term used for testing. The number of replicates above this and seedlings per family plot are dependent on the number of seedlings available and the purpose of the trial. Single tree plots have advantages in that they allow the most complete sampling of within site variation whereas row plots may allow for better sib comparisons (Loo-Dinkins 1992). Williams *et al.* (2002) notes that multiple tree plots allow for estimation of the between-tree within plot variance component which gives an indication of genetic variation within seedlots.

When large numbers of families are included in a trial, replicate size can become large and additional blocking structures are required to account for site variation. In these situations, resolvable row – columns designs (Williams *et al.* 2002) which account for site variation in two directions or incomplete block designs should be employed. Where site variation is not effectively accounted for by trial design it may be appropriate to use spatial analysis methods e.g. Dutkowski *et al.* (2002).

Acacia saligna - Koojong Wattle

Factors affecting breeding strategy

Genetic diversity

George *et al.* (2006) studied genetic diversity in 29 populations from across the geographic range of *A. saligna* using nuclear restriction fragment length polymorphisms (RFLP). They identified 3 genetic groups, two of which corresponded with the ssp. *lindleyi* and ssp. *stolonifera*. The third group included both ssp. *saligna* and ssp. *pruinescens*. In that study ssp. *saligna* and ssp. *pruinescens* could not be genetically differentiated between, despite strong morphological differences. A subsequent study using microsatellite markers developed specifically for *A. saligna* (Millar and Byrne 2007b) that show greater levels of polymorphism than RFLPs, has recently been conducted. Millar *et al.* (2008) investigated genetic structuring among 15 populations across the species range and achieved a greater level of resolution between ssp. *saligna* and ssp. *pruinescens*. The four subspecies were shown to cluster into four genetically distinct groups and although a degree of genetic affinity was still found between ssp. *saligna* and ssp. *pruinescens*, the authors support the elevation of these two entities to subspecies rank. Further sampling may be required to differentiate between these two subspecies. Relative to other species assessed using RFLP loci, genetic diversity for *A. saligna* was considered high compared to *Acacia mangium,* similar to the *Melaleuca uncinata* complex and lower than that found in eucalypts (George *et al.* 2006).

In another study, George *et al.* (in press) found that the highest dry matter digestibility, crude protein and phosphorous content were exhibited by ssp. *saligna* and ssp. *pruinescens* groups although ssp. *pruinescens* was observed to have a higher level of protein precipitable tannins which are known to inhibit digestion. The relative strengths of the different subspecies are yet to be fully established. Data collected from range-wide family-provenance trials will give direction as to whether one or more subspecies are best suited to further development. Options may include discarding one or more subspecies or the development of hybrids.

Provenance variation

Work on provenance variation is limited. Poblete and Rojas (2004) reported the results of a study of provenance variation on two sites in northern Chile. Their study included 14 Western Australian provenances from the Sanford River in the north down to Ravensthorpe in the south across the natural range of *A. saligna*. Measurements were made of basal diameter, stem height and mean canopy diameter at age 15 months. Significant provenance x environment interaction was found suggesting that site specific selection may be required for future breeding and operational requirements. This finding was supported by relatively low type B genetic correlations at the provenance level. It is likely that at least some of the reported variation may be attributable to differences amongst subspecies.

Genetic parameters

At present nothing is known of the heritability and genetic correlations of growth parameters such as height basal diameter Biomass yield or nutritional traits such as crude protein content, dry matter digestibility or tannin content in *A. saligna*. George *et al.* (in press) found a positive phenotypic correlation between dry matter digestibility and crude protein whilst both were negatively correlated to tannin content. Estimation of these parameters will be important in further development of the breeding strategy.

Reproductive biology

Acacia species are vector-pollinated (Sedgley, 1986). *A. saligna* is monoecious and has hermaphroditic flowers. The flowers of acacias are small and grouped into spherical or cylindrical inflorescences (Sedgley and Harbard 1993) and inflorescences range from simple or racemose to paniculate (Maslin 2001).

Kenrick (2003) in a review of pollen-pistil interactions in acacia noted that pollen grains of most Australian acacias are grouped into polyads consisting of eight, twelve or sixteen grains arranged in a biconvex disc. George (2006) found that polyads of *A. saligna* were composed of sixteen pollen grains. The receptive site of the acacia stigma consists of a shallow saucer shaped depression or cup that is just large enough to hold a single polyad. Observations in a number of species demonstrate that a high proportion of fertilisation is accomplished by a single polyad, however, this is not always the case (Casiva 2004).

Most Australian acacias are protogynous (Sedgley 1986) which means that stigma receptivity precedes anther dehiscence. This feature enhances opportunity for outcrossing over self pollination and is advantageous in controlled pollination (Sedgley and Harbard 1993, Bernhardt *et al.* 1984). George (2006) observed that for *Acacia saligna*, flowers were protogynous with indistinct male and female flowering phases. Flowers within a flower head opened asynchronously. Female sterility was observed in about 8% of flowers and the viability of fresh pollen was found to be low. On average more than half the pollen grains in a polyad were viable in 49% of polyads whilst in 12% of polyads less than half of the pollen grains were viable. He also found that stored pollen loses viability rapidly. After one month stored at -20ºC only 4% of polyads had one or more viable pollen grains. After two months viability was zero. Two percent of polyads had one or more viable pollen grains after 153 days at -80 ºC. The ability to store pollen for prolonged lengths of time may be critical for controlled pollination to produce hybrids or to execute crosses between individuals with asynchronous flowering times. Low numbers of viable pollen grains per polyad in stored pollen is likely to result in poor seed set since there is only room for one or at most two polyads to occupy the stigma. Indistinct male and female flowering phases, asynchronous opening of flowers combined with low pollen viability of stored pollen may render controlled crossing impractical as a large scale mating strategy for breeding *A. saligna*.

Correlated paternity

Muona *et al.* (1991) observed spatially distributed patterns of correlated matings in A*cacia melanoxylon.* They found that a high proportion of seed pods were pollinated by one male and that within a globular cluster of pods the probability of a common pollen source for any pair of pods was high. The probability of this occurring between pods from different parts of the tree was much lower. This hierarchical mating results from the grouping of flowers into clusters. Insects are more likely to pollinate several flowers on a single flower head or within a cluster, with polyads from the same paternal parent. Similar patterns were observed by Casiva *et al.* (2004). George (2006) found moderate levels of correlated paternity in *A. saligna* suggesting that a similar pattern was occurring. Hierarchical mating has significant implications for seed collection and also for estimates of genetic parameters. Muona *et al.* (1991) point out that if progeny from any given family are assumed to be half sibs when they are in fact full sibs, heritability estimates would be inflated. This problem can be circumvented to some extent by collecting seed from around the entire plant to maximise paternal diversity in the sample. A further precaution may be to collect only one seed per pod.

Mating system

Knowledge of the mating system is an important factor in the design of a breeding strategy as it determines what approach can or must be taken to maximise efficiency in the improvement of the breeding population. Predominant outcrossing is known to occur in a number of acacia species. For example *A. auriculiformis* and *A. crassicarpa* were both found to be predominantly outcrossing with multilocus outcrossing rates ranging from 0.92 to 0.93 and 0.93 to 0.99 respectively (Moran *et al.* 1989), as was *A. baileyana* (Morgan *et al.* 2002). *A. mearnsii* and *A. decurrens* are known to be predominantly outcrossing as well (Moran *et al.* 1989). Tendani and Johnson (2004) demonstrated that *A. mearnsii* can also produce selfed seed.

Preliminary studies by George (2006) indicate a mixed mating system with preferential outcrossing rates in *A. saligna*. He found an average outcrossing rate of 0.86 and suggested that some degree of selfing may occur. Conversely, post zygotic selection against selfed individuals was indicated by higher levels of heterozygosity between the parent populations as compared to the progeny. In another study Millar *et al.* (2007) found a high multi-locus outcrossing rate of 0.98. Similar levels of outcrossing have been found in eucalypts. Moran and Bell (1983) reported outcrossing rates ranging between 0.69 and 0.86 for ten eucalypt species. This has implications for breeding in that inclusion of selfs in trials may inflate estimates of heritability, perhaps in a manner similar to that of eucalypts. Griffin and Cotterill (1988) in a study comparing outcrossed, open pollinated and selfed seedlings found that the presence of selfs of *E. regnans* in a progeny trial was confounded with the effects of families. The effect of this was to inflate estimates of additive genetic variance, which in turn inflated estimates of heritability. It was also found that open pollinated progeny performance was not necessarily reliable in predicting breeding value of parents – particularly if the parent was isolated spatially from others and had produced a lot of selfed seed. The recommendation in this case was to limit family selection in the first generation so that potentially good families are not excluded from the breeding population. Estimation of heritability in *A. saligna* may require some adjustment of the coefficient of relationship to compensate for selfing effects as is commonly done with eucalypts. For example Volker *et al.* (1988) used r = 0.4 for estimating heritability in *E. globulus*.

Inbreeding depression

The effect of inbreeding depression as a result of selfing or related mating is not known for *Acacia saligna*. Harwood *et al.* (2004) reported strong inbreeding depression as a result of self pollination in *A. mangium*. Studies in other *acacia* species indicate varying levels of self incompatibility. For example Bernhardt *et al.* (1984) found that *A. retinodes* was highly self incompatible and that crosses between siblings of parents and progeny resulted in reduced pod set whilst the converse was true for inter-population crosses. Controlled crossing experiments are therefore required to examine the effect of inbreeding depression as result of selfing and related mating in *A. saligna.*

Flowering phenology

Provisional peak flowering times, as described on the World Wide Wattle website, (retrieved 05/06/2007) indicate similar peaks for ssp. *lindleyi* and ssp. *stolonifera* in mid October whilst the ssp. *saligna* flowering peak ranges from August to September and ssp. *pruinescens* peaks in late September. Seed orchards including individuals from different subspecies will need careful design to ensure that temporal isolation in flowering does not result in the production of high proportions of selfed seed or significant levels of intra- subspecific or intra-provenance assortative mating.

Reproductive success

Goal and Fox (2002) found that reproductive success in *A. saligna* was lower than some other species. Pod set was particularly sensitive to drought with only 0.7% of inflorescences developing a seed pod in a drought year compared with 10% of inflorescences developing a seed pod in a non-drought year. Factors influencing the reproductive success in acacias include number of phyllodes per branch - higher numbers of phyllodes lead to more inflorescences which in turn set more pods. Other factors observed to affect reproductive success include frost during the reproductive phase and rainfall. Lower rainfall resulted in lower pod set and or seed abortion. Frost resulted in damaged seed and lower seed set (Goal and Fox 2002). George (2006) found that reproductive output as measured by pod-set was low in *A. saligna* but comparable to other published studies for acacia. Across eight populations, 9.5% of flower heads set pods. Relative to the initial number of flower heads, the total number of pods produced was 16.4%. Design of seed orchards will need to take into account the relatively low seed production capacity with adequate replication in order to produce seed volumes required for production.

Cytogenetics

Early investigation of Australian acacias (New 1984) found they were diploid with 2n = 26, while species from other parts of the world tend to be multiples of this. Crompton (1992) notes that *A. saligna* is diploid with 2n = 26.

Cloning

Acacia saligna has been successfully cloned using tissue culture e.g. Jones *et al.* (1990), Barakat and El-Lakany (1992). Maslin and McDonald (2004) note that *A. saligna* can be propagated from cuttings. Further work is needed to determine how practicable the production of either root cuttings or stem cuttings is and how it varies within and between families and subspecies. The ability to use cuttings from branches or young shoots on the stem may be desirable, particularly if there is room for doubt as to which tree a root belongs to in a densely planted trial. Grafting may be another useful option if production of stem or root cuttings proves impractical.

Disease resistance

Acacia saligna is known to be susceptible to the rust fungus *Uromycladium tepperianum* (Sacc) McAlpine (Fox 1995). Infection by the rust is manifested by the presence of brown galls on the fruit, phyllodes, peduncles and stems Gathe (1971) and often results in death for the tree. In South Africa *U. tepperianum* was introduced from Australia as a biological control for *A. saligna*. Tree density in infected stands was noted to have decreased by at least 80% (Morris 1997). Selection for resistance to *U. tepperianum* will be an important selection trait in ensuring the successful domestication of the species.

Salt tolerance

Acacia saligna is variously reported as having moderate to high salt tolerance. Reports range from 100-150 mS/m, 400-800mS/m up to 1200-2000 mS/m (Dept Agriculture 2004). It is not known how salt tolerance varies within or between subspecies or indeed between families. Development of salt tolerant lines may have application for saline areas.

Acacia saligna Breeding Strategy

A breeding strategy needs to take into account everything that is known about the biology of the species in terms of seed production, flowering i.e. stage of life when the species flowers, timing of flowering within and between provenances, ease of control pollination, out-crossing rates, propensity for clonal propagation. Flexibility is necessary because knowledge is incomplete. Sometimes changes are required as new knowledge comes to light or other factors such as drought, poor flowering and seed set or changes in funding and availability of personnel affect how or when various tasks can be done.

Indistinct male and female flowering phases, asynchronous opening of flowers combined with low pollen viability of stored pollen suggest that open pollination is likely to be the most suitable mating strategy for breeding *Acacia saligna*. Strategies such as nucleus breeding (Cotterill 1989, White *et al.* 1999) or rolling front (Borralho and Dutkowski *et al.* 1998) require controlled crossing programs, which are likely to be impractical for *A. saligna*. Given that it is necessary to minimise costs the most appropriate breeding strategy is likely to be recurrent selection as outlined in an earlier section of this document.

Breeding objective

The primary traits of interest in *Acacia saligna* include biomass production, wood basic density, disease resistance and nutritional characters. Economic analysis will be required to ascertain appropriate economic weightings for these traits.

Strategy Outline

1. Early measurements should be made for height, survival and form as well as at rotation age. Little is known about the growth patterns of the various *A. saligna* subspecies. In any tree breeding program it is important to know at how early an age selection for individuals can reliably take place. As successive years of data are accumulated juvenile-mature correlations can be tracked between years. The earliest age which correlates most highly to rotation age measurements will give an indication as to when the first measurements and selections may be made in subsequent generations. First year survival followed by second year and fourth year measurements may be appropriate. Choosing the optimal time to conduct selection will maximize gains in the next generation.

2. Initiation of cuttings experiments should begin as soon as possible to determine the most appropriate method and time of year as well as family variation in ability to strike roots from stem cuttings. Initially, material from outside the trials would be used to establish the technique.

3. Conduct a final measurement of height, stem diameter, form and flowering. Basic density at near rotation age will also be important for a range of different products including pulp, panel board biomass and bioenergy production. Conduct assessment of foliage nutritional value. This measurement may be done at around age four years when individual plants are likely to be close to their final relative size. It is envisaged that assessment of nutritional value will be conducted using NIR reflectance spectroscopy. Traits to be assessed include crude protein level, digestible dry matter, ash content and tannin content.

4. Data analysis and assessment of relative importance of subspecies, provenance and family variation as well as genotype x environment interaction. Based on this information an assessment can be made as to the suitability of each of the four subspecies for future breeding and which ones should be kept or potentially dropped from future breeding activity. It is considered most probable that ssp. *saligna* and ssp. *lindleyi* will be most suited to breeding owing to relatively high growth rates and potentially better form. If this is the case it is likely that further seed collections will be necessary for ssp. *saligna* as there are only four provenances of this sub species represented in this trial.

Other decisions requiring attention include whether or not to lump the subspecies together for the purpose of breeding, breed them separately, or hybridise them. This may be determined by nature. The reported asynchronous flowering times (see above) between the ssp. *saligna* and ssp. *lindleyi* may preclude hybridisation in a breeding program without the use of controlled pollination. Additional complications may exist with subspecies. M. Millar (unpublished results) found that mating between two provenances of ssp. *saligna* in an *A. saligna* provenance trial totalled only 5.5% of their progeny, despite the provenance plots being planted adjacent to each other. The majority of the progeny (87.5%) resulted from within provenance mating. Hybridisation with a ssp. *lindleyi* provenance comprised 7% of the progeny. The reported low viability of stored pollen may inhibit the use of controlled pollination of individuals with different floral phenologies. Detailed floral assessments will be necessary to determine how flowering times vary within and between the subspecies within the trials.

5. Select the best individuals from the best families using index selection. At this point the family provenance trial can be converted into a breeding population by culling the worst families and worst individuals from retained families. Given the vagaries of the breeding system it may be best to carry forward as many families as possible into the next generation. Thinning of the trial can be biased so that the poorest families have fewer representatives than the better families, thus increasing the

proportion of better genes transmitted to the next generation. If it is considered inappropriate to thin the trial it may be possible to construct a breeding population by means of cloning the best say 300 individuals into a replicated clonal seed orchard.

6. After the thinned breeding population has flowered, collect seed and establish the second generation progeny trial. Material from new seed collections from the wild can be added or infused into the population at this point. It may be preferable to put new introductions through one generation of selection and recombination prior to incorporation into advance generation breeding populations.

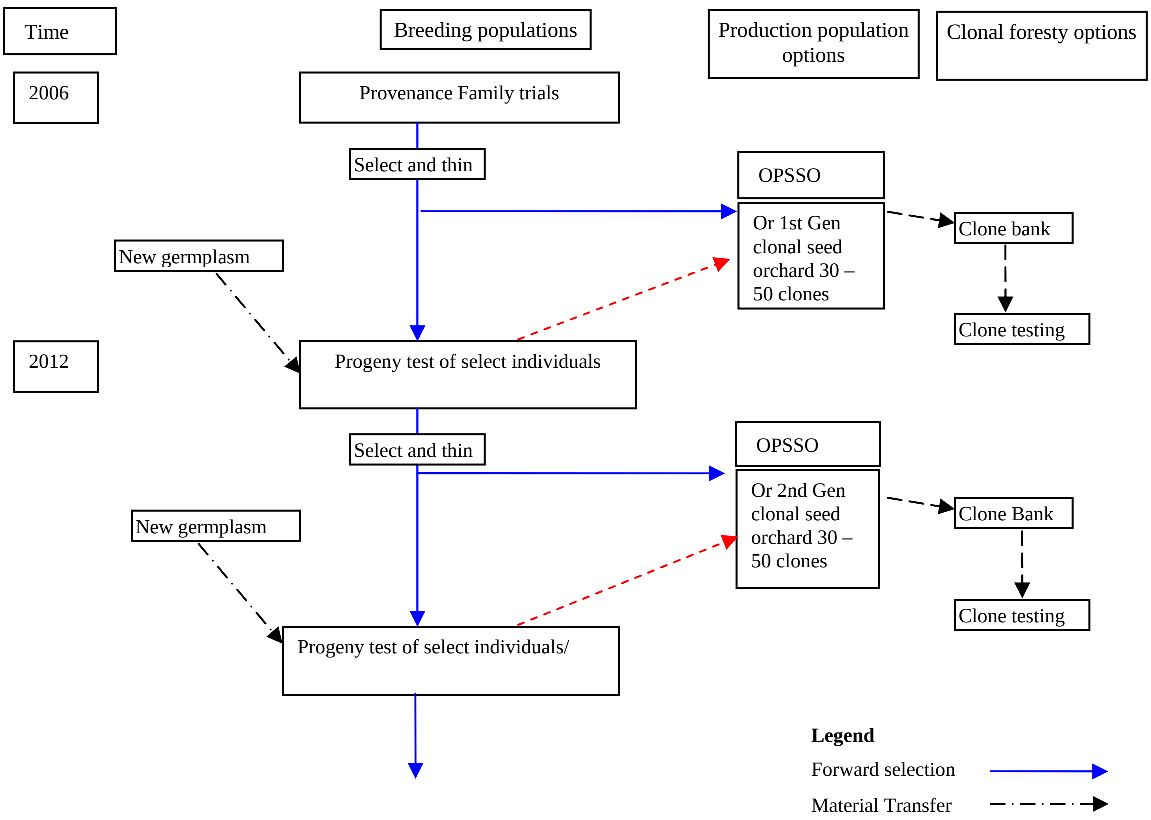
7. The best thirty or forty forwards selected individuals can be used for establisment of first generation production populations or seed orchards. Depending on the ease of grafting or cuttings establishment either a clonal seed orchard or seedling seed orchard may be established. Gains from a clonal seed orchard with subsequent rogueing from backward selection are likely to be the best in this scenario but if cloning via grafts or cuttings is impractical, a viable alternative based on work by Shelbourne (1992) is to establish open pollinated seedling seed orchards (OPSSO's) using seed from the best trees in the breeding population. These seedling seed orchards may be either pedigreed or unpedigreed (see Shelbourne 1992) and are likely to produce similar levels of gain.

8. Measure the second generation trial at the age determined most appropriate using juvenile- mature correlations and conduct backward selection to select the best individuals from the best families in the clonal seed orchard if established.

If mass propagation via cuttings is possible then clonal forestry becomes an option and a parallel program of clonal testing in a range of environments will become necessary in order to select the most stable clones or clones for specific kinds of environment and end products e.g. it may be desirable to develop salt tolerant clones**.**

The breeding strategy for *A. saligna* is outlined in schematic form in Fig. 32. Table 29 presents a tentative time-line for implementation of various aspects of the strategy. A degree of flexibility is required in any strategy dealing with the domestication of a new species. Methodology, direction or timing may need to be adjusted to account for new knowledge as it comes to light.

Fig. 32. Schematic diagram of *Acacia saligna* breeding strategy.



Research Priorities

Breeding Objective

The breeding objective is an essential part of any breeding program as it sets the direction that improvement will take (Woolaston and Jarvis 1995). It may be considered the overall goal of the improvement program. A breeding objective can be expressed in terms of an aggregate genotype i.e. breeding values for a number of traits of interest are weighted by their economic importance and then summed to yield a single value (White and Hodge 1989):

$$\mathbf{H = m_1g_1 + m_2g_2 + m_3g_3}$$

Where,

H = the aggregate (economic) genotype

m_1, m_2 are economic weights of traits and

g_1,g_2 are the estimated breeding values

It should be noted that not all traits of economic value may be directly measurable and hence the traits that are actually used in an index may be considered selection criteria (Schneeberger *et al.* 1991). For example whole tree biomass is not easily measured in the field without destructive sampling, so a correlated selection trait such as basal stem diameter may be used to select for high biomass.

Traits of primary economic interest in *A. saligna* are likely to include woody biomass, basic density and cellulose content. Nutritional traits are likely to include measures of crude protein content, dry matter digestibility and tannin content. Economic analysis of the relative profitability of these traits is necessary prior to selection for breeding.

Table 29. Timeline for breeding and establishment of *Acacia saligna*.

Calendar Year	Month	Activity	Comments
2006	Jul – Aug	Establish family provenance trials	
2007	Jun – Jul	Survival assessment	
2007	Aug – Sep	Initiate cuttings/ grafting experiments	Use wild material-trials too small
2008	Jun – Jul	First measurement at 2yrs (Height, form)	
2009	Oct – Dec	Floral assessment	Assumes flowering has initiated
2010	May	2nd measurement at 4yrs. Height-width-width, basal diameter, form, , nutrition	Assumes that this age is reasonable representation of performance at rotation age. Thinning at this age also gives time for seed production prior to trees dying
2010	Jul	Data analysis, Index selection	
2010	Aug	Select best trees in trials, thin trials to improve pollen quality Optional Select best trees for cuttings /clonal seed orchard establishment	Thinning complete prior to flowering or at early stages of flowering. Best 20 unrelated individuals for establishment of OPSSO’s Graft or Strike Cuttings
2010	Nov – Dec	Seed collection from best individuals	Includes seed collection from external sources e.g. better provenances of a particular species. As well as seed for first generation OPSSO’s Establish Clonal seed orchards and potentially a clone bank for “storage” of clonal material. Becomes a source for clonal multiplication if required
2011	Jan	Seed collection	Includes seed collection from external sources e.g. better provenances
2011	Nov	Sow seed in nursery	Assumes sufficient seed has been collected
	May – Jun	Label and assemble trials in Nursery	
2012	Jul – Aug	Plant second generation progeny trial/breeding population Plant first OPSSO of improved seed Establish first generation clonal testing trials in different environments	
2013		Trials growing	
2014	May – Jun	Measurement of Clonal trials Measurement of Progeny trials?	Time of measurement is dependant on the rate of growth and also juvenile mature correlation data from the first generation trials. Backward selection in first trial to check on efficacy of forward selection

Estimates of genetic parameters

Heritability is important for estimation of gains to be made from selection and will influence the way in which selection is carried out. For example, Ruotsalainen and Lindgren (1998) observed that low heritability favoured backward selection and high heritability favoured forward selection. It was also found that where selection intensity was high in the forest it was better to select the best parents using backward selection and the remainder using forward selection. Estimation of breeding values using BLUP enables direct comparison of breeding values of both parents and progeny and will simplify decisions as to which direction (forward, backward or a combination of both) selection will result in the highest gains.

When the second generation progeny test is established and grown for about four years it will be possible to test the efficacy of forward selection in the previous generation. If the best backward selected parents on the basis of the progeny test are the same as those ranked as best during forward selection in the first generation, it will be strong confirmation of the efficiency and accuracy of forward selection. If not then it may be better to construct clonal seed orchards on the basis of backward selection.

Controlled crossing

Sensitivity to inbreeding and related mating is unknown in *A. saligna*. A small diallel crossing experiment of say six males and females is likely to provide some insight and provide clues as to how much bias may be introduced into heritability estimates and prediction of gains.

Clonal propagation

The ability to clone superior genotypes will be important in establishment of clonal seed orchards of superior genetic quality. Grafting is likely to be the easiest option , however if cuttings strike roots easily they may be preferable as this eliminates problems with graft incompatibility and maintenance. Techniques will need to be developed for cuttings establishment using either shoot or root cuttings.

Nutrition

Establishment of rapid measurement techniques for reliably screening large numbers of samples will be necessary for the improvement of nutritional value of *Acacia saligna*. The use of Near Infra Red Reflectance spectroscopy is an effective method for prediction of a range of nutritional parameters (e.g. Coleman 2005; Ciudad *et al.* 2004). Starks *et al.* (2004) demonstrated that the use of a hand held radiometer gave very similar results to bench top NIR in monocultures of Bermuda grass. The use of this kind of technology may have application for *A. saligna.*

Atriplex nummularia - Old Man Saltbush

Two key traits in the breeding objective for OMS include metabolisable energy (ME) and edible biomass production. The initial concept was to integrate economic data and genetic information derived from the trials into a selection index and thereby maximise genetic and economic gains in these traits. Consensus in the early stages of planning was that development of a cheap and efficient means of screening nutritional parameters in the field using NIR was feasible. The preliminary strategy outlined here was framed on that basis. Since the projects inception however, difficulties with the application of NIR technology resulted in significant changes in both selection protocol and the final breeding strategy to be implemented and these will be documented elsewhere.

Background information

Cytogenetics

Both *A. nummularia* ssp. *nummularia* and ssp. *spathulata* are octoploid (2n = 72) Le Houérou (2000b). Nobs (1980) found that *Atriplex nummularia* from five sources, two in New South Wales, one in the Northern Territory and another from Western Australia plus a fifth planting in the botanic gardens in the ACT were consistently octoploid. Meiosis was observed to be completely regular in all cases except at Ejanding WA where hybridisation was occurring with *Atriplex amnicola.*

Genetic parameters

There are no existing estimates of genetic parameters for *Atriplex nummularia* in the literature. Estimates of heritability are found in the literature for a range of other polyploid crops and are often high. For example Coman and Popescu (1997) found high narrow sense heritabilities in strawberries (octoploid and outcrossing) for fruit weight (h^2= 0.68) and firmness ($h^{2=}$ 0.54). In sugar cane (variable ploidy) Silva *et al.* (2002) reported narrow sense heritabilities for five yield traits ranging from 0.54 up to 0.77. Narrow sense heritability in *Coffea arabica* (tetraploid) for height and stem diameter was more variable with values of h^2= 0.37 and h^2= 0.001 respectively (Cilas *et al.* 1998). Stutz *et al.* (1979), quoting Pope (1976), reported heritability estimates of greater than 0.5 for unspecified traits in the hexaploid *Atriplex tridentata*. They did not indicate if these heritabilities were narrow sense.

If heritability is high and correlations between traits are positive or at least neutral then better progress is likely to be made than with high heritability and negative correlations between some traits. If heritability proves to be extremely low for all economically desirable traits then progress will be slow. Primary research objectives should therefore include the estimation of heritability and phenotypic and genetic correlations between key traits, as this will directly affect the way the breeding strategy is conducted.

Breeding system

A. nummularia is wind pollinated (De Kock 1980) and predominantly dioecious (Wilson 1984) although some plants do occur with both male and female flowers. Dioecy is an adaptation against self-pollination (Boshier 2000) and may bring significant advantage to a breeding program through the elimination of self pollination and any resultant inbreeding depression. Related mating will be limited to that between close relatives.

Inbreeding Depression

Inbreeding depression is of potential concern in breeding of outcrossing species particularly in breeding populations of limited size. Management of inbreeding levels within breeding populations is an integral part of most tree breeding programs, e.g. Cotterill (1984 1986 1989) and White (1992, 1995). Nothing is known about the effects of inbreeding depression in *A. nummularia*. Self compatibility is often considered necessary to the successful establishment of new autotetraploids (Raush *et al.* 2005, Galloway *et al.* 2003). However, the genetic basis of inbreeding depression and its variable magnitude is not fully understood (Husband and Schemske 1997). The level of inbreeding depression in polyploids relative to diploids is variable and has been shown to be worse in some polyploids and less in others (Husband and Schemske 1997). Examples of polyploids exhibiting inbreeding depression include the herbaceous autotetraploid *Campanula americana* (Galloway *et al.* 2003), sugarcane Hogarth (1968) and strawberries (Shaw 1995). Breeding strategies for the octoploid strawberry often include recurrent selection within closed populations followed by clonal propagation of superior genotypes (Shaw 1995). Shaw reports that inbreeding depression does occur with closely related matings. For example, in a controlled crossing experiment, trait means for half-sib crosses ranged from 2-17% lower than those from unrelated crosses in four different traits. This was not perceived to be a problem as long as strong directional selection and adequate population sizes were in use. Controlled crossing experiments will be necessary to ascertain the importance of inbreeding in an *A. nummularia* breeding program.

Deliberate selection of dioecious individuals for use in the improvement program may be a useful tool in the control of inbreeding. The fact that some plants are monoecious may present opportunity to examine the effects of controlled self pollination and the expression of inbreeding depression.

Atriplex nummularia Breeding Strategy

Domestication of *Atriplex nummularia* for commercial use is in its infancy. Whilst there is considerable knowledge and experience around the world in the agronomy of the species, the converse is true for breeding. Given the genetic complexity of the plant, development of high quality cultivars through convential breeding may not be straightforward. In order to rapidly harness genetic variation for commercial production whilst ensuring long term development of the species, a two pronged strategy is likely to be appropriate. The first and quickest approach will be the production of commercial clones and the second will consist of more conventional breeding methodology. As with every breeding strategy, flexibility to accommodate change is necessary and regular review of progress and strategy is an integral part of the process.

Clone development

The initial stages of plant development through clonal methods are readily achieved by:

1. Screening of the progeny trials (and subsequent generations of progeny trials) for desirable individuals;

2. Clonal propagation and multiplication via cuttings; and

3. Testing of the clones in a range of environments to ensure stability of desired traits prior to release.

Development of high quality cultivars

The objective in breeding out-crossing perennials is to concentrate desirable alleles in the breeding population. Factors affecting this process include choice of parents, mating system, heritability, selection intensity, the number of traits selected for, genetic and phenotypic correlations between traits. The ultimate goal of fixing desirable genes in the population may be difficult in octoploids.

Conventional cultivars may be put through one or more cycles of sexual reproduction prior to release as sufficient seed is generated for commercial seed production (Sleper and Poehlman 2006). In order to ensure that the cultivar developed remains true to type, it is considered that a saltbush cultivar should consist of seed generated from a set of clones of known performance, established in a clonal orchard or clonal seed orchards. The breeding strategy then requires a simple means of managing the breeding population whilst producing new clonal orchards with each turn of the breeding cycle.

Influence of breeding system on strategy

Design and implementation of a breeding strategy is largely dependent on the breeding system of the plant. Recurrent selection is well proven as a strategy for improvement of outcrossing plants and variations on it are used widely in forestry and in agriculture. The octoploid nature of *A. nummularia* and its response to selection is something of an unknown quantity, although selection has been shown to work in octoploid strawberries. Dioecy is a feature of the breeding system of *A. nummularia* which confers both advantages and disadvantages. One such advantage is that self pollination and potential inbreeding from self pollination is eliminated. A potential disadvantage is that backward selection on males may be problematic should the need arise to use that option.. This will be discussed briefly below.

Given the need to minimise costs, open pollination is likely to be the option of choice for mating.

Selection of parents in the initial breeding population and first generation clonal seed orchards would be conducted on the basis of forward selection using BLUP and may achieve reasonable gains given heritabilities of 0.1 or more and if sufficient selection intensity is applied. The most intensive selection for parents of the next breeding population is performed on the seed parents Shelbourne (1992) notes that some selection on males in the breeding population can be done via thinning prior to seed production.

Significant gains may be possible using clonal seed orchards. Shelbourne (1992) estimated gains of about ten percent for traits with heritability of 0.1 and a selection ratio of 0.2 applied to families and 0.025 within familes for forwards selection of clones. He calculates that further significant gains can be made by culling the poorest performing clones on the basis of their progeny performance in the second generation breeding population (backward selection). In the dioecious *A. nummularia* it is necessary to have both male and female clones in the clonal orchard. Because the identity of male parents of OP progeny is usually unknown, backward selection on the male parents in the clonal seed orchard would not be possible. Potential gains may therefore be reduced. If heritability is relatively high and a high forward selection intensity is imposed on the males, potential losses in gain owing to inability to backward select may be mitigated to some extent. However, Burdon and Kumar (2004) found that if heritability is very low, backward selection using maternal half sib families of non-select pollen parentage (approximating open pollination) is likely to yield greater gains than forward selection over a range of selection intensities. The assumption here is that open pollinated (OP) families approximate half sib families. If this is the case, it follows that a means of backward selection on the males as well as the females would be advantageous.

In the context of this project and given the relative ease with which *A. nummularia* can be struck from cuttings, if realised gains are similar (or better) to predicted gains, rapid cycling of open pollinated breeding populations using forward selection together with establishment of clonal seed orchards for seed production (Fig. 33) may be a cheap and effective option. If heritabilities are low and predicted gains are not being realised then it may be necessary to explore alternative strategies involving controlled pollination (CP) to facilitate backward selection.

The situation may also arise where it is feasible to use a combination of both forwards and backwards selection as outlined by Ruotsalainen and Lindgren (1998). The use of BLUP analysis facilitates the selection process in that it provides for direct comparison of breeding values between parents and progeny (Jarvis *et al.* 1995).

An advantage of CP for selection purposes is that identity of male and female parents is retained. Calculation of breeding values and efficient backward selection can then be applied to both the females and the males. A disadvantage is that CP introduces significant extra cost in terms of time and money and most probably will preclude the use of backwards selection for the main breeding population.

An alternative may be to use a form of open nucleus breeding similar to that of Cotterill (1989) where only the very best individuals are used in the controlled crossing program and the remainder which constitute the “main” population are allowed to cross using open pollination and progressed using forwards selection (Fig. 34). Initially the best say 40 male and female parents are control crossed to generate a nucleus population separate to the main population. The best say 30 each of unrelated males and females are cloned and established in clonal seed orchards. Index selection and controlled crossing is conducted in the nucleus to produce successive generations. Each successive generation of the nucleus acts as a progeny test of the previous generation allowing accurate ranking of both the best males and females and subsequent roguing of the clonal seed orchard. Index selection combined with open pollination is used to advance the main population. In each generation the best ten male and female parents from the main population are infused into the nucleus using either seed or pollen, to minimize inbreeding in the nucleus. Similarly, seed from the best female individuals in the nucleus is put back into the main population to ensure that genetic gain achieved in the nucleus is incorporated into the main population. Genetic gain in the nucleus will advance more quickly than in the main population. A cost benefit analysis will be necessary prior to engaging in the more complex breeding strategy, but this will be most effective when there is a better understanding of the biology of *A. nummularia* and how it responds to selection.

Strategy outline

1. Measure trials for edible biomass using the Adelaide method (Andrew *et al.* 1979) and nutritional traits e.g. metabolisable energy, using NIR.

2. Assess relative importance of subspecies, provenances, families and genotype x environment interaction for edible biomass and metabolisable energy. An assessment of gender and synchrony of flowering times will also be important. Based on this information an assessment can be made of the need for regional breeding programs, suitability of either or both subspecies to different environments and whether there are some provenances that may be worth further exploration. Flowering data will enable a simple assessment of the potential for crossing using open pollination between provenances and potentially, between subspecies. Timing of flowering will be particularly important for the construction of clonal seed orchards

Important questions to answer at this point will be whether to breed both sub-species together, separately, use separate breeding populations with hybridisation between the two or drop one subspecies entirely. For the purposes of illustrating the breeding strategy, it will be assumed both subspecies will be bred together. Variations to accommodate any of the above scenarios are easily implemented.

3. Select the best individuals from say the best 300 families across all trials (assuming GxE is not significant). The simplest approach is likely to be selecting for stable performance across sites rather selecting for breeding in different regions. This will depend on the magnitude of GxE. The optimal ratio of males to females is yet to be determined. Wild populations appear to have relatively even mixtures. Selection is based on an index incorporating breeding values and economic weights. If NIR is not feasible, it may be possible to construct an index using other measures such as scores derived from sheep grazing preferences, if they are correlated to metabolisable energy or other nutritional traits. The selected individuals may be cloned using cuttings to establish a separate breeding population. Alternatively the trials could be thinned at this point to eliminate related individuals within family plots and the worst provenances and/ or families from the trial. This effectively converts the progeny trial into the first generation main breeding population by preventing poorer individuals contributing genes to the second generation. Given the relative ease of cloning the species from cuttings, a first generation clonal seed orchard could be constructed from say the best 30 males and 30 females and then rogued based on performance of clones progeny in the second generation breeding trial as per Fig. 33. This represents the simplest scenario. If forward selection proves relatively ineffective then it may be useful to implement controlled pollination in a nucleus breeding system as discussed above.

4. For the establishment of a nucleus breeding system, select the best 40 males and 40 females (may select more intensively on the males) to form the nucleus. Conduct control pollinated (CP) crosses in the form of an assortative mating design to generate the next generation of the nucleus. If these select individuals are widely dispersed across the progeny trials in different states it may be necessary to clone them to facilitate the crossing program. Alternatively if pollen is easily stored it may be possible to conduct controlled crosses *in situ*, saving time otherwise lost waiting for clones to mature and flower.

5. Collect seed from the select individuals in the main population and establish a progeny test. This progeny test will form the second generation breeding population. The progeny test will also provide a means of checking on the effectiveness of forward selection in the original family-provenance trials. This check is important because little is known about the effectiveness of selection in old man salt bush.

6. CP seed from the nucleus parents is also established in progeny tests.

7. The second generation main population is measured and selection and thinning conducted in the same manner as for the first generation.

8. Measurement of the second generation nucleus trials enables performance of the first generation parents to be ranked. Commercial seed orchards are then established using clones of the best unrelated nucleus parents. On the basis of the progeny tests, these individuals are known to produce superior progeny and constitute the first cultivar for seed production. Seed from this first generation clonal seed orchard (CSO) is used until it is superseded by the next generation of improved clonal seed orchards and so on. This process circumvents the segregation and subsequent decline in performance that can occur from cycling through multiple generations of a conventional cultivar.

9. Intensive selection is conducted in the second generation nucleus population to select the best individuals. Controlled crossing is then used to generate the next nucleus population. Seed or pollen from the best 10 individuals in the main population can then be used to introduce new genetic material into the nucleus. Similarly seed from the best individuals in the nucleus is incorporated into the main population.

10. The improved seed from the clonal seed orchards constitutes a cultivar which is sold with seed certification specifying that growers will not be able to cycle it through more than one generation without it segregating too much and losing some or all genetic gain derived from the breeding process. Consequently growers should buy seed from the breeding program for reliable production.

11. If forward selection proves to be completely ineffective then a progeny testing stage may need to be introduced between each generation of breeding population and nucleus population. Backward selection can be used to select the best parents for regenerating the next breeding population. This would increase the time required to cycle through generations.

Table 30 and Table 31 present tentative time-lines for implementation of the simplest breeding strategy with an option for a nucleus breeding strategy. A degree of flexibility is required. Methodology, direction or timing may need to be adjusted to account for new knowledge as it comes to light.

Fig. 33. Schematic diagram of a recurrent selection strategy using clonal seed production areas for commercial seed production.

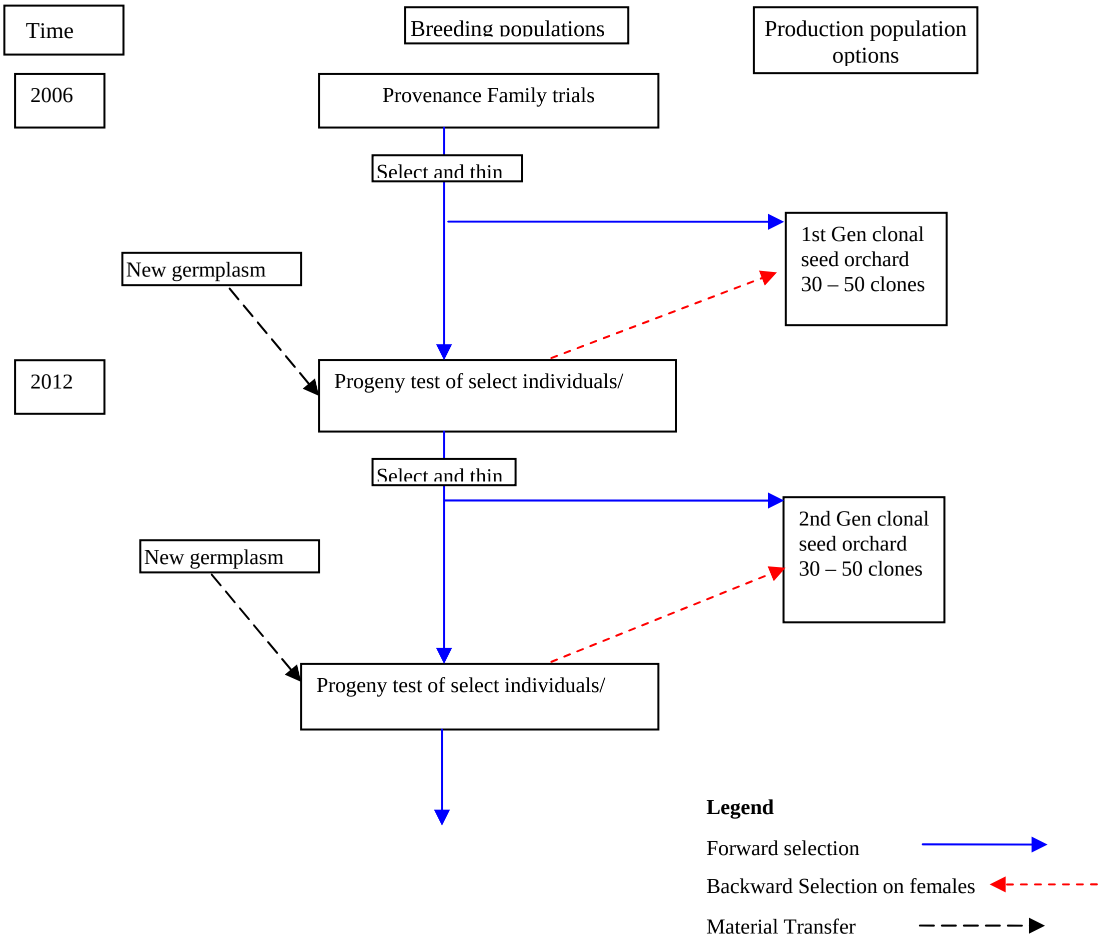


Fig. 34. Schematic diagram of a Nucleus Breeding strategy for *Atriplex nummularia.*

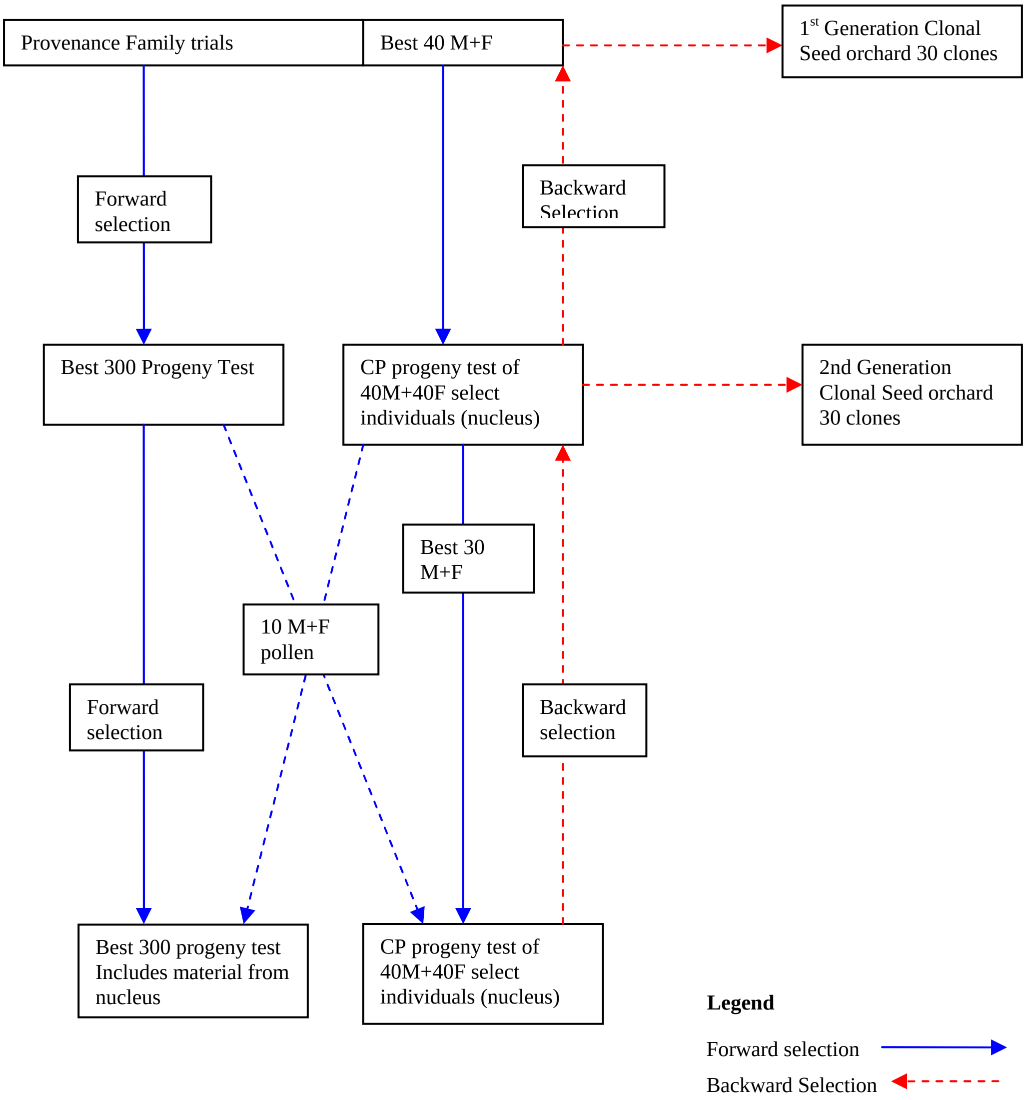


Table 30. Potential timeline for breeding activities

Year	Month	Activity	Comments
1	Jul – Aug	Establish family provenance trials	
2	Sep – Oct	First measurement – Biomass, survival, form and gender. Initiate cuttings experiments	Gender assessment assumes flowering has initiated
3	Nov	Data analysis	
4	Feb – Apr	Assess trials for Animal preference, and nutritional traits using NIR if available.	
5	Feb – Apr May	Second round of animal preference testing to confirm earlier results. NIR Index selection and thin trials to improve genetic quality – remove close relatives. Should be done prior to flowering	Another option in the first generation is to clone unrelated individuals from the best the best 300 individuals This may be better if there is a need to breed one or other subspecies. The timing of events would be delayed by one year if this option is employed.
5	Nov – Dec	Strike cuttings for Clonal Orchards and for clonal testing of potential commercial clones	
6	Jun – Jul	Establish Clonal Seed Orchards (CSO) Establish clone trials on multiple sites	Could also establish clone bank for "storage" of clonal material. Becomes a source for clonal multiplication if required
6	Nov – Dec Dec – Jan	Collect post thinning seed for progeny tests Sow seed in Nursery	Collections of new material from superior provenances may be introduced in separate trials at this point.
7	Jul – Aug	Establish second generation progeny tests	
8	Jul – Aug	First measurements of second generation progeny test	
9	Feb – Apr	First round of animal preference testing and nutritional testing	Data will determine if forward selection is effectivei.e. if gains achieved are acceptable or whether backward selection may be necessary to improve gains achieved are is necessary. If so Proceed to table 31 Will enable backward selection and roguing of worst females from clonal seed. Thinning of males is dependant on forward selection
10	Feb – Apr May Nov – Dec	Second Round of animal preference testing to confirm earlier results Index selection and thinning of breeding population and roguing first generation clonal seed orchard Post thinning seed collection and sow in the nursery	May include new seedlots from best provenances as determined in original trials
11	Jul – Aug	Establish trials in field	

Table 31. Potential timeline for breeding and establishment of old man saltbush trials using a nucleus breeding system.

Year	Month	Activity	Comments
10	Feb – Apr	Second round of animal preference testing	
	May	Index selection and thinning of Breeding population trial	
		Rogue first generation clonal seed orchard	
		Select clones for second generation clonal seed orchard and also clonal tests of potential commercial clones	
	May – Aug	Strike cuttings	
		Controlled pollination (CP) for nucleus using backward selected parents	Flowering period to be determined. Difficulty and time required for CP is yet to be determined. To facilitate crossing It may be easier to clone all the parents so that they are in the same place rather than attempting insitu pollination in the field.
	Nov – Dec	Collect post thinning seed for second generation breeding population and nucleus progeny tests	
		Establish in the nursery	
11		Establish second generation clonal seed orchards and trials of potential commercial clones	
		Establish third generation breeding population and first nucleus population trials	

Research Priorities

Breeding objective

As with *A. saligna,* it is necessary to establish a breeding objective for *Atriplex nummularia* in order to effectively direct selection and maximise profitability. As the primary end product is fodder, the traits of main interest will be edible biomass, dry matter digestibility (an indirect measure of metabolisable energy), crude protein and leaf salt content. Other factors which may be important include neutral detergent fibre, acid detergent fibre and secondary compounds such as oxalates.

Preliminary modelling using MIDAS (Model of Integrated Dry Land Agricultural Systems) suggests strong increases in profitability with increasing nutritive value and biomass (D. Revell pers. comm.). The system may be used to develop economic weightings for the breeding objective.

Numerous morphological traits may be measured e.g. height, width in two directions, basal diameter, internodal length, leaf size, leaf density and branching all of which may be of some value in estimating edible biomass production. Andrew *et al.* (1979) described a simple visual technique for estimating the weight of forage of chenopod shrubs which they designated the “Adelaide” technique. Comparison of the Adelaide technique with shrub dimension measurement and another technique using a capacitance probe (Andrew *et al.* 1981) demonstrated that the Adelaide technique was the most accurate and worked well with grazed and ungrazed shrubs.

Nutrition research

Problems currently exist in establishing a reliable relationship between *in vivo* dry matter digestibility and that predicted by *in vitro* methods. Further research is required to improve the correlation such that mass screening is possible using NIR technology or potentially, radiometry (Starks *et al.* 2004).

Palatability is another important issue in assessment of old man saltbush. It is not fully understood what constitutes a palatable plant. Experience from Chile with Old Man Saltbush suggests that salt content is a primary factor affecting palatability (C. Torres pers. comm.).

Phenology

Gender distribution and synchrony of flowering times between subspecies, provenances and families will be critical.

Hybridization potential

It is not known whether the two sub-species hybridise naturally in areas where distributions overlap.

Pollen

Is pollen storage possible and for how long is viability maintained? This will have ramifications for controlled crossing programs. Other important questions include those of pollen dispersal and gene flow – how far is pollen carried?

Genetic conservation and genetic pollution

Following on from the previous points the question arises as to whether there is an unacceptable risk of genetic pollution associated with the deployment of one subspecies within the natural distribution of the other. A full decision process such as that outlined by Wallace (2006) including appropriate benefit-cost analyses may need to be conducted.

Trial measurement sampling strategy

Large numbers of families have resulted in large trial sizes. The problem exists to assess the trials effectively using the resources available. Assessment of morphological traits can be achieved rapidly and relatively cheaply however sampling for nutritional traits is likely to be more expensive. It is therefore necessary to think carefully about the possibilities for sub-sampling.

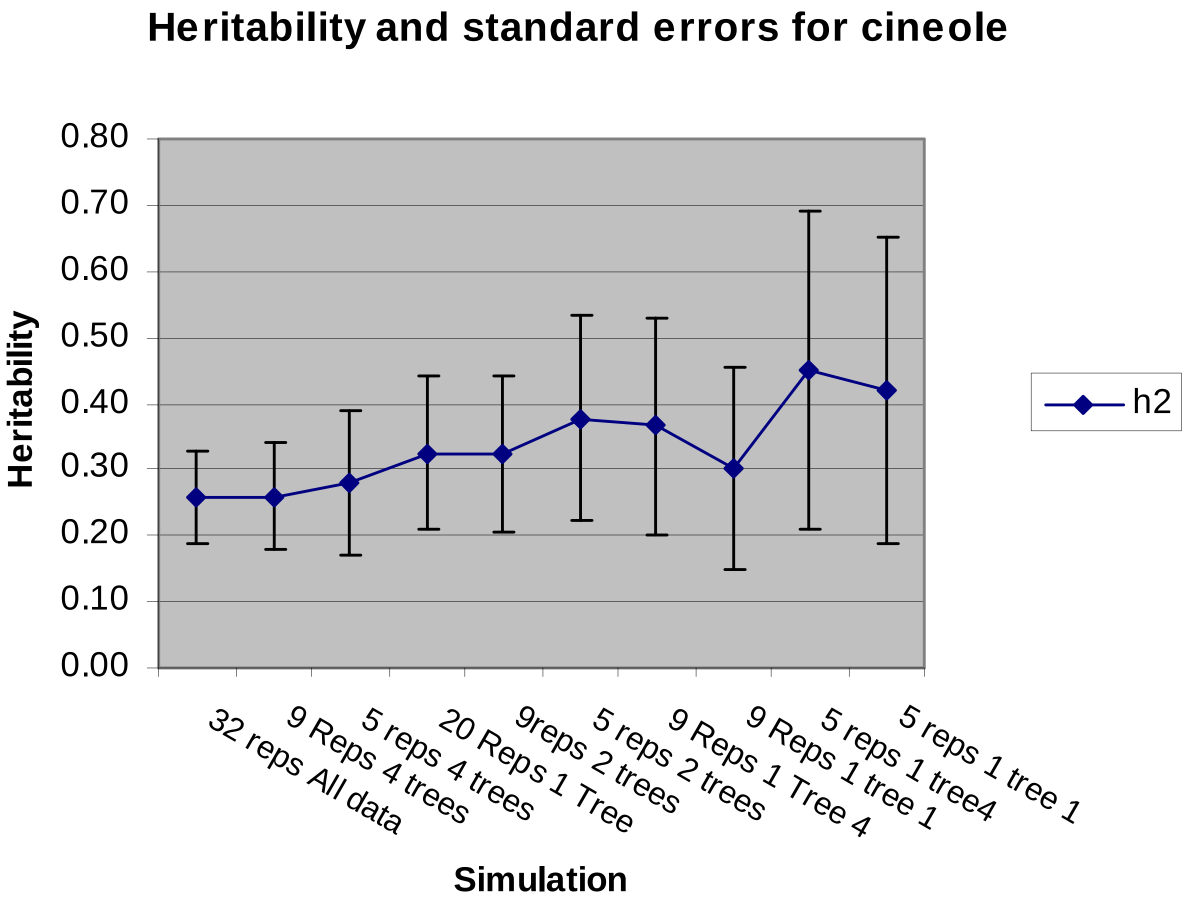
Reliable estimates of genetic parameters e.g. additive variance, heritability, genetic and phenotypic correlations within a trial, are essential for making decisions regarding the most appropriate breeding strategy. In turn, the more accurately these parameters can be estimated, the more accurate estimates of breeding values will be and ultimately, the greater the genetic gains achieved. Accuracy attainable is largely dependant on sample size. Apiolaza *et al.* (1999) looked at the effect of subsampling one trait on the efficiency of bivariate estimates of heritability and genetic correlations and backward selection of parents in half sib progeny tests. In a simulated trial with 30 individuals in each of 200 families, all individuals of low heritability growth traits were measured whilst subsampling rates of 3, 9, 15, and 30 trees for a second trait with higher heritability but deemed more expensive to measure. Whilst larger sub-samples of the second trait gave better estimates of genetic parameters and larger amounts of genetic gain, little extra benefit was gained from sampling more than 15 individuals per family. Sample sizes below this were less reliable.

Sub-sampling is possible in the Old Man Saltbush trials but should be considered carefully. The study described assumed relatively high heritability of the subsampled trait but the authors acknowledge that more individuals may be needed for traits of lower heritability. The heritability of nutritional traits in old man saltbush is unknown and if it is low then it is likely to be necessary to measure more than fifteen individuals e.g. a minimum of twenty individuals as suggested by Cotterill and James (1984). They suggested that twenty individuals per family was necessary to reliably estimate family means and concluded that similar numbers should be used to estimate heritability.

In order to evaluate the effect of varying sample size on the accuracy of heritability estimates for a moderately heritable trait (leaf cineole concentration), a simulation was run using data from a *Eucalyptus polybractea* progeny trial (Mazanec unpublished data). The trial was originally set up with 32 replications and four tree row plots so that it could be thinned down to the best individuals within the best families for use as a seed orchard. Heritability was estimated using a range of subsets of the data (Fig. 35).

Relative to the complete data set, the best result was achieved using nine replicates and all four trees per family row plot with little gain in accuracy achieved using extra replicates. The next best is 5 replicates with 4 trees per row plot. Worst results are given with 5 replicates and 1 tree per family plot with standard errors greater than 50% of the heritability estimate. It is also of interest to note that with lower numbers of trees the actual value of the heritability estimate was less stable. These results are in good agreement with Cotterill and James (1984).

Fig. 35. Estimates of heritability and standard errors in a *Eucalyptus polybractea* progeny trial for different number of replicates and trees sampled per 4-tree family row plot.



Conclusions and Future Directions

Acacia saligna

Primarily a tree crop for production of biomass, some hurdles exist for *A. saligna*. The impact of the Gall Rust fungus on biomass production is yet to be determined and may influence adoption of the species for commercial use. Elucidation of the relative influence of genetics, environment and silviculture will be an important component of future work.

Realisation of the fodder potential of *A. saligna* will require some consideration. Young seedlings are vulnerable to grazing and require fencing over the first year. By age two years, a significant proportion of the edible foliage is likely to be beyond the reach of sheep. Management practices, such as hedging to keep plant height within reach of stock or early grazing regimes are likely to conflict with the objective of maximising woody biomass production. Mechanical harvest of foliage for use in feed pellets is a potential solution. Careful management protocols will need to be developed to ensure harvest of foliage is not detrimental to woody biomass production objectives. Alternatively, selection and establishment of two breeding populations, one for biomass production and the second for fodder production may better cater for divergent breeding objectives. This strategy is consistent with the observations of Le Houérou (2000b).

Further work is required to required to establish strong relationships between animal nutrition and NIR measurement techniques.

Atriplex nummularia

Economic analysis dictates that metabolisable energy is the trait of primary importance in raising profitability of Old Man Saltbush as a fodder crop. Difficulties associated with assessment of nutritional parameters such as metabolisable energy and palatability present the largest obstacle in conducting efficient selection. If cheap and rapid assessment techniques cannot be developed, it will be necessary to resort to other protocols, for example using sheep grazing preferences to guide selection for nutritional traits. If sheep preference scores on each plant can be related to nutritional value then it may be possible to incorporate such scores into a selection index as a proxy for NIR.

5. Breeding and Evaluation Trials

Richard Mazanec1,2, David J. McKenna2,3, Daniel Huxtable1,2, Merv Tucker2,3, Wayne O'Sullivan1,2, Craig Neumann2,3, Trevor Hobbs2,3, Michael Bennell2,3, John Bartle1,2 and Peter Jessop1,4

[1] Department of Environment and Conservation, Bentley WA 6983
[2] Future Farm Industries Cooperative Research Centre, Crawley WA 6009
[3] Department of Water, Land and Biodiversity Conservation, Urrbrae SA 5064
[4] Department of Primary Industries, Tamworth NSW 2340

Introduction

Fundamental to any breeding program is the genetic base that underpins it. History records more than one example of early eucalypt plantation programs derived from only a handful of parents (Eldridge *et al.* 1994). Characterised by poor growth and loss of production due to inbreeding, these early plantation experiences wrought a new understanding of the importance of the genetic base and the role of tree improvement.

It is now established practice to begin a breeding program with an investigation of genetic variation in a species using material from as wide a range of provenances as possible. Significant gains can often be made simply by identifying the best provenances.

Under the auspices of FloraSearch phase two, comprehensive seed collections were made from across the natural range of *Acacia saligna* and *Atriplex nummularia* followed by the establishment of family/provenance trials in Western Australia and in the eastern states. The objective of this work was to examine variation in traits of commercial interest and to provide a base population from which a breeding program for each species might be initiated. This section details seed collection and trial establishment for both species.

Acacia saligna Seed Collection

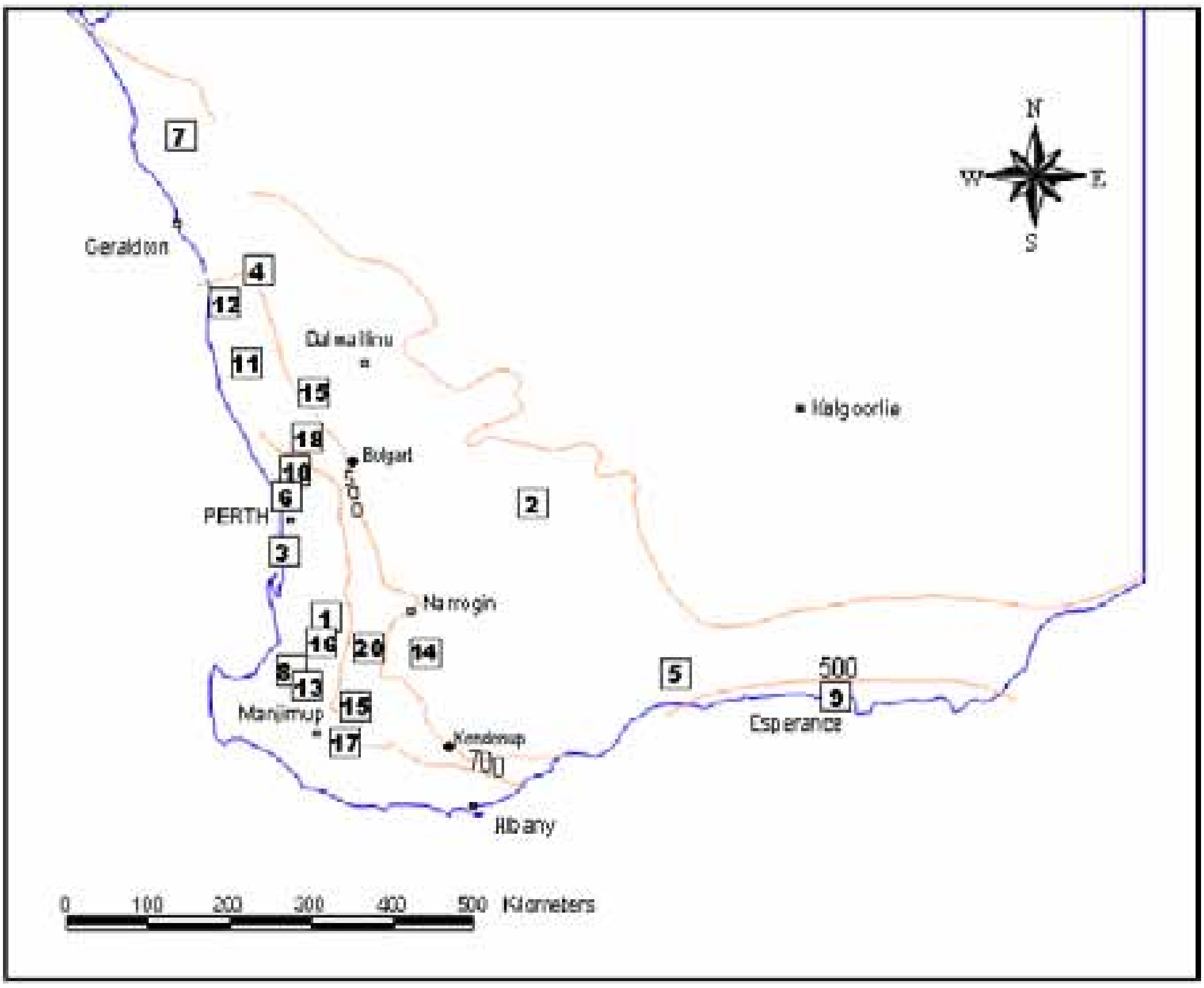
Seed collection was carried out over two seasons commencing in November 2004 through to January 2005 and the second season spanning November 2005 through to January 2006 (Fig. 36, Table 34). Seed collected in 2005/06 from Darkan, Boyup and Parkyeering was physically of poor quality (Wayne O'Sullivan pers.comm.). Cool weather in these areas delayed maturation of seed by up to a month. This extended ripening time was correlated with a high percentage of aborted seed, and greater than usual levels of insect attack. The final seed collection contains some 20 provenances each with 20 families, totalling 400 families.

The objective for the seed collection was to collect representative numbers of provenances for each subspecies. Subspecies *lindleyi* has the widest distribution and was observed to be quite variable across its distribution, therefore a higher number of provenances were required to obtain a representative sample than for the other subspecies. Subspecies *saligna* has a smaller distribution relative to ssp. *lindleyi* but is of high interest owing to its better form and greater biomass production. A total of four provenances were collected to represent the variation within this subspecies. The remaining two subspecies have much smaller distributions and as such were represented by only two provenances each. Because *A. saligna* is widely used in amenity plantings in Western Australia, considerable care was exercised in ensuring that populations included in the collection were in fact natural stands. Numbers of provenances per subspecies can be seen in Table 34.

Data collected at each population included GPS location of each tree, Botanical district, land tenure, rainfall, site description. Each tree was measured for height, crown diameter, number of stems was recorded along with a brief form description and crown density assessment

Fig. 36. Provenance collections for FloraSearch *Acacia saligna* trials established at Bolgart and Kendenup in 2006.

Numbers in squares correspond to provenances listed inTable 34.



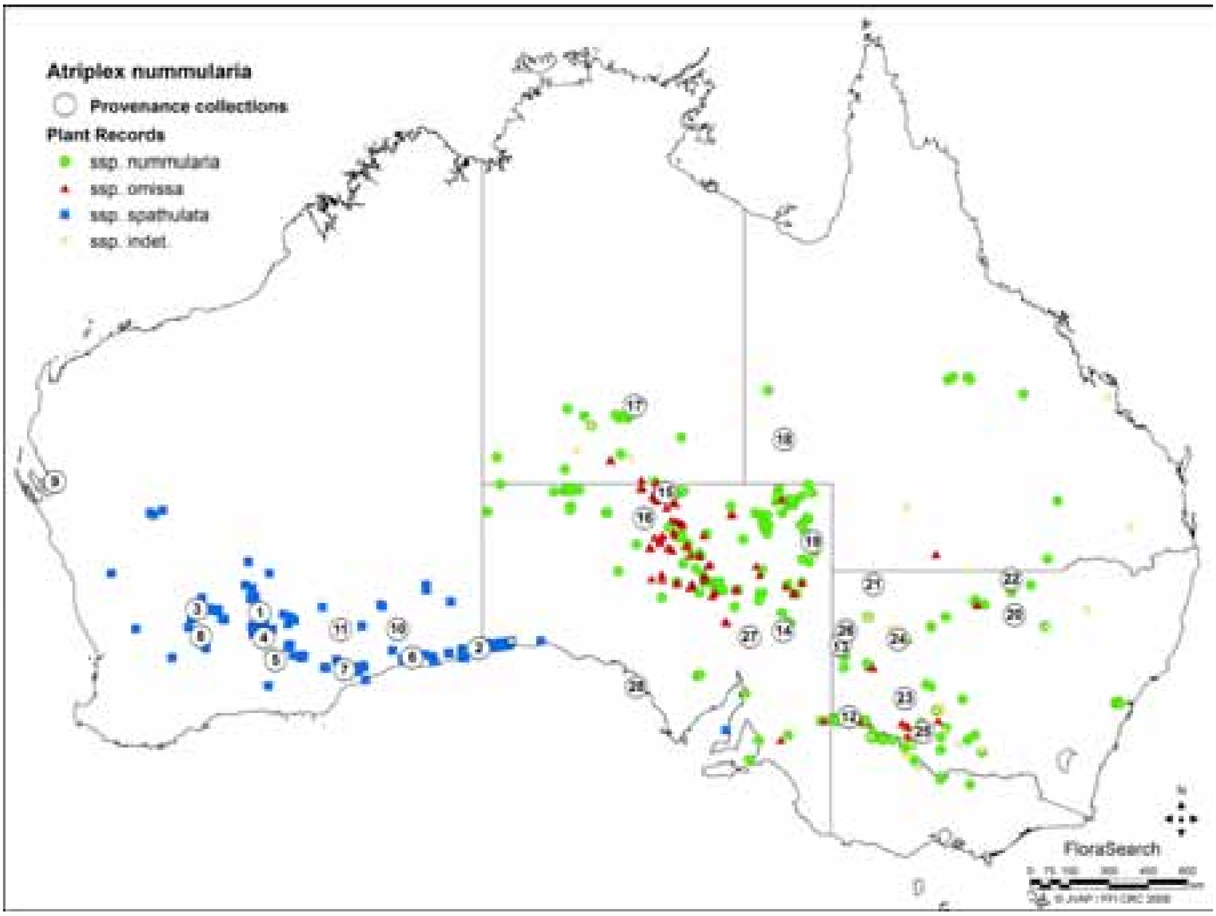
Atriplex nummularia Seed Collection

The objective of the seed collection was to collect from a wide range of provenances representing the known distribution of the three subspecies. Seed collection was carried out starting in November 2005 in Western Australia by the Department of Environment and Conservation. Late flowering and seed set, possibly as a result of drought, delayed collection of seed for ssp. *nummularia* until January 2006. At the time of collection, no populations of ssp. *omissa* had produced seed. As a result this subspecies was not included in the collection. Seed collection of eastern states populations were conducted by the New South Wales Department of Primary Industries. The final seed collection consists of 11 provenances of *A. nummularia* ssp. *spathulata* and 16 provenances of *A. nummularia* ssp. *nummularia.* Within each provenance seed was collected from 20 widely spaced individuals (Fig. 37 and Table 36).

GPS locations of every plant collected from were taken along with observations of soil type, pH, land form, associated vegetation, and dimensions of the parent plant.

Fig. 37. Distribution of *Atriplex nummularia* and location of provenance collections.

Numbers in circles correspond to provenances listed in Table 36.



Eucalyptus rudis Seed Collection

Seed from fourteen provenances were collected between January 2007 and January 2008 (see Table 32). The collection covers a traverse from Hall River in the north through to Kalgan River in the south. Absence of seed crops precluded collection of seed in the south west corner and this gap may need to be filled prior to establishment of trials.

Table 32. *Eucalyptus rudis* - WA collections, provenances and families in DEC - FFICRC seed collection.

ProvNo	Species [Provenance]	No. of Families	ProvNo	Species [Provenance]	No. of Families
1	*E. rudis* [Wandering]	20	8	*E. rudis* [Arthur River]	20
2	*E. rudis* [Dingo Rd]	21	9	*E. rudis* [Balgarup River]	21
3	*E. rudis* [Hill River]	21	10	*E. rudis* [Toolibin]	20
4	*E. rudis* [New Norcia]	20	11	*E. rudis* [Gordon River]	20
5	*E. rudis* [Toodyay]	20	12	*E. rudis* [Kalgan River]	23
6	*E. rudis* [Williams]	20	13	*E. rudis* [Wood's Lake]	20
7	*E. rudis* [West Dale]	20	14	*E. rudis* [Thompsons Lake]	20

Acacia saligna Trial Establishment

Trial Site selection

Two sites were selected on the basis of soil type, rainfall, geographic separation and secure location for establishing the trials. The first near Kendenup WA, (Lat 34º 27'; Long 117º 44') has a mean annual rainfall of about 550 mm and the second near Bolgart WA (Lat 31 º 11'; Long 116 º 27') has approximately 450mm mean annual rainfall. Soil consists of pale sand over pallid clay at both sites.

Trial establishment and design.

Seeds of the 400 families were sown between the first and third of February 2006 at Kalannie in Col-Max 64 cell trays and grown until June 2006. During that time, seedlings of adequate size were labelled with family identity. Severe frost in the nursery resulted in burning of apical shoots and phyllodes in the young Acacia seedlings. The majority of seedlings survived, but many sustained a significant set-back in growth. Retarded growth reduced the size and quality of seedlings available for planting and may ultimately affect survival in the field.

Once final numbers of seedlings for each seedlot were known, trial designs were generated using CycDesign 3.01 (CycSoftware 2006). Cycdesign outputs were then expanded into trial maps depicting field layouts. Using the trial maps, trial assembly plans were generated using an Excel macro TrayPack (Mazanec 2006). The macro translates the field map into a numbered sequence of trays each with the families arranged in appropriate order for planting. The trial maps are simultaneously annotated with tray number, deployment position on the ground and planting direction along the ripline or mound. Labelled seedlings were then pre-packed into trays in the correct sequence ready for planting in the field. Sufficient seedlings survived in the nursery to enable 398 families to be established at Kendenup and 380 families at Bolgart. All provenances were represented in both trials (Table 33 and Table 34).

Trials were established as nine replicate, latinised row-column designs. Families were established in four tree row plots. Spacing was 4m between rows and 2m within rows. The trial at Bolgart was planted in July 2006 and the trial at Kendenup was planted in August 2006.

Table 33. *Acacia saligna* trials - locations, numbers of families, replicates and total trees (excluding buffers).

Trial	Location	No. of Families	No. of Reps	No. of Trees/Plot	Total Trees/Trial
AS01	Kendenup	398	9	4	14,328
AS02	Bolgart	380	9	4	13,680
All Trials					**28,008**

Table 34. *Acacia saligna* trials - WA collections, subspecies, provenance and family allocations by site.

ProvNo	Subspecies [Provenance]	Variant	No. of Families by Site	
			WA Kendenup [AS01]	WA Bolgart [AS02]
1	ssp. *lindleyi* [Long Gully]	Typical	20	19
2	ssp. *lindleyi* [Muntagin]	Typical	20	19
4	ssp. *lindleyi* [Mingenew]	Typical	20	19
5	ssp. *lindleyi* [Ravensthorpe Elvardton Rd]	Typical	20	19
7	ssp. *lindleyi* [Murchison River]	Typical	20	20
11	ssp. *lindleyi* [Cantabilling Rd]	Typical	20	19
12	ssp. *lindleyi* [Arrowsmith River]	Typical	20	19
14	ssp. *lindleyi* [Parkeryeering Lake]	Typical	20	20
15	ssp. *lindleyi* [Kojonup - Boyup Rd]	Typical	19	19
18	ssp. *lindleyi* [Wannamal Lake]	Typical	19	19
19	ssp. *lindleyi* [Moora Miling Rd]	Typical	20	19
20	ssp. *lindleyi* [Darkan]	Typical	20	19
16	ssp. *pruinescens* [Palmer Block]	Tweed	20	17
17	ssp. *pruinescens* [Weinup]	Tweed	20	20
3	ssp. *saligna* [Lake Cooloongup]	Cyanophylla	20	19
6	ssp. *saligna* [Flynn Drive]	Cyanophylla	20	17
9	ssp. *saligna* [Bandy Creek Esp]	Cyanophylla	20	20
10	ssp. *saligna* [Bambun Rd Gin Gin]	Cyanophylla	20	19
8	ssp. *stolonifera* [Attwood Rd]	Forest	20	19
13	ssp. *stolonifera* [Grimwade]	Forest	20	19
20	**Totals**		**398**	**380**

Atriplex nummularia Trial Establishment

Site selection

Atriplex nummularia shows a preference for clay or clay-loam soils (Hall *et al.* 1972). It was important to select sites that were representative of the areas in which *A. nummularia* will be grown. Provenance/family trials were established on four sites (Table 35). Two trials were established on farmland (Lat 31° 36' Long 117° 27') near Tammin in Western Australia. The sites were chosen because they are representative of WA wheat belt soils on which saltbush might be planted and also owing to their proximity to experimental sites for which significant site characterization had been conducted (Norman *et al.* 2007). Mean annual rainfall in the area is about 317 mm. The first site was on non-saline land. The soil type is commonly associated with salmon gum and gimlet gum and consists of a shallow duplex comprising red sandy loam over clay. The saline site consists of a morrell soil (Norman *et al.* 2007). It is a shallow duplex soil comprised of grey alluvial sands over pallid clay. The water table is at an approximate depth of 1.2 metres and is highly saline. Shallow ground water salinity in adjacent experimental plots ranged from 22000 – 48000mgL^{-1}. (Norman *et al.* 2007). The third site was established at Monarto south east of Adelaide in South Australia (Lat. 35° 07' Long. 139° 07'). The soil at Monarto consists of sandy loams over red clay. The mean annual rainfall for

Monarto is 360 mm. The fourth site was established at Condobolin in New South Wales (Lat 33° 04’ Long 147° 14'). Soil is red clay. Mean annual rainfall is 439 mm.

Trial design and establishment

Improved germination of *Atriplex nummularia* seed is obtained by removing the bracteoles (Campbell and Matthewson 1992, Abu Zanat and Samarah 2005). Bracts were removed manually from each seedlot by technicians from the Department of Environment and Conservation in Western Australia and also the South Australian Research and Development Institute (SARDI). Western Australian seed lots were sown in Kalannie nursery during the first week of February 2006. Eastern Australian seed lots were sown in Kalannie nursery during the fourth week of February 2006. Owing to poor germination some seed lots were re-sown in mid-March 2006 to make up numbers.

Seed was sown into Col-Max 64 cell trays and grown until June 2006. During that time, seedlings of adequate size were labelled with family identity. Severe frost, which resulted in burning of apical shoots and phyllodes in the young acacia seedlings in the same nursery, had minimal effect on the saltbush seedlings. Once final numbers of seedlings for each seedlot were known, families were allocated to trials and trial designs were generated as for the *A. saligna* trials. Labelled seedlings were then pre-packed into trays in the correct sequence ready for planting in the field. Allocation of seedling numbers to trials is given in Table 35. The numbers of families per provenance allocated to each of the family trials is given in Table 36. All provenances were represented in the trials in Western Australia and Monarto. Insufficient seedlings were available to represent the Oodnadatta provenance in the trial at Condobolin (Table 36). The commercially available clone "cv. Eyres Green" was included in the trials as a control but will not be included in any breeding operations.

Trials were established as nine replicate, latinised row-column designs. Families were established in four tree row plots. Spacing was 3 m between rows and 1.5 m within rows.

Table 35. *Atriplex nummularia* trials - locations, numbers of families, replicates and total trees (excluding buffers).

Trial	Location	No. of Families	No. of Reps	No. of Trees/Plot	Total Trees/Trial
OMS01	Tammin Non-Saline	520	9	4	18,720
OMS02	Tammin Saline	500	9	4	18,000
OMS03	Monarto	528	9	4	19,008
OMS04	Condobolin	475	9	4	17,280
All Trials					**73,008**

Table 36. ***Atriplex nummularia*** **- collections, subspecies, provenance and family allocations by site.**

Provno	Subspecies [Provenance]	Collection State	No. of Families by Site			
			WA Tammin Non-saline [OMS01]	WA Tammin Salt (TS) [OMS02]	SA Monarto (MS) [OMS03]	NSW Condo-bolin [OMS04]
1	ssp. *spathulata* [Broad Arrow]	WA	19	20	20	19
2	ssp. *spathulata* [Eucla]	WA	20	20	20	20
3	ssp. *spathulata* [Mt. Jackson]	WA	20	19	20	19
4	ssp. *spathulata* [Lefroy]	WA	20	20	20	20
5	ssp. *spathulata* [Norseman]	WA	20	20	20	20
6	ssp. *spathulata* [Tableland]	WA	20	20	20	20
7	ssp. *spathulata* [Woorlba]	WA	20	20	20	20
8	ssp. *spathulata* [Southern Cross]	WA	20	20	20	20
9	ssp. *spathulata* [Yaringa]	WA	20	20	20	20
10	ssp. *spathulata* [Haig]	WA	18	18	19	17
11	ssp. *spathulata* [Zanthus]	WA	20	18	19	18
12	ssp. *nummularia* [Dareton]	NSW	18	17	17	14
13	ssp. *nummularia* [Broken Hill]	NSW	20	20	20	20
14	ssp. *nummularia* [Lake Frome]	SA	20	20	20	19
15	ssp. *nummularia* [Dalhousie Springs]	SA	18	17	18	16
16	ssp. *nummularia* [Oodnadatta]	SA	17	12	18	
17	ssp. *nummularia* [Trephina Gorge]	NT	19	18	19	17
18	ssp. *nummularia* [Glengyle Station]	Qld	18	14	19	11
19	ssp. *nummularia* [Innamincka]	SA	20	19	20	19
20	ssp. *nummularia* [Carinda]	NSW	13	12	19	12
21	ssp. *nummularia* [Moalie Park Station]	NSW	20	20	20	20
22	ssp. *nummularia* [Goodooga]	NSW	18	15	18	14
23	ssp. *nummularia* [Hatfield]	NSW	20	20	20	20
24	ssp. *nummularia* [Wilcannia]	NSW	20	20	20	20
25	ssp. *nummularia* [Moulamein]	NSW	21	20	21	20
26	ssp. *nummularia* [Rowena Station]	NSW	20	20	20	20
27	ssp. *nummularia* [Motpena Station]	SA	20	20	20	19
28	ssp. *nummularia* [cv. Eyres Green]	SA	1	1	1	1
28	**Totals**		**520**	**500**	**528**	**475**

Acacia saligna Preliminary Performance

Assessment of both trials for survival in 2007 determined overall survival as 84% for the *Acacia saligna* trial at Bolgart and 79.2% at Kendenup. Poorer survival at Kendenup is in part due to the burying of young seedlings by wind blown sand. A rescue operation aimed at digging out buried seedlings resulted in greater overall survival. Presence of *Uromycladium teperiannum* infection was assessed at the same time as survival at Bolgart. Subspecies *stolonifera* appears to have been the most susceptible to infection (Table 37) at the Bolgart site. Spatial plots of infected trees together with observations in the field, showed that the highest concentration of infection occurred in the area of fastest growth in the trial. It is likely that higher crown density restricted air movement and elevated relative humidity thereby providing better conditions for infection.

Overall survival was highest for *A. saligna* ssp. *saligna* at both sites. Murchison River provenance had highest survival on both sites and lowest percentage of trees infected with *Uromycladium*.

Table 37. *Acacia saligna* - first year survival at both sites and percentage of trees exhibiting disease infection at Bolgart by provenance (excluding buffer plants).

ProvNo	Subspecies [Provenance]	Survival		WA Bolgart *Uromycladium* infection
		WA Kendenup	WA Bolgart	
1 - 20	**All Plants (Mean)**	**79.2%**	**84.3%**	**13.7%**
	ssp. *lindleyi* (All provs, Mean)	*77.3%*	*82.5%*	*12.2%*
	ssp. *pruinescens* (All provs, Mean)	*72.5%*	*85.7%*	*9.5%*
	ssp. *saligna* (All provs, Mean)	*87.3%*	*88.8%*	*15.6%*
	ssp. *stolonifera* (All provs, mean)	*80.7%*	*84.4%*	*23.2%*
1	ssp. *lindleyi* [Long Gully]	80.8%	84.6%	22.5%
2	ssp. *lindleyi* [Muntagin]	84.2%	83.9%	14.0%
4	ssp. *lindleyi* [Mingenew]	71.8%	84.5%	7.9%
5	ssp. *lindleyi* [Ravensthorpe Elvardton Rd]	76.4%	85.2%	26.2%
7	ssp. *lindleyi* [Murchison River]	97.5%	95.3%	3.9%
11	ssp. *lindleyi* [Cantabilling Rd]	83.5%	77.8%	9.6%
12	ssp. *lindleyi* [Arrowsmith River]	94.3%	95.0%	12.9%
14	ssp. *lindleyi* [Parkeryeering Lake]	62.6%	78.9%	13.1%
15	ssp. *lindleyi* [Kojonup - Boyup Rd]	62.2%	73.0%	11.3%
18	ssp. *lindleyi* [Wannamal Lake]	76.9%	80.8%	11.7%
19	ssp. *lindleyi* [Moora Miling Rd]	75.0%	76.5%	6.4%
20	ssp. *lindleyi* [Darkan]	62.5%	74.3%	7.3%
16	ssp. *pruinescens* [Palmer Block]	68.2%	85.8%	11.3%
17	ssp. *pruinescens* [Weinup]	76.8%	85.7%	7.9%
3	ssp. *saligna* [Lake Cooloongup]	94.3%	93.4%	12.6%
6	ssp. *saligna* [Flynn Drive]	76.5%	81.7%	16.7%
9	ssp. *saligna* [Bandy Creek Esp]	91.7%	91.5%	26.3%
10	ssp. *saligna* [Bambun Rd Gin Gin]	86.5%	87.7%	6.6%
8	ssp. *stolonifera* [Attwood Rd]	84.2%	87.1%	34.8%
13	ssp. *stolonifera* [Grimwade]	77.2%	81.7%	11.5%

Atriplex nummularia Preliminary Performance

Five of the 9 replicate Old Man Saltbush plots at the Monarto and the Tammin salt sites were assessed for survival and biomass accumulation at 12 months of age in September 2007. Plants were visually assessed for standing biomass using the method termed the Adelaide technique by Andrew *et al.* (1979). Briefly, this approach requires taking a branch unit that is representative of the leaf size, density and branching structure within the plant to be measured. A count is then made of the number of these representative branch equivalents on each of the trial plants matching that branch type. At the same time, a count is made of the number of representative branch equivalents in a series of sacrificial standard plants that represent the range of plant sizes available in the population. These standards are later destructively sampled and separated into edible (leaf and fine stem < 3mm) and woody (all material > 3mm) biomass components, with green and dry biomass recorded. The counts of the branch equivalents for the standards are then regressed against their dry weights to produce a predictive equation, which can be used to estimate biomass in the trial plants based on the recorded branch counts for each individual.

The summary presented here is intended to provide a first look at the raw data without in-depth analysis. More detailed statistical analysis and estimation of genetic parameters will be reported elsewhere.

Overall, the survival of the subspecies '*nummularia*' was higher than subspecies '*spathulata*'. This trend was repeated at both trial sites but survival was higher at Monarto than at Tammin (Table 38). Survival in the first 12 months was also high for all of the provenances at both sites, ranging from 85% to 100% at Monarto and 92% to 100% at Tammin, although mean survival was again slightly higher at Monarto (Table 38).

The largest mean edible dry biomass figures were from the clone 'Eyres Green' at both the Monarto and Tammin sites, producing 1.32 and 1.92 t/ha/yr respectively. The next nearest provenance at Monarto was ssp. *nummularia* [Lake Frome] with 0.82 t/ha/yr, and at Tammin ssp. *nummularia* [Dareton] produced 1.01 t/ha/yr (Appendix 1). Biomass figures for the highest producing individuals in each provenance revealed a reduced dominance of cv. Eyres Green. Of the top 20 individual biomass plants at each site there were only 3 cultivar Eyres Green individuals suggesting good potential for selection of native germplasm that is equal to or better than the cv. Eyres Green.

In terms of biomass production at the subspecies level, subspecies *nummularia* consistently produced more edible dry biomass (t/ha/yr) than subspecies *spathulata* at this age (Fig. 38). Variability within a provenance was large with strong differences between the provenance mean and the largest individual in a *provenance* (Fig. 38). This trend was repeated across both sites, with mean edible dry biomass (t/ha/yr) being 0.70 and 0.47 at Monarto and 0.95 and 0.66 at Tammin for ssp. *nummularia* and ssp. *spathulata* respectively. Provenance means at Tammin were also larger than the same provenance at Monarto (Table 38). The Tammin site has a saline water table at 1.2m below the surface so plants at this site would most likely have had access to this extra water within the first year of development. Rainfall differences over this time were only small.

Because selections of improved germplasm would focus on these better performing individuals we utilised a simple metric to explore variations in productivity levels within each provenance. This productivity difference ratio shows the proportional difference between the most productive individual and the mean productivity value for all plants within that provenance. It is simply calculated by dividing the maximum edible biomass producing individual from a provenance by the average edible biomass figure for that provenance at each site.

This metric is an indicator of maximum increase in yield (expressed by an individual) above the mean within a particular provenance (see Fig. 38). The greatest positive value, relative to the mean was for ssp. *nummularia* [Glengyle Station] from south-western Queensland, which had the largest individual at 6.3 times the provenance mean (Fig. 39). In general, the ratio was larger for ssp. *nummularia* than for ssp. *spathulata*, although there were some exceptions in the Lefroy and Haig provenances, which ranked at 3rd and 11th of the 28 provenances with values of 5.13 and 3.88 times the mean respectively (Fig. 39). As may be expected, the clonal cv. Eyres Green displayed the least amount of variability in biomass production around the mean, having the lowest ratio value in the trial at 2.23.

While our simple ratio gives a good indicator of the productive variations within a provenance, one of the aims of selection will be to maximise overall productivity rather than the productivity relative to the mean of a single provenance. For example, achieving a large increase within a provenance with a small mean may still not give as much resulting biomass as a small advancement from a provenance that has large mean biomass productivity rate. Therefore a second simple metric of within provenance productivity difference (i.e. difference between the largest individual in a provenance and the average of that provenance) was calculated for each provenance and site.

The within provenance productivity difference results in a general separation of the two subspecies (Fig. 40), primarily due to the larger mean values and propensity for variation around this mean, of ssp. *nummularia* (see Fig. 38). The only exception to this was ssp. *spathulata* [Lefroy], which ranked at 8th highest potential value. The ssp. *nummularia* [Glengyle Station] provenance again achieved highest ranking with a score of 1.84 kg/plant. These results indicate the exciting potential to be gained from individual selections within our collection of wild germplasm.

Fig. 38. Edible dry biomass average of provenance by trial site, and difference to most productive individual.

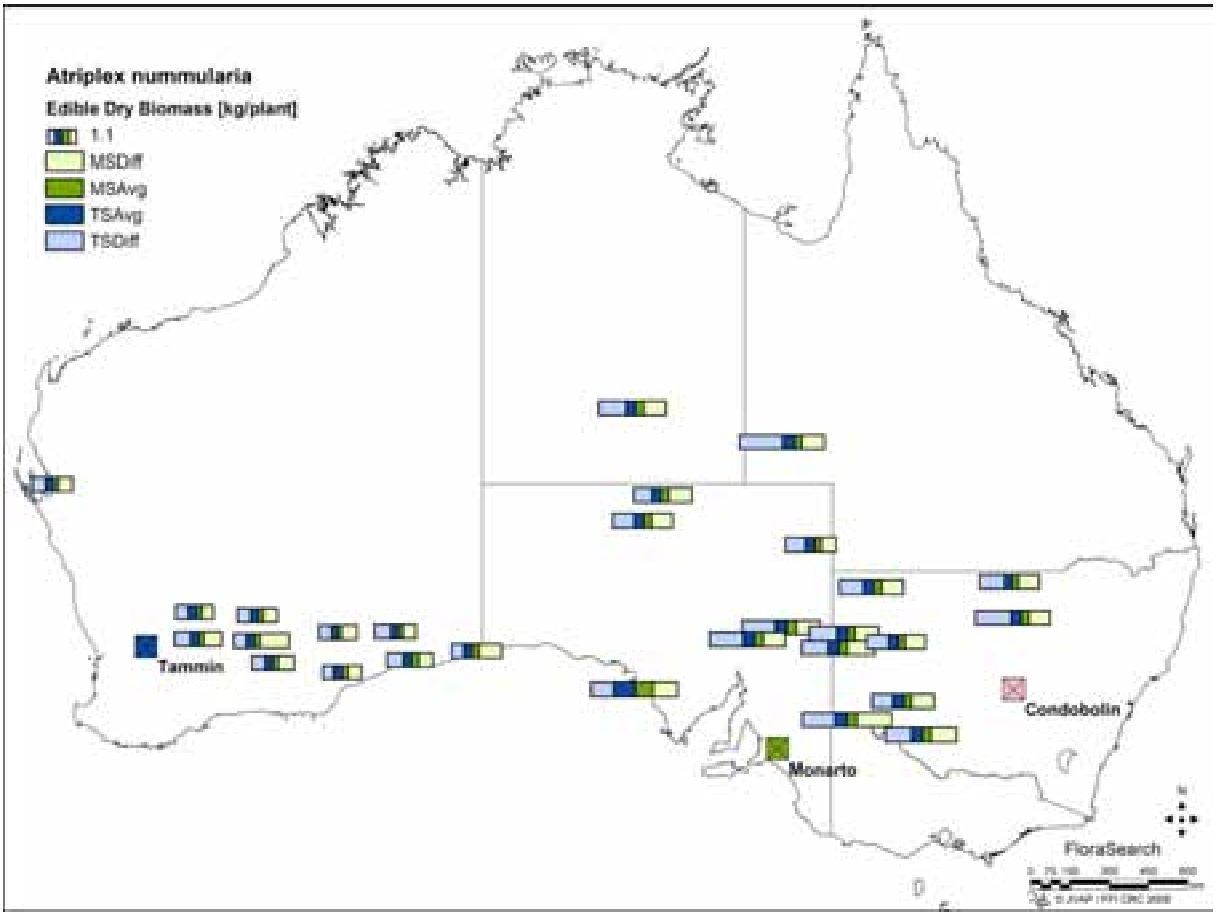


Table 38. Atriplex *nummularia* - survival, height, crown width and productivity of 1 year old subspecies and provenances (planted 2006) at Monarto South dryland (MS) and Tammin saline (TS) trial sites in 5 replicates assessed in 2007.

		Survival		Height [m]		Crown Width [m]		Green Biomass [t/ha/yr]		Edible Dry Biomass [t/ha/yr]	
ProvNo	**Subspecies [Provenance]**	**MS**	**TS**	**MS**	**TS**	**MS**	**TS**	**MS**	**TS**	**MS**	**TS**
1 - 28	**All provs**, mean (n=28)	**98.2%**	**95.3%**	**0.55**	**0.59**	**0.55**	**0.74**	**3.76**	**5.27**	**0.61**	**0.84**
	Range	*85*-100%	*92*-100%	*0.37*-0.86	*0.41*-0.90	*0.37*-1.03	*0.48*-1.36	*1.84*-8.86	*2.73*-14.79	*0.36*-1.32	*0.51*-1.92
12 - 28	**ssp. *nummularia***, Mean (n=17)	**98.2%**	**95.7%**	**0.64**	**0.67**	**0.62**	**0.84**	**4.56**	**6.34**	**0.70**	**0.95**
	Range	*85*-100%	*92*-100%	*0.56*-0.86	*0.61*-0.90	*0.50*-1.03	*0.68*-1.36	*3.31*-8.86	*4.47*-14.79	*0.51*-1.32	*0.68*-1.92
1 - 11	**ssp. *spathulata***, Mean (n=11)	**98.2%**	**94.7%**	**0.42**	**0.46**	**0.44**	**0.58**	**2.54**	**3.62**	**0.47**	**0.66**
	Range	*96* -99%	*92*-97%	*0.37*-0.45	*0.41*-0.50	*0.37*-0.50	*0.48*-0.62	*1.84*-3.27	*2.73*-4.03	*0.36*-0.60	*0.51*-0.74
12	ssp. *nummularia* [Dareton]	98.2%	92.1%	0.63	0.67	0.68	0.94	5.14	6.63	0.79	1.01
13	ssp. *nummularia* [Broken Hill]	99.3%	98.0%	0.66	0.69	0.58	0.80	4.48	6.39	0.70	0.97
14	ssp. *nummularia* [Lake Frome]	98.8%	94.3%	0.65	0.66	0.65	0.82	5.25	6.38	0.82	0.98
15	ssp. *nummularia* [Dalhousie Springs]	99.2%	95.6%	0.61	0.63	0.63	0.80	4.44	5.04	0.68	0.77
16	ssp. *nummularia* [Oodnadatta]	98.9%	93.8%	0.59	0.61	0.61	0.80	4.08	5.48	0.63	0.84
17	ssp. *nummularia* [Trephina Gorge]	98.9%	93.3%	0.64	0.69	0.59	0.80	4.29	5.43	0.66	0.83
18	ssp. *nummularia* [Glengyle Station]	99.5%	96.4%	0.61	0.71	0.58	0.90	3.85	6.40	0.59	0.98
19	ssp. *nummularia* [Innamincka]	97.8%	96.8%	0.60	0.65	0.55	0.84	3.45	5.46	0.54	0.83
20	ssp. *nummularia* [Carinda]	99.5%	94.6%	0.64	0.66	0.55	0.73	4.35	5.70	0.67	0.87
21	ssp. *nummularia* [Moalie Park Station]	99.5%	96.5%	0.64	0.67	0.61	0.84	4.44	5.72	0.68	0.87
22	ssp. *nummularia* [Goodooga]	99.4%	94.3%	0.56	0.62	0.50	0.68	3.31	4.47	0.51	0.68
23	ssp. *nummularia* [Hatfield]	98.3%	96.0%	0.64	0.67	0.54	0.79	4.03	6.30	0.62	0.96
24	ssp. *nummularia* [Wilcannia]	99.3%	95.8%	0.62	0.65	0.52	0.74	3.82	5.27	0.59	0.81
25	ssp. *nummularia* [Moulamein]	98.8%	95.8%	0.69	0.68	0.59	0.78	4.90	6.11	0.75	0.94
26	ssp. *nummularia* [Rowena Station]	99.0%	97.5%	0.63	0.66	0.59	0.82	4.03	6.08	0.62	0.93
27	ssp. *nummularia* [Motpena Station]	99.8%	96.0%	0.59	0.61	0.66	0.84	4.78	6.21	0.75	0.95
28	ssp. *nummularia* [Eyres Green]	85.0%	100.0%	0.86	0.90	1.03	1.36	8.86	14.79	1.32	1.92
1	ssp. *spathulata* [Broad Arrow]	96.3%	94.0%	0.42	0.48	0.43	0.57	2.34	3.57	0.44	0.65
2	ssp. *spathulata* [Eucla]	98.8%	96.3%	0.44	0.48	0.49	0.62	3.17	4.02	0.58	0.73
3	ssp. *spathulata* [Mt. Jackson]	97.8%	92.4%	0.43	0.50	0.41	0.61	2.27	3.87	0.42	0.71
4	ssp. *spathulata* [Lefroy]	98.8%	95.3%	0.43	0.46	0.44	0.58	2.59	3.69	0.48	0.67
5	ssp. *spathulata* [Norseman]	99.0%	94.8%	0.45	0.48	0.44	0.56	2.60	3.44	0.48	0.63
6	ssp. *spathulata* [Tableland]	98.8%	96.8%	0.43	0.46	0.50	0.62	3.27	4.03	0.60	0.74
7	ssp. *spathulata* [Woorlba]	99.3%	94.3%	0.45	0.49	0.46	0.60	2.99	3.91	0.54	0.72
8	ssp. *spathulata* [Southern Cross]	97.5%	94.5%	0.43	0.47	0.44	0.58	2.44	3.52	0.46	0.65
9	ssp. *spathulata* [Yaringa]	98.0%	96.5%	0.40	0.44	0.42	0.58	2.26	3.58	0.43	0.66
10	ssp. *spathulata* [Haig]	98.4%	93.9%	0.39	0.45	0.42	0.59	2.14	3.46	0.40	0.63
11	ssp. *spathulata* [Zanthus]	98.2%	93.3%	0.37	0.41	0.37	0.48	1.84	2.73	0.36	0.51

Fig. 39. Within provenance average (2 sites) productivity difference ratio of edible dry biomass per plant (Maximum Individual / Provenance Average, mean of 2 sites).

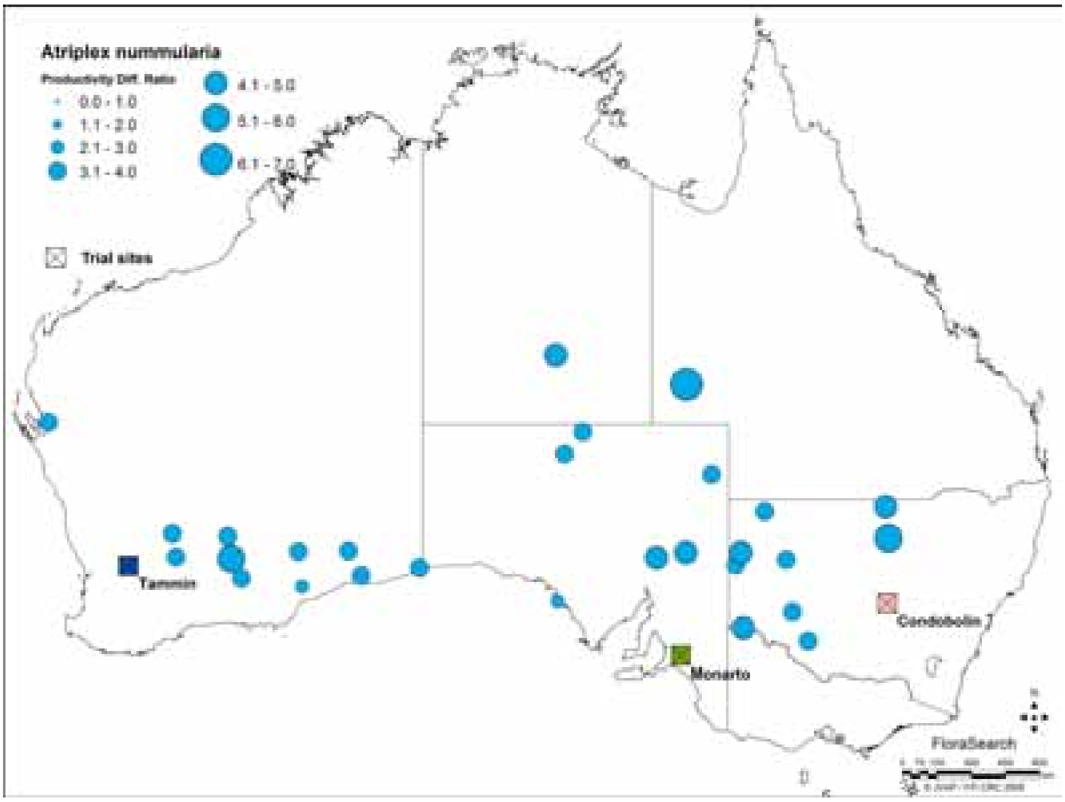
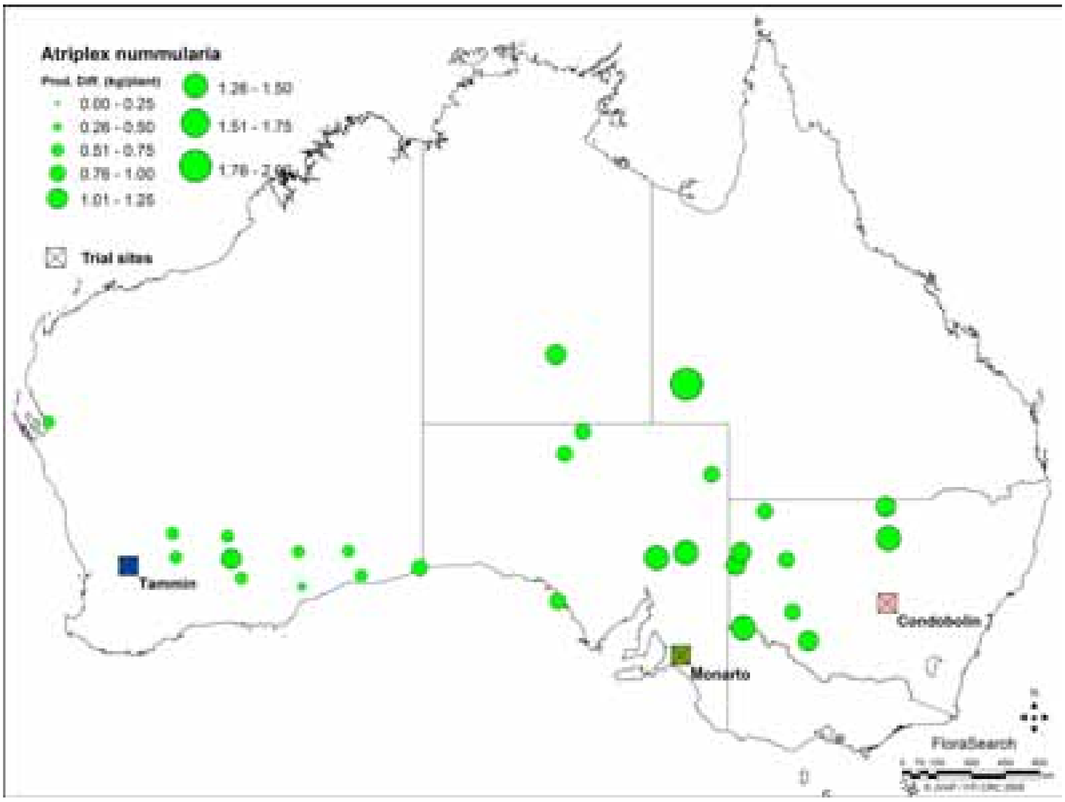


Fig. 40. Within provenance average (2 sites) productivity difference by provenance of edible dry biomass per plant (Maximum Individual - Provenance Average, mean of 2 sites).



Future Evaluations

Collections of leaf material have been taken from each of 487 Old Man Saltbush families at the Monarto site and these are awaiting analysis for nutritional components by CSIRO Livestock Industries in Perth. The aim is to use Near Infra Red (NIR) analysis and wet chemistry on a selected sub sample to examine nutritional characteristics and help to develop reliable calibrations that will enable the rapid assessment of nutritional components using the NIR technique. The next stage of evaluations for Old Man Saltbush will involve a sheep grazing preference trial in late Autumn of 2008. The Tammin salty, Monarto, and Condobolin sites will be grazed at low and medium intensity to examine sheep preference and palatability. Plants will be scored using visual estimates of the degree of grazing and re-examined the following autumn to score the regrowth potential. Further leaf material will be collected from a range of individuals that represent the continuum of sheep preference from untouched to highly preferred. This leaf material will then be analysed with the goal of identifying measurable nutritional components that will be useful as predictors of palatability by sheep.

Following these trials the selection of a range of individuals will be made and the breeding program will continue as outlined by Mazanec in Section 4 of this report.

Discussion and Recommendations

Acacia saligna

First year survival of *A. saligna* was very good considering the extremely dry winter and sand drift problems encountered at the Kendenup site. Long term effects of *U. tepperiannum* on biomass production and survival will be critical in determining the success of the species in commercial settings. Bi-annual assessment of number of trees infected together with level of infection sustained by each tree will give good insight into the genetic basis of resistance.

Atriplex nummularia

Initial survival and productivity assessments have revealed that Old Man Saltbush is indeed a very hardy and resilient shrub in low rainfall conditions. Variation within and between provenances was wide, with productivity of a number of individual plants equal to or better than the best individuals of the commercial clone Eyres Green. This does suggest that substantial improvements biomass can be made through judicious selections of highly productive individuals.

It should be noted that biomass allocation is only one component of a successful fodder plant. Nutritional content and livestock preference are two very important components for which we still have limited understanding. The planned future evaluations at the existing trial sites should make significant contributions to our understanding in these areas and enable us to make successful selections for plant improvement.

6. Conclusion and Future Directions

Michael Bennell[1,2], Trevor J. Hobbs[1,2] and John Bartle[2,3]

[1] Department of Water, Land and Biodiversity Conservation, Urrbrae SA 5064
[2] Future Farm Industries Cooperative Research Centre, Crawley WA 6009
[3] Department of Environment and Conservation, Bentley WA 6983

Engagement with industries that market wood based products and can utilise this new source of feedstock is critical. The potential markets and products can best be considered in 3 broad categories:

1. Existing larger scale markets that are largely commodity based, (e.g. pulp and export wood chip) that are well developed, have been operating for a significant period and have well developed supply chains from traditional forestry operations;

2. Existing smaller scale and 'niche' markets that are generally developed but operate on a smaller scale (e.g. firewood, fibreboard products, forage, Eucalyptus oil); and

3. Emerging markets that are still developing with supply and demand channels not well established (e.g. carbon sequestration and bioenergy).

Product options are broadened in scope as government policy and commercial opportunities related to climate change mitigation and adaptation become more significant. For example, introduction of an Australian emissions trading scheme proposed for 2010 and is expected that carbon sequestration would be counted as an offset against fossil fuel emissions (DCC 2008a,b,d). Similarly, the Australian government is committed to a national renewable energy target of 20% by 2020 which will promote the adoption of alternative energy sources including those sourced from biomass (DCC 2008c). At a national and international scale significant amount of research and development funding is being invested to bring new technologies online many with the capacity to transform our agricultural and industrial landscape.

Biomass as an alternative feedstock for electrical energy generation, and transport fuel production from second-generation biofuels technology provides benefits in offsetting fossil carbon release to the environment. It is a renewable energy source that provides a positive multiplier of energy gained over the energy used to produce it. Initially new development in this area will probably be largely focused on wood waste from forestry industries but this is expected to be the first step in industry shaped by changing policy and growing demand for feedstock as new technology becomes available. As the scale of demand increases dedicated biomass crops will be an obvious source of supply.

Forage production using mixtures of species and based on native shrubs such as Old Man Saltbush has been highlighted as a viable option worthy of ongoing development. The concept is accepted in the farming community to some extent, and it can fit into the existing livestock industry. It also has great potential as part of strategies for adaptation to the drying trend in the more marginal part of the southern Australian farming regions. Building from research within the FloraSearch project, and through synergies with other research within the Future Farm Industries CRC and CSIRO Livestock Industries, this fodder shrub-based research had sufficient merit to win support for funding and development of a separate project (Enrich) where these fodder shrub species and production systems will be explored further.

Species Evaluations

Priority Species

Our research identifies several high priority species for future research, development and domestication as new woody biomass crops in lower rainfall regions of southern Australia. The highest priority species for domestication include Koojong Wattle (*Acacia saligna*), Old Man Saltbush (*Atriplex nummularia*) and Blue Mallee (*Eucalyptus polybractea*. Other strong candidates are Sugar Gum (*E. cladocalyx*), Flat-topped Yate (*E. occidentalis*), Flooded Gum (*E. rudis*), Mallee Box (*E. porosa*), Smooth-barked York Gum (*E. loxophleba* ssp. *lissophloia*) and Rough-barked Manna Gum (*E. viminalis* ssp. *cygnetensis*). These species, and several less well-known potential candidates, may gain further momentum from our current research and trials on provenances variations within this group of species.

Species trials - early results

Comprehensive trials of prospective species were established across southern Australian in 2004 and 2005. Early results can sometimes be misleading as some species that initially grew strongly in the 2004 trials such as *Viminaria juncea*, have more recently deteriorated once the soil moisture stores were depleted. However, several hardy mallee species (e.g. *Eucalyptus loxophleba*, *E. porosa*, *E. polybractea*) initially grew slowly but are now strong and persistent biomass producers. The species with the best survival and productivity rates across most sites have been considered favourably for development as their ability to persist widely in drier conditions reduces the economic risk over the life of a plantation.

Eucalyptus camaldulensis, *E. cladocalyx*, *E. polybractea* and *E. occidentalis* have a reputation for being hardy and productive in a wide range of climate and soil conditions. They have been included in several past trials and studies (Kiddle 1987, Eastham et al. 1993, Wildy 2000a) and results from our field trials support these earlier species selections for farm forestry potential. Applying new allometric relationships (Hobbs *et al.* 2006) to data previously collected on other sites has confirmed that many of these species are productive (above-ground plant biomass/ha/year) across a range of sites. The potential of several new candidates (e.g. *Acacia saligna, Atriplex nummularia, Eucalyptus loxophleba* ssp. *lissophloia, E. petiolaris, E. rudis, E. viminalis* ssp. *cygnetensis*) are also confirmed. Their generally consistent performance across these trials strengthens the case for further development for short-rotation crops and provides a benchmark for performance of new species trialled. With such a large target area and limited resources it was inevitable that not all soil types or climatic zones could be represented within the trials. *Eucalyptus gomphocephala* is an example of a species that has performed extremely well in the 2005 trials at Murray Bridge, but has only been included at 1 site suggesting that more extensive work is warranted to predict the species performance of additional options over a wider range of sites.

Future directions

More reliable evaluations will be gained as the trees and mallees mature, and the differences in germplasm between and within species may become more apparent. The use of early evaluations can enable fast-tracking of selections, reduce the cost of plant improvement programs and promote the process of developing commercially viable cultivars. However, we acknowledge that more reliable evaluations would be gained from assessments made closer to their age of harvest. The continued periodic assessment (~3 year interval) of these trials is required. Selections of the most productive and hardy germplasm can then be made and germplasm advanced into breeding programs and clonal cultivar production.

Our research has already identified several species with widespread potential (“Generalists”) for agroforestry in lower rainfall regions of southern Australia. We have also noted several species that are more regional or soil specific in their application (“Site specialists”) and these have the potential to be more productive in some environments than “generalist” species. However, these “Site specialists” require more detailed assessments of site characteristics (e.g. soils, climate) to match individual species’ requirements.

Although the 2004 trials were not specifically designed to measure differences in subspecies and provenance growth rates, the trials did include multiple sets of germplasm for some species. Two subspecies of the fast growing species, *Acacia saligna,* were included at several sites. At these sites *Acacia saligna* ssp. *saligna* consistently out performed (+21%) *Acacia saligna* ssp. *lindleyi.* This variation between germplasm of the same species is also illustrated by *Atriplex nummularia* at Murray Bridge, where the clone cultivar ‘Eyres Green’ almost doubled the productivity of the Yando provenance. These examples show the potential productivity gains that can be achieved by examining subspecies and provenance variations to locate the best germplasm for woody crop breeding and development.

Many of the species in this study have not been examined from an integrated tree processing plant (ITP) viewpoint in the past, particularly those from eastern Australia. The opportunity exists to select some of the better performers from this study and examine them more closely. Species like *Eucalyptus bakeri, E. porosa* and *E. odorata* could well prove outstanding candidates for ITP industries in the future producing both renewable energy and industrial solvents to replace the petroleum based solvents in use today. Wildy *et al.* (2000a) found that different species of mallee best suited particular niches and climatic zones. His work suggests that a suite of oil mallee species would need to be developed to select different species to match environments not suited to current oil mallee candidates. Our results from the single Currency Creek Arboretum site can only give an indication of what species may prove productive in cultivation, but this work suggest some of the species should be well suited to sites with similar soils and climates to our study location. *Eucalyptus cneorifolia,* a species that occurs naturally in southern areas of SA has a history of use in the *Eucalyptus* oil industry. In sampling of this species, total eucalyptus oil rates varied from 4.7 to 2.0 % leaf oil and 2.1 to 0.56% cineole content by fresh weight, demonstrating the wide variation possible within species and the need for selection of germplasm.

Building on these early results the FloraSearch program aims to progress the domestication of several of the species, including *Acacia saligna* and *Atriplex nummularia.* These 2 species have been established in provenance/family trials with *Atriplex nummularia* at sites in SA, NSW and WA and *Acacia saligna* in WA only. Plant improvement strategies have been developed for these 2 species and ongoing support is being sought to continue work through to the development and release of cultivars. *Acacia saligna* is primarily a tree crop for production of biomass but with some potential for forage. Particular challenges exist due to the potential impact Gall Rust fungus on biomass production and may influence adoption of the species for commercial use. *Atriplex nummularia* is a forage species with minor challenges for the development of increased palatability and improved feed values for livestock.

There is therefore opportunity to commence genetic improvement for these species and to expect rapid genetic advance. Investment in genetic improvement and availability of superior planting material would be seen as a major attraction to adoption by growers and an excellent opportunity for investors to become the holder of potentially valuable plant breeder’s rights in a new set of industries.

WA DEC, ALRTIG and some small breeders with a focus on *Eucalyptus polybractea* have undertaken pioneer work on genetic improvement but there is a good prospect that these parties can be drawn into a new round of national scale collaborative breeding. Such a national breeding consortium, coinciding as it may with the major new forces of climate change, the emergence of bioenergy and quickening structural change in agriculture, could become a prominent driver to the rapid emergence of woody crops.

Future research on Old Man Saltbush (*Atriplex nummularia*) is being conducted within the Future Farm Industries CRC's Enrich project. This project is also investigating other notable fodder species including *Atriplex amnicola*, *A. rhagodioides* and *A. cinerea* and is evaluating mixed species fodder systems, planting designs, and on-ground implementation and adoption.

Reducing the Cost of Establishment

With increasing prospects for woody crops as a strategy of agricultural adaptation and enviromental adjustment the development of cost-effective and reliable methods for plant establishment are essential. Revegetation is being targeted at harsh and highly variable environments where risk of failure can be high (e.g. retired irrigated land in north-central Victoria), salt affected soils and in the marginal agricultural areas. For fine-seeded species establishment from nursery grown seedlings is commonly prefered because of the reduced risk of failure and the opportunity for regular spacing. Since many of the prospective commercial species are fine-seeded (*Eucalyptus* spp*., Atriplex* spp., *Rhagodia spp.)* improvement of direct seeding methods with reduced establishment costs would be a valuable contribution to adoption of new land-use practices based on woody perennials.

A recent review of direct seeding (Carr et al. 2005) revealed a focus on regionally-based methodological knowledge, with a poor understanding of the principles and processes to support translation of the current experience to new sites and conditions. This highlights the need to improve establishment methods to result in significant gains in establishment success and production. A detailed scientific understanding of seed germination and establishment through knowledge of seed physiology and interactions between the seed, soil and climatic conditions combined with extensive field testing will lead to significant technological improvements.

Recommendations

Future research is recommended with the following aims:

- Undertaking research to understand the interaction of seed physiology, soil physical and chemical conditons, and climatic conditions and the impact on the probability of successful establishment 6 months after sowing.

- Incorporate these results in applied field application to develop an advanced approach to direct seeding that significantly reduces the risk of failure at a much reduced cost compared with current methods.

Woody Crop Production Systems

Future research aims to provide improved plant production systems and harvest methods to meet emerging markets. However, the question remains as to where to place these new systems in highly variable landscapes and how to optimise returns while retaining the most productive aspects for traditional cropping whilst integrating new options. Economic analysis will need to include all of the direct tangible costs and benefits in order to evaluate returns to investors. This can be applied to alternative uses for land at the farm and regional scale so that the best options are selected while accounting for opportunity costs. The adoption challenge will be optimising landowner returns whilst selectively adopting new crop options and managing risks and uncertainties around new land use options.

Economic evaluation of new crop opportunities requires reliable estimates of productivity (e.g. harvestable yield and carbon accumulation). While there is a long tradition of forest growth modelling, accurate predictions in the dryland agricultural belt are still undeveloped. In lower rainfall regions the spatial variations of climate, soils and hydrological processes have an even greater influence on woody crop productivity.

We need to explore and evaluate the potential and optimum spatial arrangement of a range of innovative woody crop systems suited to the dryland cereal cropping. The decisions will be driven by economic analyses at the farm level for different rainfall zones, based on a analysis of key factors (markets, returns and industrial infrastructure) and processes that influence the productive and carbon sequestration potential of our farming landscapes (eg. climate, soils, water use and species selection). A better understanding of spatial variations in crop production, and processes to identify optimal farming system designs in variable landscapes needs to be developed.

Yield mapping from precision agriculture has shown that significant proportions of cropland effectively produce low to negative returns. Spatial differences in yield can be of an order of magnitude and this spatial variation presents an opportunity for optimisation. This suggests a potential for adaptation of current systems by targeting those sites with low returns and exploring the potential gains that can be made by alternative woody crop options. Through a better understanding of the optimal productive arrangement of annual and woody crops in a farming enterprise issues of competition with woody crop options can be avoided and reduce opportunity costs to existing landuses. New farming system metrics that are location specific potentially provide for a substantial economic benefit as placement of new options in the landscape considered. Future work will also provide a greater capacity for location-specific economic analysis and provide results on profitability of different spatial scenarios (general economic viability of woody perennials, feasibility to utilise fine-scale pattern of negative or low economic return from annuals to suggest placement of woody crops, minimum size of profitable woody crop establishments and others).

One production system approach, widely applied to mallee plantings in WA, is the use of crop alley - tree belt designs to maximise water harvesting and production of woody crops in annual cropping districts. An investigation of the economics of belts in crop systems (Cooper et al. 2005) showed that for the mallee crop to break even with conventional annual plant agriculture belt designs would need to efficiently exploit lateral flows of surface and shallow surface water to achieve sufficient yield. This approach needs to consider land lost to production and the potential reduction in annual crop performance in areas adjacent to belts and windbreaks (Jones and Sudmeyer, 2002, Bennell and Cleugh 2002, Cleugh 2003). Research into belt plantings as part of the National Windbreaks Project showed that belts as windbreaks may not economically viable in many situations (Jones and Sudmeyer 2002) and careful consideration must be given to understanding site attributes to achieve successful and profitable outcomes.

Improvements in productivity are thought to be achievable following Future Farm Industry CRC research showing that mallees have high water use potential and display a strong yield response to extra water. Several workers have shown that considerable vertical (>10 m) and horizontal depletion (up to 20 m) of soil water in the root zone of mallee belts can occur on a wide range of soils (Harper *et al.* 2008, Sudmeyer and Goodreid 2007). Mallee belts appear to have the capacity to create a substantial sink for surplus water and, if water is available to recharge that sink, to respond with higher water use and greater yield. The water use attributes of mallee are likely to be shared to a substantial degree by other eucalypt tree crops. In some situation there will be potential to manipulate water sources and sinks to capture extra water to achieve yield increases. Lateral flows of shallow subsurface water can be captured by belts or on the surface by grade banks and diverted to belts or small block plantings.

There is concern that loss of productive land to biomass crops will undermine the capacity for food production. Integrating novel crops into the agricultural landscape so that the most productive lands for traditional crops are retained and enhances will be a key target to aim for. Climate change adaptation will need to be included in planning of new production systems.

Recommendations

We need to develop a predictive understanding of how woody perennials will perform in landscapes which may vary strongly in space and time and make informed decisions through farm level economic analysis. This must aim for optimal arrangements of traditional and new crops in these landscapes, the net carbon sequestration of such arrangements helping to prepare farmers for participation in future carbon emissions trading or offset schemes as well as dealing with long standing environmental challenges of dryland salinity and soil erosion. Key points to be addressed by future research include:

- Identification of modelling needs and data availability for estimating spatial and temporal scales of profitability and measuring essential biological processes;

- Identification of target zones on the basis of rainfall and cropping profitability (extent of areas ~50km). Matching species and new crop options to appropriate parts of the landscape;

- Test profitability and feasibility of spatial mix of different land uses;

- Develop decision making models and tools for location specific economic analyses of woody crop options based on yield predictions under a range of climate change, market and policy scenarios as compared with a range of other future farm industry options;

- Estimate carbon pools and fluxes, requiring increased process understanding on climate and soil influences on the suitability and productivity of plant species selected for development as new woody crops;

- Develop plant and water interactions in variable landscapes.

- Create predictive capacity of biomass productivity, carbon sequestration rates and carbon dynamics in woody crop systems (carbon metrics).

Conclusion

There are many significant drivers for the ongoing research and development of woody crops in Australia. There are challenges on many fronts of plant selection and improvement, improving the effectiveness and efficiencies of establishing and managing woody crops for improved economic viability, and spatially and economically optimising the blend of conventional agricultural landuses with new woody crop options.

A well funded and supported FloraSearch research team and its evolution within the Future Farm Industries Cooperative Research Centre, and beyond, will continue to develop the prospects of broadscale commercially-viable, adaptable and sustainable woody crop species and production systems that benefit a diverse array of Australian landscapes, industries, communities and our natural environment.

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Appendix A. – Field Trials of Woody Germplasm Preliminary Results

Table 39. Survival, height, crown width and productivity of 3 year old short cycle plants (planted 2004) at MurrayBridge (MB), Roseworthy (RW), South East - Lucindale (SE), Rutherglen (RG), Coorow (CR) and Toolibin (TB) trial sites.

	Survival @ 3 years						Height @ 3 years [m]						Crown Width @ 3 years [m]						Green Biomass [t/ha/yr]					
Species [Provenance]	**MB**	**RW**	**SE**	**RG**	**CR**	**TB**	**MB**	**RW**	**SE**	**RG**	**CR**	**TB**	**MB**	**RW**	**SE**	**RG**	**CR**	**TB**	**MB**	**RW**	**SE**	**RG**	**CR**	**TB**
Short Cycle (3 x 1.5 m; 2222tph)																								
Acacia aneura [Glendambo]	14%						0.16						0.10						0.00					
Acacia bartleana [Dandaragan]					86%	61%					4.59	2.55					1.76	1.29					15.69	4.35
Acacia deanii ssp. deanii [Biloela]	82%						1.48						0.74						1.77					
Acacia lasiocalyx [Muntadgin]	39%				75%	80%	0.82				3.86	2.99	0.50				2.34	1.85	0.34				19.43	11.35
Acacia leucoclada [ATSC]	66%	85%	98%	97%			0.48	1.99	1.78	2.85			0.24	1.26	1.17	1.29			0.15	5.22	5.84	7.49		
Acacia mearnsii [Bungendore]	25%						2.77						1.48						2.28					
Acacia melanoxylon [Mt. Compass]	42%						0.95						0.35						0.20					
Acacia pycnantha [Kuipto]	94%	67%	33%	4%			1.33	2.19	1.67	2.65			0.91	1.51	1.58	1.39			2.24	5.27	2.44	0.38		
Acacia pycnantha [McLaren Flat]	99%						1.69						1.26						4.65					
Acacia pycnantha [Onka NP]	93%						1.48						0.97						2.69					
Acacia retinodes var. retinodes (hill form) [Bull Creek]	75%			82%			1.40			3.53			0.74			1.56			1.56			9.80		
Acacia retinodes var. retinodes (hill form) [Clare/Spalding]	63%	89%					1.00	2.76					0.51	1.69					0.60	10.41				
Acacia retinodes var. retinodes (hill form) [Eden Valley]	91%						1.44						0.97						2.68					
Acacia retinodes var. retinodes (swamp form) [BSC]	53%	76%	27%	52%			2.09	2.60	3.71	3.50			1.27	1.81	2.97	1.87			3.02	9.08	9.45	8.02		
Acacia salicina [Condobolin]	90%						0.61						0.46						0.50					
Acacia salicina [Mambray Creek]	92%	90%		6%			0.69	1.19		2.13			0.52	1.08		1.03			0.68	2.66		0.24		
Acacia salicina [SFMB]	80%						0.43						0.27						0.12					
Acacia saligna ssp. lindleyi [Parkeyerring]	98%	73%	92%	97%	59%	69%	2.40	2.86	2.68	4.02	3.84	2.70	1.46	1.73	2.07	2.43	2.06	1.69	7.88	9.54	16.94	25.17	12.25	7.56
Acacia saligna ssp. saligna [Mandurah]	98%				69%	76%	2.08				3.44	2.30	1.65				2.22	1.91	9.01				14.76	8.97
Acacia victoriae [Copley]	85%						0.47						0.62						0.55					

Species [Provenance]	Survival @ 3 years						Height @ 3 years [m]						Crown Width @ 3 years [m]						Green Biomass [t/ha/yr]					
	MB	RW	SE	RG	CR	TB	MB	RW	SE	RG	CR	TB	MB	RW	SE	RG	CR	TB	MB	RW	SE	RG	CR	TB
Agonis flexuosa [Esperance]						42%						1.05						0.87						0.75
Allocasuarina huegeliana [Beverley]					82%	57%					3.34	2.39					1.42	1.08					8.08	2.82
Allocasuarina huegeliana [Toolibin]						67%						2.03						1.08						3.20
Alyogyne hakeifolia [Salmon Gums]						65%						2.16						1.83						6.70
Alyogyne huegelii [Yorke Peninsula]	31%			0%			0.83						0.68						0.49					
Atriplex *nummularia* [Eyres Green]	99%						1.48						2.50						16.75					
Atriplex *nummularia* [Yando]	99%	97%	47%	99%	86%	12% {93%}	1.45	1.74	1.29	1.50	1.22	1.49 {0.80}	1.81	2.48	1.35	1.43	1.12	1.68 {0.54}	10.31	18.13	3.06	9.69	3.89	1.06 {1.16}
Bursaria occidentalis [Mullewa]					1%	0%					1.50						0.78						0.02	
Callitris gracilis [Murray Bridge]	96%	100%					0.65	1.08					0.33	0.76					0.26	1.56				
Casuarina obesa [Salt Creek]	86%						1.07						0.66						1.12					
Casuarina obesa [Yornaning]					97%	80%					2.23	2.05					1.39	1.29					6.82	4.65
Codonocarpus cotinifolius [Goodlands]	0%																		0.00					
Codonocarpus cotinifolius [Youanmi]					0%																		0.00	
Codonocarpus cotinifolius [Youanmi]	0%																		0.00					
Dryandra sessilis [Kendenup]						21%						1.49						0.87						0.46
Eucalyptus baxteri [Willunga]	20%						0.97						0.69						0.24					
Eucalyptus bridgesiana [Cullerin Range]	71%	63%		94%			1.28	1.71		3.41			1.24	1.45		1.65			2.84	3.92		12.94		
Eucalyptus camaldulensis var. camaldulensis [Lake Albacutya]	100%	97%	96%	99%			2.11	3.53	1.99	4.27			1.38	1.79	1.22	1.96			6.83	14.82	7.37	20.00		
Eucalyptus chloroclada [Dalby]	93%						0.86						0.54						0.77					
Eucalyptus cladocalyx [Wirrabara SFMB]	98%	93%	43%	95%			2.18	3.95	2.55	3.44			1.37	2.01	1.64	1.79			6.55	18.76	5.35	13.59		
Eucalyptus cneorifolia [Kangaroo Island CS]	97%	30%	52%	88%			1.03	1.03	0.69	1.32			0.86	0.77	0.70	1.06			1.71	0.49	0.54	2.71		
Eucalyptus cyanophylla [Alawoona]	92%						0.82						1.00						1.73					
Eucalyptus globulus ssp. bicostata [Mt. Bryan CS]	69%	44%	63%	91%			1.09	1.71	1.70	2.92			0.94	1.21	1.11	1.55			1.54	2.09	4.50	9.75		
Eucalyptus globulus ssp. bicostata [Mt. Bryan FS]	82%		53%	93%			1.14		2.45	3.36			0.99		1.54	1.64			2.10		5.20	11.64		
Eucalyptus globulus ssp. bicostata [Wee Jasper & Mt. Bryan FS]		89%						2.73						1.95						12.43				
Eucalyptus goniocalyx [Mt. Osmond]	44%	16%	16%	81%			0.90	0.97	1.64	2.55			0.97	1.16	1.57	1.69			0.86	0.46	1.41	8.83		
Eucalyptus incrassata [Finnis]	96%						0.95						0.93						1.78					
Eucalyptus incrassata [Jabuk]	79%						0.77						0.88						1.18					

Species [Provenance]	Survival @ 3 years						Height @ 3 years [m]						Crown Width @ 3 years [m]						Green Biomass [t/ha/yr]					
	MB	RW	SE	RG	CR	TB	MB	RW	SE	RG	CR	TB	MB	RW	SE	RG	CR	TB	MB	RW	SE	RG	CR	TB
Eucalyptus incrassata [Owen]	99%	90%	74%	88%			0.96	1.51	0.70	1.45			0.91	1.41	0.71	1.19			1.86	4.73	0.99	3.57		
Eucalyptus leucoxylon ssp. leucoxylon [Wirrabara]	96%						1.46						1.16						3.66					
Eucalyptus loxophleba ssp. lissophloia [Newdegate]	96%	93%	60%	92%	82%		2.26	3.53	1.55	1.77	2.29		1.46	1.88	1.06	1.57	1.32		7.33	15.00	2.29	6.38	5.43	
Eucalyptus macrorhyncha ssp. macrorhyncha [Clare]	11%						0.48						0.34						0.03					
Eucalyptus obliqua [Macclesfield]	0%																		0.00					
Eucalyptus occidentalis [Bundaleer cult.]					92%	69%					2.70	3.24					1.26	1.45					6.25	6.96
Eucalyptus occidentalis [Redhill cult.]	99%	91%	88%	98%			2.98	3.92	2.71	4.42			1.39	1.59	1.29	1.70			8.54	12.85	8.68	15.72		
Eucalyptus ovata [Back Valley]	37%	52%	13%	86%			1.23	1.81	2.91	3.77			0.84	1.49	2.07	2.02			0.80	3.57	2.21	17.58		
Eucalyptus petiolaris [Ungarra]	99%	81%	100%	99%			1.54	2.75	2.53	3.62			1.38	1.95	1.77	2.19			5.23	11.94	14.83	20.64		
Eucalyptus polybractea [Collie cult.]					80%	62%					1.27	1.66					0.96	1.26					2.11	3.07
Eucalyptus polybractea [WA cult.]	98%	93%	93%	97%			1.34	1.98	0.90	2.52			1.08	1.43	0.78	1.63			3.12	6.20	1.56	9.44		
Eucalyptus porosa [Laura]	97%			99%			1.05			3.23			0.96			2.03			2.09			16.66		
Eucalyptus porosa [Yorke Peninsula]	95%						0.80						0.88						1.45					
Eucalyptus rubida ssp. rubida [Boboyan Forest]	23%						1.03						0.98						0.51					
Eucalyptus rudis [Narrogin]	56%				91%	76%	0.90				2.69	2.54	0.56				1.74	1.43	0.56				10.86	6.42
Eucalyptus socialis [Chapman Bore]	97%	67%	91%	95%			0.88	0.97	0.88	2.63			1.23	1.40	1.13	1.74			2.82	2.67	2.67	11.22		
Eucalyptus viminalis ssp. cygnetensis [Williamstown]	70%	72%	44%	97%			1.28	2.55	4.52	4.38			1.02	1.63	2.35	1.99			1.96	6.94	12.81	20.30		
Grevillea candelabroides [Geraldton]					4%						2.51						2.75						0.93	
Gyrostemon ramulosus [Arrowsmith]					21%						3.29						2.73						5.73	
Hakea oleifolia [Manjimup]					78%	51%					2.01	1.42					1.37	1.16					4.67	1.75
Indigofera australis [Scott Creek]	21%			0%			0.38						0.27						0.04					
Jacksonia sternbergiana [Tambellup]					80%	44%					2.95	2.13					1.70	1.31					10.05	2.90
Lambertia inermis [Esperance]						10%						1.44						1.09						0.34
Melaleuca preissiana [Manjimup]					95%	64%					2.08	1.17					1.01	0.64					3.77	0.82
Melaleuca uncinata [Finnis]	92%	78%					0.54	0.86					0.39	0.83					0.27	1.09				
Paraserianthes lophantha [Boddington]					66%	75%					3.49	3.01					2.63	1.96					17.61	11.22
Pittosporum phylliraeoides [Pingrup]					2%	38%					0.38	0.42					0.20	0.18					0.00	0.05
Senna pleurocarpa [Gutha]					64%	65%					1.31	0.97					1.63	1.69					4.47	3.28
Taxandria juniperina [Marbelup]					50%	27%					1.64	1.50					0.63	0.67					0.79	0.44

Species [Provenance]	Survival @ 3 years						Height @ 3 years [m]						Crown Width @ 3 years [m]						Green Biomass [t/ha/yr]					
	MB	RW	SE	RG	CR	TB	MB	RW	SE	RG	CR	TB	MB	RW	SE	RG	CR	TB	MB	RW	SE	RG	CR	TB
Trymalium floribundum [Harvey]					1%	1%					0.50	0.80					0.43	1.03					0.00	0.02
Viminaria juncea [Harvey]					57%	70%					2.82	1.79					1.62	0.81					6.40	2.13
Viminaria juncea [Mt. Compass]	12%	43%	33%	0%			1.90	2.13	2.26				0.67	1.04	1.45				0.25	1.74	2.53			

Note: Atriplex *nummularia* [Yando] for Rutherglen (underlined) is 2 year old data as these plots were grazed in January 2007; Toolibin replants in 2005 {2 year old data in curly brackets}.

Table 40. Survival, height, crown width and productivity of 3 year old plants (planted 2004) at MurrayBridge (MB), Roseworthy (RW) and Rutherglen (RG), and #2 year old plants (planted 2005) at Thurloo (T1) in long cycle and spacing experiment trial sites.

	Survival				Height [m]				Crown Width [m]				Green Biomass [t/ha/yr]			
Species [Provenance]	**MB**	**RW**	**RG**	***T1#***	**MB**	**RW**	**RG**	***T1#***	**MB**	**RW**	**RG**	***T1#***	**MB**	**RW**	**RG**	***T1#***
Long Cycle (3 x 3 m; 1111tph)																
Callitris gracilis [Murray Bridge]	92%	97%	98%		0.48	0.89	2.04		0.23	0.63	0.91		0.05	0.49	2.81	
Casuarina cunninghamiana ssp. *cunninghamiana* [Coonabarabran]	49%	94%	99%	*68%*	0.74	2.59	3.62	*0.98*	0.29	1.62	1.65	*0.58*	0.10	4.51	8.09	*0.46*
Eucalyptus camaldulensis var. *camaldulensis* [Lake Albacutya]	95%	97%		*89%*	1.45	3.38		*1.67*	0.85	1.88		*0.85*	1.24	7.82		*2.08*
Eucalyptus cladocalyx [Wirrabara SFMB]	95%	92%		*90%*	1.83	3.71		*2.17*	1.21	2.15		*1.31*	2.26	9.49		*4.16*
Eucalyptus occidentalis [Redhill cult.]	98%	91%		*93%*	2.28	4.31		*1.85*	1.19	1.79		*1.13*	2.71	8.25		*3.04*
Nelder Plant Spacing Experiment (2394tph)																
Acacia salicina [Mambray Creek]	61%				0.38				0.31				0.14			
Atriplex nummularia [Yando]	99%				1.38				1.75				10.26			
Eucalyptus cladocalyx [Wirrabara SFMB]	89%				1.71				1.19				5.33			
Eucalyptus globulus ssp. *bicostata* [Wee Jasper]	38%				1.48				1.25				1.98			
Eucalyptus occidentalis [Redhill cult.]	86%				1.74				0.91				3.32			
Eucalyptus polybractea [WA cult.]	89%				0.73				0.54				0.80			

Table 41. Survival, height, crown width and productivity of 2 year old trees/shrubs (planted 2005) at MurrayBridge (MB), Roseworthy (RW), South East - Lucindale (SE), and Thurloo (T1) trial sites.

	Survival				Height [m]				Crown Width [m]				Green Biomass [t/ha/yr]			
Species [Provenance]	**MB**	**RW**	**SE**	**T1**	**MB**	**RW**	**SE**	**T1**	**MB**	**RW**	**SE**	**T1**	**MB**	**RW**	**SE**	**T1**
Acacia dealbata [NS]	65%		17%		0.39		0.31		0.31		0.32		0.17		0.04	
Acacia decora [ATSC]	67%				0.32				0.37				0.22			
Acacia decurrens [BSC]	69%		4%		0.70		0.70		0.53		1.00		0.82		0.09	
Acacia filicifolia [NSWF]	79%				0.80				0.55				0.84			
Acacia implexa [ATSC]	74%		13%		0.57		0.56		0.34		0.37		0.34		0.06	
Acacia iteaphylla [NM]#	76%	95%	0%		0.39	0.65			0.54	0.73			0.51	1.52		
Acacia leucoclada [ATSC]			97%	85%			1.05	1.05			0.83	0.79			2.68	1.92
Acacia mearnsii [BSC]		23%	99%			0.99	2.35			0.62	1.62			0.56	13.62	
Acacia melanoxylon [Lower South East]	92%		46%		0.69		0.45		0.34		0.27		0.44		0.12	
Acacia melanoxylon [Tasmania]			48%				0.85				0.36				0.28	
Acacia myrtifolia [Adelaide Hills]#	24%	27%	0%		0.47	0.79			0.42	0.44			0.11	0.22		
Acacia pycnantha [Kuipto]			51%				0.80				0.71				1.03	
Acacia retinodes var. retinodes (hill form) [Clare/Spalding]				94%				1.67				1.16				5.89
Acacia retinodes var. retinodes (hill form) [Harrogate]			99%				2.52				1.80				16.80	
Acacia retinodes var. retinodes (swamp form) [BSC]				34%				1.60				1.03				1.83
Acacia retinodes var. retinodes (swamp form) [Parawa]			94%				2.12				1.51				11.12	
Acacia retinodes var. uncifolia [Kangaroo Island SFMB]#	59%				0.30				0.24				0.09			
Acacia salicina [Mambray Creek]			0%	89%				0.78				0.67				1.42
Acacia saligna ssp. lindleyi [Parkeyerring]				95%				1.83				1.09				6.03
Agonis flexuosa [WA]	0%															
Allocasuarina huegeliana [Katanning]	63%				0.26				0.13				0.04			
Angophora floribunda [NSWF]	100%				0.47				0.54				0.64			
Anthocercis littorea [Wanneroo]	58%				0.50				0.57				0.39			
Atriplex *nummularia* [Eyres Green]#	96%	99%	88%		1.23	1.44	1.17		1.92	2.66	1.47		14.51	30.45	7.16	

Species [Provenance]	Survival				Height [m]				Crown Width [m]				Green Biomass [t/ha/yr]			
	MB	**RW**	**SE**	**T1**	**MB**	**RW**	**SE**	**T1**	**MB**	**RW**	**SE**	**T1**	**MB**	**RW**	**SE**	**T1**
Atriplex *nummularia* [Yando]#			99%	99%			1.08	1.45			0.76	1.36			2.96	8.62
Callitris gracilis [Murray Bridge]				80%				0.77				0.30				0.30
Casuarina obesa [Salt Creek]			81%				0.83				0.50				0.89	
Chamaecytisus prolifer [NSWF]#	67%		54%		0.34		1.17		0.15		1.01		0.05		2.10	
Chenopodium nitrariaceum [Hay]#	93%		100%		0.84		0.88		1.10		0.88		3.26		2.42	
Codonocarpus cotinifolius [Goodlands]	0%															
Codonocarpus cotinifolius [Riverland]	0%															
Eucalyptus aromaphloia ssp. sabulosa [Balmoral]	38%		96%		0.37		1.88		0.46		1.28		0.19		7.67	
Eucalyptus banksii [Tenterfield]	88%		83%		0.81		1.32		0.93		1.04		2.14		4.15	
Eucalyptus blakelyi [Mendooran]	95%		92%		0.62		1.34		0.51		1.08		0.76		4.59	
Eucalyptus botryoides [Orbost]	42%				0.47				0.40				0.21			
Eucalyptus bridgesiana [Cullerin Range]			98%	54%			1.68	1.57			1.25	1.27			7.05	4.02
Eucalyptus camaldulensis var. camaldulensis [Lake Albacutya]			100%	94%			2.53	2.10			1.52	1.15			13.82	7.99
Eucalyptus citriodora ssp. citriodora [NM]	58%				1.07				0.69				1.49			
Eucalyptus cladocalyx [Lower Eyre Peninsula]	82%		52%		0.90		1.31		0.83		1.09		1.82		2.47	
Eucalyptus cladocalyx [Wirrabara SFMB]			55%	92%			1.37	2.08			1.05	1.30			2.50	8.19
Eucalyptus cneorifolia [Kangaroo Island CS]				88%				0.66				0.47				0.58
Eucalyptus cneorifolia [Kangaroo Island SFMB]			58%				0.70				0.59				0.70	
Eucalyptus conica [Forbes]	96%		100%		0.47		0.78		0.70		0.82		0.98		2.11	
Eucalyptus cosmophylla [Victor Harbour]	96%		67%		0.42		1.21		0.43		1.00		0.48		2.46	
Eucalyptus cyanophylla [Alawoona]			67%				0.31				0.47				0.30	
Eucalyptus dalrympleana [Lenswood]	60%				0.51				0.60				0.52			
Eucalyptus dalrympleana [SFMB]			83%				1.47				1.13				4.50	
Eucalyptus dealbata [ATSC]	90%				0.48				0.49				0.64			
Eucalyptus fasciculosa [Milang]	96%				0.75				0.77				1.61			

Species [Provenance]	Survival				Height [m]				Crown Width [m]				Green Biomass [t/ha/yr]			
	MB	RW	SE	T1	MB	RW	SE	T1	MB	RW	SE	T1	MB	RW	SE	T1
Eucalyptus fibrosa ssp. nubila [Gilgandra]	94%				0.47				0.36				0.34			
Eucalyptus globulus ssp. bicostata [Mt. Bryan CS]			81%	45%			1.03	1.02			0.72	0.86			1.90	1.29
Eucalyptus globulus ssp. bicostata [Wee Jasper]			92%				1.75				1.23				7.46	
Eucalyptus globulus ssp. bicostata [Wee Jasper] / [Mt. Bryan FS]				27%				1.43				1.22				1.65
Eucalyptus globulus ssp. globulus [SFMB]	36%	8%	52%		0.80	1.59	1.64		0.65	1.06	1.06		0.55	0.44	3.42	
Eucalyptus gomphocephala [NM]	96%				1.66				1.40				7.82			
Eucalyptus goniocalyx [Mt. Osmond]			45%	10%			0.95	1.00			0.80	0.92			1.07	0.28
Eucalyptus grandis [NSWF]	63%		77%		0.90		1.66		0.59		1.15		0.81		5.02	
Eucalyptus incrassata [Owen]				89%				0.70				0.59				0.95
Eucalyptus largiflorens [NSWF]	91%		83%		0.40		0.41		0.51		0.53		0.57		0.47	
Eucalyptus leucoxylon [Adelaide Hills]	92%				0.80				0.73				1.56			
Eucalyptus leucoxylon ssp. leucoxylon [Barossa]			96%				1.34				1.15				4.77	
Eucalyptus leucoxylon ssp. pruinosa [Northern Mt. Lofty Ranges]	89%				0.74				0.75				1.45			
Eucalyptus leucoxylon ssp. stephaniae [Narrung]	76%		96%		0.48		0.99		0.54		1.05		0.54		3.34	
Eucalyptus loxophleba ssp. lissophloia [Newdegate]				95%				1.03				0.83				2.25
Eucalyptus maculata [Kangaroo River]	79%	38%	25%		0.37	0.60	0.76		0.40	0.41	0.78		0.36	0.26	0.54	
Eucalyptus mannifera ssp. mannifera [Lakes Entrance]	46%				0.48				0.55				0.36			
Eucalyptus megacornuta [SFB]	54%				1.00				0.76				1.17			
Eucalyptus melliodora [SFB]	88%				0.60				0.82				1.51			
Eucalyptus microcarpa [Toll Gate]	100%				0.62				0.62				1.01			
Eucalyptus occidentalis [Redhill cult.]			85%	90%			1.98	1.76			1.12	1.00			5.84	4.73
Eucalyptus odorata [Lower Eyre Peninsula]	89%		96%		0.55		0.88		0.56		0.74		0.71		1.66	

Species [Provenance]	Survival				Height [m]				Crown Width [m]				Green Biomass [t/ha/yr]			
	MB	RW	SE	T1	MB	RW	SE	T1	MB	RW	SE	T1	MB	RW	SE	T1
Eucalyptus odorata [Two Wells]	94%				0.54				0.57				0.75			
Eucalyptus oleosa [Far North]	88%				0.51				0.78				1.12			
Eucalyptus oleosa [Port Wakefield NB]		89%				0.79				1.00				2.43		
Eucalyptus oleosa [Port Wakefield NTB]	88%				0.63				0.92				1.74			
Eucalyptus oleosa [Port Wakefield SFMB]			74%				0.58				0.67				0.93	
Eucalyptus ovata [Back Valley]			80%	9%			1.61	1.04			1.27	0.79			6.04	0.23
Eucalyptus petiolaris [Ungarra]			100%	85%			1.50	1.48			1.28	1.27			6.64	5.73
Eucalyptus polyanthemos [Bruthen]	90%				0.66				0.51				0.85			
Eucalyptus polybractea [WA cult.]			92%	94%			0.84	1.15			0.76	0.87			1.82	2.84
Eucalyptus porosa [Adelaide Plains]			92%				1.10				1.03				3.52	
Eucalyptus porosa [Flinders Ranges]	100%		100%		1.00		0.94		1.28		0.92		4.66		2.98	
Eucalyptus porosa [Laura]				93%				1.20				1.15				4.27
Eucalyptus radiata [Tenterfield]	8%		0%		0.53				0.39				0.03			
Eucalyptus rossii [NSWF]	63%				0.38				0.32				0.15			
Eucalyptus saligna [NSWF]	50%		32%		0.84		1.22		0.47		0.80		0.41		1.02	
Eucalyptus sideroxylon [Gilgandra]	96%				0.67				0.62				1.14			
Eucalyptus socialis [Chapman Bore]				81%				0.64				0.83				1.40
Eucalyptus socialis [Far North]	94%				0.64				0.87				1.68			
Eucalyptus tereticornis ssp. tereticornis [NSWF]	92%				1.23				0.91				2.90			
Eucalyptus viminalis ssp. cygnetensis [Mount Barker]			94%				2.33				1.47				11.13	
Eucalyptus viminalis ssp. cygnetensis [Williamstown]			96%	30%			2.31	1.34			1.48	1.08			11.34	1.33
Eucalyptus viminalis ssp. viminalis [Cleland]	79%		100%		0.66		1.94		0.77		1.31		1.29		8.85	
Eucalyptus viridis ssp. viridis [NSWF]	96%	80%			0.75	0.88			0.59	0.58			1.09	1.03		
Grevillea leucopteris [Gin Gin]	32%				0.28				0.30				0.12			
Grevillea robusta [SFMB]	88%				0.39				0.25				0.14			
Melaleuca armillaris ssp. armillaris [BSC]	90%		4%		0.60		0.40		0.33		0.32		0.35		0.01	

Species [Provenance]	Survival				Height [m]				Crown Width [m]				Green Biomass [t/ha/yr]			
	MB	**RW**	**SE**	**T1**	**MB**	**RW**	**SE**	**T1**	**MB**	**RW**	**SE**	**T1**	**MB**	**RW**	**SE**	**T1**
Melaleuca uncinata [Finnis]				95%				0.71				0.54				0.88
Melaleuca uncinata [Tumby Bay]	56%		25%		0.36		0.50		0.32		0.33		0.14		0.10	
Senna pleurocarpa var. pleurocarpa [Mt. Newman]	0%															
Taxandria juniperina [NS]	0%		0%													
Templetonia retusa [Murray Bridge]	58%				0.37				0.07				0.013			
Trymalium floribundum [Harvey]	0%															
Viminaria juncea [Mt. Compass]			11%				1.40				0.86				0.45	

[#] Fodder species

Table 42. Fodder shrub 2 year old (planted 2005) survival, height, crowth width and productivity at Murray Bridge trial site.

	Survival	Height [m]	Crown Width [m]	Green Biomass [t/ha/yr]
Acacia acinacea [SFB]	100%	0.37	0.79	1.01
Acacia iteaphylla [NM]	76%	0.39	0.54	0.51
Acacia ligulata [Wellington]	85%	0.46	0.72	0.97
Acacia longifolia var. longifolia [SFMB]	92%	0.70	0.90	1.91
Acacia montana [SFB]	88%	0.68	0.85	1.59
Acacia murrayana [SFB]	46%	0.42	0.56	0.31
Acacia myrtifolia [Adelaide Hills]	24%	0.47	0.42	0.11
Acacia pendula [BSC]	73%	0.19	0.17	0.04
Acacia retinodes var. uncifolia [Kangaroo Island SFMB]	59%	0.30	0.24	0.09
Allocasuarina muelleriana [Crafers]	92%	0.38	0.34	0.28
Atriplex amnicola [Yorke Peninsula]	96%	0.74	2.87	12.69
Atriplex cinerea [Yorke Peninsula]	100%	1.03	1.69	7.28
Atriplex *nummularia* [Eyres Green]	96%	1.23	1.92	14.51
Atriplex paludosa [Port Gawler]	100%	0.57	1.61	4.11
Atriplex rhagodioides [Moorook]	100%	0.95	1.69	7.51
Atriplex semibaccata [Port Neill]	92%	0.19	1.25	1.23
Atriplex semibaccata [SARDI1]	83%	0.17	1.27	0.92
Atriplex semibaccata [SARDI2]	88%	0.18	1.28	1.05
Atriplex semibaccata [SARDI3]	88%	0.20	1.34	1.19
Atriplex vesicaria [Hay]	96%	0.60	1.23	2.87
Bursaria spinosa [Finnis]	4%	0.14	0.16	0.00
Chamaecytisus prolifer [NSWF]	67%	0.34	0.15	0.05
Chenopodium auricomum [SARDI]	100%	0.75	1.01	3.20
Chenopodium nitrariaceum [Hay]	93%	0.84	1.10	3.26
Daviesia latifolia [SARDI]	13%	0.43	0.24	0.02
Daviesia mimosoides [SARDI]	33%	0.29	0.11	0.01
Enchylaena tomentosa [Hay]	48%	0.45	1.23	1.09
Eremophila bignoniiflora [Riverland]	19%	0.63	0.60	0.21
Eremophila glabra [SFMB]	75%	0.47	0.78	0.87
Eremophila longifolia [Mannum]	67%	0.58	0.61	0.74
Eremophila maculata [Riverland]	100%	0.64	0.87	1.96
Geijera parviflora [NM]	42%	0.23	0.18	0.03
Maireana brevifolia [Hay]	21%	0.30	0.51	0.08
Maireana convexa [SARDI]	96%	1.03	1.00	2.99
Maireana pyramidata [Hay]	100%	0.59	0.89	1.70
Maireana pyramidata [Whyalla]	88%	0.62	1.12	2.26
Maireana rohrlachi [NTB]	79%	0.38	0.64	0.60
Maireana sedifolia [Hay]	70%	0.62	0.84	1.08
Maireana sedifolia [Morgan]	52%	0.58	0.79	0.75
Myoporum platycarpum [NTB]	83%	0.77	0.91	1.78
Nitraria billardierei [Hay]	0%			
Pultenaea daphnoides [Millbrook]	0%			
Rhagodia candolleana [Yorke Peninsula]	96%	0.48	1.25	2.39
Rhagodia crassifolia [Narung]	96%	0.59	1.48	3.61
Rhagodia parabolica [NM]	100%	0.68	1.45	3.96
Rhagodia spinescens [Hay]	100%	0.66	1.37	3.66
Rhagodia spinescens [Mannum]	100%	0.75	1.61	5.07
Rhagodia spinescens [Penong]	96%	0.62	1.51	4.09

Table 43. Monarto tree and mallee provenances, 1 year old results, planted 2006.

Species [Provenance]	Survival	Height [m]	Green Biomass [t/ha/yr]
Acacia decurrens [Bungonia]	92%	0.35	5.39
Acacia decurrens [Picton]	84%	0.27	3.61
Acacia mearnsii [Bairnsdale]	95%	0.46	7.71
Acacia mearnsii [Bungendore]	99%	0.48	8.47
Acacia mearnsii [George Town]	95%	0.41	6.64
Acacia mearnsii [Grampians]	98%	0.51	9.04
Acacia mearnsii [Kyneton]	98%	0.48	8.50
Acacia mearnsii [Tantanoola]	95%	0.51	8.93
Acacia retinodes var. retinodes (hill form) [Littlehampton]	91%	0.51	8.44
Acacia retinodes var. retinodes (swamp form) [Fryerstown]	98%	0.76	14.31
Acacia retinodes var. retinodes (swamp form) [Grampians/Lake Bellfield]	94%	0.69	12.42
Acacia retinodes var. retinodes (swamp form) [Kangaroo Island]	98%	0.51	8.87
Acacia retinodes var. retinodes (swamp form) [Kuitpo]	98%	0.53	9.35
Acacia retinodes var. uncifolia [Kangaroo Island BSC]	99%	0.55	9.83
Acacia saligna [WA]	87%	0.36	5.38
Eucalyptus aromaphloia ssp. aromaphloia [Anglesea]	83%	0.30	4.01
Eucalyptus aromaphloia ssp. aromaphloia [Yarram Park]	94%	0.38	5.98
Eucalyptus aromaphloia ssp. sabulosa [Balmoral]	86%	0.39	5.76
Eucalyptus aromaphloia ssp. sabulosa [Little Desert]	89%	0.41	6.17
Eucalyptus camaldulensis [Silverton]	100%	0.72	13.62
Eucalyptus camaldulensis x globulus ssp. globulus [SG34]	97%	0.48	8.16
Eucalyptus camaldulensis x globulus ssp. globulus [SG35]	81%	0.51	7.27
Eucalyptus camaldulensis x globulus ssp. globulus [SG39]	89%	0.50	7.80
Eucalyptus camaldulensis x globulus ssp. globulus [SG40]	86%	0.48	7.25
Eucalyptus camaldulensis x grandis [SG06]	80%	0.64	9.54
Eucalyptus camaldulensis x grandis [SG13]	84%	0.67	10.57
Eucalyptus camaldulensis x grandis [SG18]	89%	0.66	11.01
Eucalyptus camaldulensis x grandis [SG21]	63%	0.67	7.94
Eucalyptus cladocalyx [Bundaleer cult.]	89%	0.50	7.96
Eucalyptus cladocalyx [Cape Border]	97%	0.60	10.77
Eucalyptus cladocalyx [Flinders Chase]	100%	0.49	8.66
Eucalyptus cladocalyx [Kersbrook cult.]	93%	0.53	8.96
Eucalyptus cladocalyx [Wail]	90%	0.50	7.97
Eucalyptus cladocalyx [Wirrabara CS]	83%	0.43	6.11
Eucalyptus cneorifolia [Kingscote]	92%	0.36	5.54
Eucalyptus globulus ssp. bicostata [Barkly]	90%	0.46	7.34
Eucalyptus globulus ssp. bicostata [Mt. Bryan CS]	89%	0.52	8.42
Eucalyptus globulus ssp. bicostata [Wee Jasper]	87%	0.32	4.57
Eucalyptus globulus ssp. globulus [Jeeralong]	83%	0.53	7.97
Eucalyptus globulus ssp. globulus [Ottway]	89%	0.63	10.50
Eucalyptus globulus ssp. globulus [WAFPC]	67%	0.38	4.34
Eucalyptus globulus ssp. globulus [Worrolong]	74%	0.41	5.19
Eucalyptus horistes [WA]	95%	0.33	5.07
Eucalyptus loxophleba ssp. lissophloia [WA]	97%	0.44	7.36
Eucalyptus occidentalis [Gibson]	96%	0.87	16.47
Eucalyptus occidentalis [Jerdacuttup River]	95%	0.76	13.76
Eucalyptus occidentalis [Jerramungup area]	98%	0.86	16.54
Eucalyptus occidentalis [Kantanning]	97%	0.86	16.44
Eucalyptus occidentalis [Old Newgate Road]	97%	0.79	14.98

Species [Provenance]	Survival	Height [m]	Green Biomass [t/ha/yr]
Eucalyptus occidentalis [Truslove]	99%	0.92	18.21
Eucalyptus oleosa ssp. ampliata [Port Lincoln]	72%	0.33	3.80
Eucalyptus oleosa ssp. oleosa [Langhorne Creek]	95%	0.25	3.69
Eucalyptus oleosa ssp. oleosa [Mallala]	94%	0.41	6.54
Eucalyptus oleosa ssp. oleosa [Menzies]	69%	0.26	2.84
Eucalyptus oleosa ssp. oleosa [Paruna]	91%	0.29	4.27
Eucalyptus ovata ssp. grandiflora [Mt. Gambier]	86%	0.31	4.27
Eucalyptus ovata ssp. ovata [Adelaide Hills]	94%	0.46	7.56
Eucalyptus ovata ssp. ovata [Crookwell]	81%	0.33	4.44
Eucalyptus ovata ssp. ovata [Strathdownie]	97%	0.37	6.10
Eucalyptus ovata ssp. ovata [Tasmania]	92%	0.40	6.31
Eucalyptus petiolaris [Cleve Hills]	97%	0.44	7.47
Eucalyptus petiolaris [Koppio Hills]	99%	0.46	7.95
Eucalyptus polybractea [CLM29]	97%	0.42	6.89
Eucalyptus polybractea [CLM31]	99%	0.41	6.82
Eucalyptus polybractea [CLM42]	98%	0.43	7.34
Eucalyptus polybractea [Inglewood]	98%	0.37	6.01
Eucalyptus polybractea [West Wyalong]	90%	0.40	6.13
Eucalyptus porosa [Fleurieu Penn]	95%	0.35	5.50
Eucalyptus porosa [Glenloth]	89%	0.32	4.65
Eucalyptus porosa [Melton to Price]	98%	0.33	5.22
Eucalyptus porosa ssp. devestiva [Tintinara]	97%	0.32	5.10
Eucalyptus rudis [WA]	91%	0.62	10.41
Eucalyptus viminalis (FSA hybrid) [Tintinara cult.]	77%	0.43	5.72
Eucalyptus viminalis ssp. cygnetensis [Flinders Chase]	90%	0.55	8.98
Eucalyptus viminalis ssp. cygnetensis [Frances]	88%	0.48	7.51
Eucalyptus viminalis ssp. cygnetensis [Mt. Gambier]	86%	0.40	5.80
Eucalyptus viminalis ssp. cygnetensis [Onkaparinga River]	43%	0.40	2.93
Eucalyptus viminalis ssp. cygnetensis [Port Lincoln]	94%	0.44	7.18
Eucalyptus viminalis ssp. cygnetensis [Williamstown]	94%	0.44	7.11
Viminaria juncea [Gippsland]	87%	0.68	11.30
Viminaria juncea [Jervis Bay]	93%	0.67	11.69
Viminaria juncea [McLoughlins Beach]	84%	0.90	15.23
Viminaria juncea [Mt. Burr]	81%	0.44	6.26
Viminaria juncea [Mt. Gambier]	82%	0.63	9.77
Viminaria juncea [Nangkita]	88%	0.72	12.34
Viminaria juncea [Perth]	74%	0.73	10.64
Viminaria juncea [Wimmera River]	94%	0.70	12.59

Appendix B. – Additional Productivity Data

Table 44. Average and maximum observed productivity of plots for each species at each site from trial sites and surveys in the Upper South East region and neighbouring districts.

Species	Average Annual Rainfall [mm]	Age [years]	Height [m]	Trees Per Hectare	Average of Plots			Maximum of Plots		
					MAI Stemwood Volume (x1000) [m^3/plant/yr]	MAI Green Biomass [t/plant/yr]	MAI CO_2 equiv. [t/plant/yr]	MAI Stemwood Volume (x1000) [m^3/plant/yr]	MAI Green Biomass [t/plant/yr]	MAI CO_2 equiv. [t/plant/yr]
Acacia dealbata	671	3.4	3.5	904	0.99	1.24	1.12	1.66	2.13	1.91
Acacia mearnsii	492	12.5	9.9	3017	6.43	10.95	11.59	6.43	10.95	11.59
Acacia mearnsii	559	4.3	4.0	947	0.81	1.00	1.06	0.81	1.00	1.06
Acacia melanoxylon	559	8.4	4.5	947	1.12	1.49	1.33	1.12	1.49	1.33
Acacia melanoxylon	613	7.4	5.0	928	1.23	1.63	1.46	1.23	1.63	1.46
Acacia melanoxylon	671	3.4	4.6	904	1.66	2.15	1.93	2.56	3.39	3.04
Acacia melanoxylon	698	7.4	6.2	1600	3.68	5.40	4.85	3.68	5.40	4.85
Acacia melanoxylon	698	10.4	7.3	1231	6.56	10.75	9.65	14.64	25.78	23.15
Acacia melanoxylon	741	7.0	2.7	400	0.26	0.31	0.28	0.35	0.42	0.38
Acacia pycnantha	387	7.0	3.4	1000	2.07	9.73	9.15	2.07	9.73	9.15
Acacia salicina	492	9.3	3.5	684	0.87	1.14	1.02	0.87	1.14	1.02
Acacia stenophylla	492	9.3	4.9	684	1.07	1.43	1.28	1.07	1.43	1.28
Allocasuarina verticillata	492	10.9	8.6	444	17.96	33.57	36.13	17.96	33.57	36.13
Atriplex nummularia	466	3.0	1.6	966	1.89	3.97	2.80	1.89	3.97	2.80
Callitris columellaris	348	10.0	2.5	370	0.17	0.21	0.19	0.23	0.28	0.25
Casuarina cunninghamiana	698	10.4	8.0	1600	4.33	6.79	6.09	8.40	13.95	12.52
Casuarina glauca	480	8.5	4.2	961	0.73	0.95	0.85	1.01	1.33	1.20
Casuarina glauca	492	9.3	6.9	684	2.49	3.70	3.33	5.72	9.00	8.08
Casuarina glauca	509	10.3	7.4	684	3.57	5.52	4.95	10.54	17.90	16.07
Casuarina glauca	559	8.4	6.7	947	3.47	5.19	4.66	5.63	8.77	7.87
Casuarina glauca	610	8.7	3.3	1185	0.49	0.62	0.55	0.57	0.73	0.65
Casuarina glauca	625	8.6	3.8	948	0.56	0.71	0.64	0.67	0.86	0.78
Casuarina glauca	698	10.4	7.9	1600	4.54	7.06	6.34	5.02	7.88	7.08
Casuarina obesa	480	8.5	4.0	961	0.61	0.78	0.70	1.08	1.44	1.29
Casuarina obesa	610	8.7	2.8	1185	0.26	0.31	0.28	0.38	0.46	0.42
Casuarina obesa	625	8.6	2.9	948	0.26	0.31	0.28	0.38	0.47	0.42
Casuarina pauper (cristata)	364	11.4	3.7	370	0.21	0.25	0.23	0.21	0.25	0.23
Corymbia citriodora	466	5.8	2.3	1000	0.12	0.70	0.61	0.17	0.80	0.71
Corymbia maculata	466	5.8	2.8	1000	0.22	0.93	0.79	0.32	1.15	0.98
Corymbia maculata	492	10.8	9.0	556	9.24	12.53	10.68	9.24	12.53	10.68
Corymbia maculata	492	6.9	10.2	1111	12.69	18.62	15.86	12.69	18.62	15.86
Corymbia maculata	613	7.4	9.1	928	5.43	8.85	7.54	9.77	15.12	12.89
Eucalyptus astringens	320	7.3	4.3	625	0.79	2.02	1.78	0.79	2.02	1.78
Eucalyptus astringens	364	11.4	6.7	370	4.03	6.70	5.89	7.12	10.78	9.48
Eucalyptus astringens	559	8.4	7.9	947	8.17	12.70	11.17	10.79	16.02	14.09
Eucalyptus botryoides	492	9.3	9.9	684	8.51	12.94	11.38	8.51	12.94	11.38
Eucalyptus botryoides	698	7.4	10.8	1600	16.11	22.84	20.08	16.35	23.12	20.33
Eucalyptus brockwayi	348	7.0	3.6	370	1.68	3.21	2.82	4.56	7.60	6.69

Species	Average Annual Rainfall [mm]	Age [years]	Height [m]	Trees Per Hectare	Average of Plots: MAI Stemwood Volume (x1000) [m³/plant/yr]	Average of Plots: MAI Green Biomass [t/plant/yr]	Average of Plots: MAI CO_2 equiv. [t/plant/yr]	Maximum of Plots: MAI Stemwood Volume (x1000) [m³/plant/yr]	Maximum of Plots: MAI Green Biomass [t/plant/yr]	Maximum of Plots: MAI CO_2 equiv. [t/plant/yr]
Eucalyptus brockwayi	671	3.4	2.3	904	0.22	1.20	1.05	0.34	1.49	1.31
Eucalyptus camaldulensis	362	7.6	5.7	142	4.09	7.17	5.23	4.09	7.17	5.23
Eucalyptus camaldulensis	376	7.7	9.6	1079	9.52	14.05	10.24	9.52	14.05	10.24
Eucalyptus camaldulensis	445	19.4	8.5	863	2.46	4.09	2.98	2.75	4.48	3.27
Eucalyptus camaldulensis	460	10.7	11.4	952	20.70	25.68	18.72	20.70	25.68	18.72
Eucalyptus camaldulensis	492	9.9	8.2	1429	4.59	7.47	5.44	4.59	7.47	5.44
Eucalyptus camaldulensis	559	5.5	3.8	947	1.08	2.51	1.83	2.47	4.91	3.58
Eucalyptus camaldulensis	741	7.0	2.7	400	0.44	1.28	0.94	0.91	2.26	1.65
Eucalyptus camaldulensis	492	9.3	8.1	684	5.82	9.17	6.69	12.95	18.29	13.33
Eucalyptus camaldulensis	509	9.4	12.2	684	20.85	26.23	19.12	44.41	50.64	36.92
Eucalyptus camaldulensis	698	10.1	6.5	1600	7.93	11.54	8.42	19.73	25.41	18.53
Eucalyptus cladocalyx	444	19.4	10.6	1171	3.21	5.10	4.74	3.45	5.41	5.02
Eucalyptus cladocalyx	447	19.4	8.2	1032	1.38	2.55	2.37	1.48	2.70	2.51
Eucalyptus cladocalyx	460	6.7	5.6	833	3.56	6.53	6.17	3.56	6.53	6.17
Eucalyptus cladocalyx	460	6.7	5.0	1111	4.26	7.81	7.13	4.26	7.81	7.13
Eucalyptus cladocalyx	460	6.7	6.4	1212	5.10	8.85	8.22	5.10	8.85	8.22
Eucalyptus cladocalyx	460	19.3	12.3	668	6.58	9.21	8.56	7.09	9.80	9.11
Eucalyptus cladocalyx	460	10.7	14.9	625	30.55	35.65	33.13	30.55	35.65	33.13
Eucalyptus cladocalyx	466	11.0	6.1	1000	1.95	3.73	3.46	6.47	10.05	9.34
Eucalyptus cladocalyx	613	10.3	9.9	928	17.73	22.91	21.29	33.28	39.21	36.43
Eucalyptus cladocalyx	698	10.3	12.8	1600	26.38	31.35	29.13	56.38	60.57	56.28
Eucalyptus cneorifolia	492	9.3	3.9	684	0.98	3.26	3.16	0.98	3.26	3.16
Eucalyptus cneorifolia	559	8.4	3.6	947	0.38	1.61	1.57	0.42	1.74	1.69
Eucalyptus cornuta	559	8.4	9.3	947	12.59	18.20	16.00	12.59	18.20	16.00
Eucalyptus diversifolia	460	12.7	5.5	1279	4.04	13.77	13.16	4.04	13.77	13.16
Eucalyptus dumosa	348	10.3	3.6	370	0.32	1.35	1.43	0.32	1.35	1.43
Eucalyptus dumosa	387	12.0	3.8	1000	1.07	3.32	3.51	1.07	3.32	3.51
Eucalyptus dundasii	348	10.3	6.6	370	2.68	4.92	4.33	2.68	4.92	4.33
Eucalyptus dundasii	364	11.4	8.2	370	5.02	8.08	7.11	5.92	9.27	8.15
Eucalyptus dundasii	671	3.4	2.6	904	0.25	1.29	1.14	0.25	1.29	1.14
Eucalyptus famelica	509	10.3	2.4	684	0.08	0.59	0.58	0.08	0.59	0.58
Eucalyptus fasciculosa	492	9.3	1.5	684	0.01	0.27	0.24	0.01	0.27	0.24
Eucalyptus globulus	444	16.6	14.2	1165	8.62	11.81	10.05	9.52	12.83	10.91
Eucalyptus globulus	445	19.4	18.3	893	15.90	19.08	16.23	17.31	20.47	17.42
Eucalyptus globulus	457	14.2	14.2	550	10.18	13.94	11.86	11.25	15.14	12.89
Eucalyptus globulus	460	19.3	14.3	785	11.65	14.77	12.57	12.36	15.52	13.21
Eucalyptus globulus	460	10.7	12.5	1190	12.26	16.40	13.95	12.26	16.40	13.95
Eucalyptus globulus	492	6.8	11.1	1250	14.65	21.10	17.95	14.65	21.10	17.95
Eucalyptus globulus	492	15.7	18.2	1173	18.90	22.84	19.43	20.80	24.74	21.05
Eucalyptus globulus	497	13.3	13.1	973	6.94	10.21	8.69	12.44	16.63	14.15
Eucalyptus globulus	506	19.1	15.8	1231	6.29	8.90	7.57	6.70	9.37	7.97
Eucalyptus globulus	506	16.9	13.6	663	7.21	10.15	8.64	8.90	12.09	10.29
Eucalyptus globulus	510	16.7	15.5	906	7.53	10.57	8.99	7.78	10.85	9.23
Eucalyptus globulus	511	14.2	13.1	831	7.15	10.42	8.87	7.21	10.49	8.93
Eucalyptus globulus	540	27.1	25.5	1244	14.82	16.98	14.45	16.47	18.55	15.78

Species	Average Annual Rainfall [mm]	Age [years]	Height [m]	Trees Per Hectare	Average of Plots			Maximum of Plots		
					MAI Stemwood Volume (x1000) [m³/plant/yr]	MAI Green Biomass [t/plant/yr]	MAI CO_2 equiv. [t/plant/yr]	MAI Stemwood Volume (x1000) [m³/plant/yr]	MAI Green Biomass [t/plant/yr]	MAI CO_2 equiv. [t/plant/yr]
Eucalyptus globulus	554	18.7	17.6	967	7.86	10.70	9.11	9.21	12.23	10.41
Eucalyptus globulus	566	20.8	21.4	2037	8.02	10.70	9.11	8.73	11.48	9.77
Eucalyptus globulus	569	16.3	18.0	1006	11.71	15.23	12.96	15.61	19.37	16.48
Eucalyptus globulus	583	14.1	13.9	1195	7.13	10.40	8.85	7.52	10.87	9.25
Eucalyptus globulus	606	4.9	18.0	1143	42.78	54.54	46.40	42.78	54.54	46.40
Eucalyptus globulus	606	4.9	19.2	1136	43.03	54.89	46.71	43.03	54.89	46.71
Eucalyptus globulus	625	9.8	10.6	1600	7.33	11.15	9.49	13.17	18.40	15.66
Eucalyptus globulus	659	9.7	10.4	1600	5.01	8.22	6.99	7.74	11.88	10.11
Eucalyptus gomphocephala	460	12.0	12.4	500	60.85	60.63	54.42	60.85	60.63	54.42
Eucalyptus gomphocephala	559	8.4	9.5	947	33.52	40.88	35.95	33.52	40.88	35.95
Eucalyptus gracilis	364	10.3	2.7	370	0.40	1.60	1.55	0.40	1.60	1.55
Eucalyptus grandis	492	15.7	11.0	1121	4.93	7.53	6.62	5.05	7.68	6.75
Eucalyptus grandis	492	6.8	10.6	1250	13.20	19.44	17.45	13.20	19.44	17.45
Eucalyptus grandis	583	14.1	11.5	1166	4.38	6.96	6.12	4.87	7.61	6.69
Eucalyptus grandis	698	7.4	9.2	1600	8.77	13.81	12.15	9.94	15.33	13.48
Eucalyptus incrassata	374	8.0	3.7	1120	1.68	5.19	5.20	1.68	5.19	5.20
Eucalyptus incrassata	460	12.7	3.6	1235	1.49	7.24	7.25	1.49	7.24	7.25
Eucalyptus kondininensis	559	4.3	2.3	947	0.16	0.92	0.81	0.16	0.92	0.81
Eucalyptus kondininensis	671	3.4	3.5	904	0.68	2.25	1.98	0.68	2.25	1.98
Eucalyptus largiflorens	492	9.3	6.2	684	2.42	4.62	4.06	2.42	4.62	4.06
Eucalyptus largiflorens	559	7.4	3.0	947	0.20	0.78	0.69	0.34	1.11	0.98
Eucalyptus largiflorens	613	7.4	3.4	928	0.16	0.70	0.61	0.16	0.70	0.61
Eucalyptus leptophylla	348	10.3	3.1	370	0.12	0.72	0.70	0.14	0.77	0.75
Eucalyptus leptophylla	364	10.3	2.9	370	0.28	1.23	1.20	0.28	1.23	1.20
Eucalyptus leucoxylon	492	10.7	8.6	1088	6.75	10.03	9.68	6.75	10.03	9.68
Eucalyptus leucoxylon	320	7.3	3.2	625	0.11	0.57	0.55	0.20	0.79	0.76
Eucalyptus leucoxylon	364	11.4	7.8	370	4.42	7.22	6.97	6.27	9.71	9.37
Eucalyptus leucoxylon	364	13.1	7.7	500	5.54	8.51	8.22	7.80	11.35	10.95
Eucalyptus leucoxylon	492	9.3	10.8	684	13.73	18.94	18.28	22.18	28.54	27.54
Eucalyptus leucoxylon	559	8.4	6.6	947	8.18	12.56	12.12	11.84	17.30	16.69
Eucalyptus leucoxylon	613	10.3	9.3	928	12.03	16.34	15.77	33.66	39.58	38.20
Eucalyptus leucoxylon	698	10.4	10.5	1600	20.55	25.95	25.05	37.33	43.06	41.56
Eucalyptus obliqua	613	7.4	7.9	928	5.97	10.08	8.86	5.97	10.08	8.86
Eucalyptus occidentalis	320	7.3	4.6	625	0.71	1.74	1.59	1.86	3.92	3.59
Eucalyptus occidentalis	364	11.4	8.8	370	6.64	10.07	9.22	16.35	21.42	19.63
Eucalyptus occidentalis	460	6.7	8.2	980	7.31	11.90	11.09	7.31	11.90	11.09
Eucalyptus occidentalis	460	6.7	10.2	1190	13.32	19.42	17.79	13.32	19.42	17.79
Eucalyptus occidentalis	460	6.5	12.1	1111	18.93	26.44	24.22	18.93	26.44	24.22
Eucalyptus occidentalis	460	5.7	9.8	833	19.13	27.20	24.49	19.13	27.20	24.49
Eucalyptus occidentalis	492	9.9	10.5	1389	9.06	13.14	12.04	9.06	13.14	12.04
Eucalyptus occidentalis	492	9.3	13.0	684	21.40	27.39	25.10	46.50	52.64	48.23
Eucalyptus occidentalis	494	5.5	2.5	1000	0.39	1.33	1.22	0.63	1.85	1.69
Eucalyptus occidentalis	509	5.5	1.8	1000	0.09	0.65	0.59	0.17	0.84	0.77
Eucalyptus occidentalis	509	10.3	6.9	1251	3.00	5.34	4.89	9.37	13.77	12.62
Eucalyptus occidentalis	509	10.3	11.6	684	17.44	22.79	20.88	29.17	35.17	32.22

Species	Average Annual Rainfall [mm]	Age [years]	Height [m]	Trees Per Hectare	Average of Plots			Maximum of Plots		
					MAI Stemwood Volume (x1000) [m^3/plant/yr]	MAI Green Biomass [t/plant/yr]	MAI CO_2 equiv. [t/plant/yr]	MAI Stemwood Volume (x1000) [m^3/plant/yr]	MAI Green Biomass [t/plant/yr]	MAI CO_2 equiv. [t/plant/yr]
Eucalyptus occidentalis	559	8.4	11.4	947	17.58	23.85	21.85	27.00	34.18	31.31
Eucalyptus oleosa	387	6.8	3.0	2083	1.36	4.44	5.04	1.36	4.44	5.04
Eucalyptus ovata	492	9.3	10.1	684	12.08	17.27	15.19	12.08	17.27	15.19
Eucalyptus ovata	559	4.3	2.8	947	0.30	1.25	1.10	0.30	1.25	1.10
Eucalyptus ovata	698	7.4	7.8	1600	7.41	12.01	10.56	8.83	13.91	12.24
Eucalyptus porosa	348	10.3	5.8	370	1.62	4.86	4.20	1.62	4.86	4.20
Eucalyptus porosa	364	11.4	4.8	370	1.59	4.60	3.98	4.47	11.36	9.82
Eucalyptus porosa	387	6.7	3.9	2083	3.43	9.79	8.46	3.43	9.79	8.46
Eucalyptus saligna	492	6.8	9.1	1068	10.00	15.40	13.83	10.00	15.40	13.83
Eucalyptus saligna	583	14.1	11.5	1166	4.38	6.96	6.12	4.87	7.61	6.69
Eucalyptus saligna	698	7.4	9.7	1600	10.13	15.56	13.68	11.00	16.67	14.66
Eucalyptus tereticornis	509	9.4	11.0	684	14.68	19.91	17.51	23.26	29.66	26.08
Eucalyptus tereticornis	559	4.3	2.6	947	0.29	1.22	1.07	0.60	1.91	1.68
Eucalyptus tereticornis	613	9.4	11.9	928	13.42	18.69	16.43	22.96	29.35	25.81
Eucalyptus tereticornis	698	9.3	6.0	1600	5.67	9.28	8.16	5.67	9.28	8.16
Eucalyptus viminalis	460	5.7	10.0	714	20.58	28.24	22.29	20.58	28.24	22.29
Eucalyptus viminalis	492	9.9	11.1	1157	15.02	20.31	16.03	15.02	20.31	16.03
Eucalyptus viminalis	497	13.3	9.6	973	3.54	5.91	4.66	3.54	5.91	4.66
Eucalyptus viminalis	554	18.7	19.6	684	11.71	14.91	11.77	13.01	16.28	12.85
Eucalyptus viminalis	492	9.3	8.6	684	14.84	20.47	16.16	14.84	20.47	16.16
Melaleuca cuticularis	492	9.3	3.4	684	0.84	1.75	1.44	0.84	1.75	1.44
Melaleuca cuticularis	509	9.4	1.5	684	0.040	0.055	0.045	0.040	0.055	0.045
Melaleuca uncinata	348	10.3	1.6	370	0.003	0.004	0.003	0.003	0.004	0.003
Melaleuca uncinata	492	9.3	1.5	684	0.003	0.004	0.003	0.003	0.004	0.003

Table 45. Observed productivity of best performing plots within each species at each site (top 10% within species and site) from trial sites and surveys in the Upper South East region and neighbouring districts.

Species and Provenance	Av. Annual Rainfall [mm]	Age [years]	Height [m]	Trees Per Hectare	MAI Stemwood Volume (x1000) [m³/plant/yr]	MAI Green Biomass [t/plant/yr]	MAI CO_2 equiv. [t/plant/yr]
Acacia dealbata ssp. *dealbata* [Errinundra Plateau CS16271]	671	3.4	4.3		1.66	2.13	1.91
Acacia mearnsii [Kyneton CS18979]	559	4.3	4.0	355	0.81	1.00	1.06
Acacia mearnsii [Lanark Branxholme]	492	12.5	9.9	3017	6.43	10.95	11.59
Acacia melanoxylon [Blackwood Park CS15863]	698	10.4	8.9	308	14.64	25.78	23.15
Acacia melanoxylon [Cressy TFC_1998.01]	671	3.4	5.1		2.56	3.39	3.04
Acacia melanoxylon [Furner TFL_1992.02]	559	8.4	4.5	710	1.12	1.49	1.33
Acacia melanoxylon [Silver Creek CS15614]	613	7.4	5.0	928	1.23	1.63	1.46
Acacia melanoxylon [Silver Creek CS15614]	698	7.4	6.2	1400	3.68	5.40	4.85
Acacia melanoxylon [WF601]	741	7.0	2.8	244	0.35	0.42	0.38
Acacia pycnantha	387	7.0	3.4	528	2.07	9.73	9.15
Acacia salicina [Yacka FTI_P_1992.01]	492	9.3	3.5	598	0.87	1.14	1.02
Acacia stenophylla [Riverland FTI_W_1992.01]	492	9.3	4.9	171	1.07	1.43	1.28
Allocasuarina verticillata	492	10.9	8.6	395	17.96	33.57	36.13
Atriplex *nummularia*	466	3.0	1.6	966	1.89	3.97	2.80
Callitris columellaris [Mambray Creek BSC_1992.01]	348	9.4	2.9	370	0.23	0.28	0.25
Casuarina cunninghamiana ssp. *cunninghamiana* [Hunter River CS13127]	698	10.4	9.1	1400	8.40	13.95	12.52
Casuarina glauca	480	8.5	4.5	961	1.01	1.33	1.20
Casuarina glauca	610	8.7	3.7	948	0.55	0.70	0.62
Casuarina glauca	610	8.7	3.4	948	0.57	0.73	0.65
Casuarina glauca	625	8.6	3.9	877	0.67	0.86	0.78
Casuarina glauca [Coffs Harbour CS13987]	559	8.4	7.5	947	5.05	7.77	6.98
Casuarina glauca [Coffs Harbour CS13987]	559	8.4	6.5	947	5.63	8.77	7.87
Casuarina glauca [Mangrove Creek CS13143]	492	9.3	8.6	427	5.72	9.00	8.08
Casuarina glauca [Myall Lakes CS15934]	509	10.3	10.2	598	10.54	17.90	16.07
Casuarina glauca [Singleton CS13128]	698	10.4	8.5	1600	5.02	7.88	7.08
Casuarina obesa	480	8.5	4.5	865	1.08	1.44	1.29
Casuarina obesa	610	8.7	3.1	1125	0.38	0.46	0.42
Casuarina obesa	625	8.6	3.6	687	0.38	0.47	0.42
Casuarina pauper (cristata) [Flinders Range BSC_1992.02]	364	11.4	3.7	231	0.21	0.25	0.23
Corymbia citriodora ssp. *variegata*	466	5.8	2.6	563	0.17	0.80	0.71
Corymbia citriodora ssp. *variegata*	466	5.8	2.5	547	0.17	0.80	0.71
Corymbia maculata	466	5.8	3.0	734	0.29	1.09	0.93
Corymbia maculata	466	5.8	3.1	906	0.30	1.11	0.95
Corymbia maculata	466	5.8	3.1	781	0.32	1.15	0.98
Corymbia maculata	492	10.8	9.0	432	9.24	12.53	10.68
Corymbia maculata	492	6.9	10.2	685	12.69	18.62	15.86
Corymbia maculata [Orbost CS13608]	613	7.4	11.2	928	9.77	15.12	12.89
Eucalyptus astringens [Boyagin Rock CS17670]	364	11.4	7.6	370	7.12	10.78	9.48

Species and Provenance	Av. Annual Rainfall [mm]	Age [years]	Height [m]	Trees Per Hectare	MAI Stemwood Volume (x1000) [m³/plant/yr]	MAI Green Biomass [t/plant/yr]	MAI CO_2 equiv. [t/plant/yr]
Eucalyptus astringens [Cuballing CALM D921]	559	8.4	8.6	592	10.79	16.02	14.09
Eucalyptus astringens [Dryandra CALM 91038]	559	8.4	9.2	828	10.27	15.39	13.53
Eucalyptus astringens [Dryandra CS12842]	320	7.3	4.3	625	0.79	2.02	1.78
Eucalyptus astringens [Ravensthorpe CS17685]	559	8.4	7.3	237	9.75	14.74	12.96
Eucalyptus botryoides [Narooma CS15529]	492	9.3	9.9	427	8.51	12.94	11.38
Eucalyptus botryoides [Termeil CS12134]	698	7.4	10.6	1600	15.87	22.55	19.83
Eucalyptus botryoides [Termeil CS12134]	698	7.4	11.1	1600	16.35	23.12	20.33
Eucalyptus brockwayi [Davyhurst CALM 9081]	671	3.4	2.4		0.34	1.49	1.31
Eucalyptus brockwayi [Kondinin CALM 9042]	348	10.3	6.2	139	4.56	7.60	6.69
Eucalyptus camaldulensis	445	19.4	8.8	609	2.75	4.48	3.27
Eucalyptus camaldulensis	492	9.9	8.2	1103	4.59	7.47	5.44
Eucalyptus camaldulensis [Crystal Brook FTI_TD_1996.01]	559	7.4	5.4	473	2.44	4.87	3.55
Eucalyptus camaldulensis [Crystal Brook FTI_TD_1996.01]	559	7.4	5.1	473	2.47	4.91	3.58
Eucalyptus camaldulensis [Culburra cult. (P05)]	460	10.7	11.4	793	20.70	25.68	18.72
Eucalyptus camaldulensis [Kalangadoo FTI_H_1992.01]	698	10.4	9.3	1400	19.73	25.41	18.53
Eucalyptus camaldulensis [Mt. Wedge, Eyre Penn.]	376	7.7	9.6	1027	9.52	14.05	10.24
Eucalyptus camaldulensis [Sherlock cult.]	362	7.6	5.7	142	4.09	7.17	5.23
Eucalyptus camaldulensis [WF607]	741	7.0	3.2	376	0.91	2.26	1.65
Eucalyptus camaldulensis [WF608]	741	7.0	3.5	392	0.84	2.14	1.56
Eucalyptus camaldulensis var. *camaldulensis* [Lake Albacutya CS15029]	509	9.4	15.7	513	44.41	50.64	36.92
Eucalyptus camaldulensis var. *obtusa* [Lake Indoon CS15799]	492	9.3	6.9	513	12.95	18.29	13.33
Eucalyptus cladocalyx	444	19.4	10.4	1085	3.28	5.19	4.82
Eucalyptus cladocalyx	444	19.4	10.1	1077	3.45	5.41	5.02
Eucalyptus cladocalyx	447	19.4	7.6	811	1.35	2.51	2.33
Eucalyptus cladocalyx	447	19.4	9.0	939	1.48	2.70	2.51
Eucalyptus cladocalyx	460	19.3	12.8	470	7.09	9.80	9.11
Eucalyptus cladocalyx [Culburra cult. (P18B)]	460	6.7	5.6	793	3.56	6.53	6.17
Eucalyptus cladocalyx [Culburra cult. (P27)]	460	10.7	14.9	440	30.55	35.65	33.13
Eucalyptus cladocalyx [Culburra cult. (P34A)]	460	6.7	5.0	939	4.26	7.81	7.13
Eucalyptus cladocalyx [Culburra cult. (P34A)]	460	6.7	6.4	1024	5.10	8.85	8.22
Eucalyptus cladocalyx [Flinders Chase NP KI CS16022]	698	10.4	11.0	200	56.38	60.57	56.28
Eucalyptus cladocalyx [Genotype 9]	466	10.9	7.3	200	6.47	10.05	9.34
Eucalyptus cladocalyx [Kangaroo Island TFL_1993.02]	613	10.3	12.9	348	33.28	39.21	36.43
Eucalyptus cneorifolia [Kingscote CS16023]	492	9.3	3.9	171	0.98	3.26	3.16
Eucalyptus cneorifolia [Kingscote CS16023]	559	8.4	3.5	473	0.42	1.74	1.69
Eucalyptus cornuta [Albany CS11256]	559	8.4	9.3	473	12.59	18.20	16.00
Eucalyptus diversifolia [Culburra (P37A)]	460	12.7	5.5	1279	4.04	13.77	13.16
Eucalyptus dumosa	387	12.0	3.8	836	1.07	3.32	3.51
Eucalyptus dumosa [Lameroo GA_1993.04]	348	10.3	3.6	324	0.32	1.35	1.43
Eucalyptus dundasii [FTI_1996.01]	671	3.4	2.6		0.25	1.29	1.14
Eucalyptus dundasii [Norseman CS12260]	348	10.3	6.6	185	2.68	4.92	4.33

Species and Provenance	Av. Annual Rainfall [mm]	Age [years]	Height [m]	Trees Per Hectare	MAI Stemwood Volume (x1000) [m³/plant/yr]	MAI Green Biomass [t/plant/yr]	MAI CO_2 equiv. [t/plant/yr]
Eucalyptus dundasii [Norseman CS12260]	364	11.4	8.0	231	5.92	9.27	8.15
Eucalyptus famelica [Ravensthorpe NS-03871]	509	10.3	2.4	171	0.08	0.59	0.58
Eucalyptus fasciculosa [Willalooka FTI_J_1994.02]	492	9.3	1.5	85	0.01	0.27	0.24
Eucalyptus globulus	444	16.6	14.1	930	8.79	12.01	10.22
Eucalyptus globulus	444	16.6	14.9	929	9.52	12.83	10.91
Eucalyptus globulus	445	19.4	17.8	547	17.31	20.47	17.42
Eucalyptus globulus	457	14.2	14.3	491	11.25	15.14	12.89
Eucalyptus globulus	460	19.3	14.3	549	12.36	15.52	13.21
Eucalyptus globulus	492	6.8	11.1	1010	14.65	21.10	17.95
Eucalyptus globulus	492	15.7	18.2	294	20.80	24.74	21.05
Eucalyptus globulus	506	19.1	15.3	1124	6.01	8.56	7.29
Eucalyptus globulus	506	19.1	15.8	1070	6.18	8.77	7.46
Eucalyptus globulus	506	19.1	16.3	1100	6.70	9.37	7.97
Eucalyptus globulus	506	16.9	14.5	666	8.02	11.11	9.45
Eucalyptus globulus	506	16.9	14.8	417	8.07	11.16	9.50
Eucalyptus globulus	506	16.9	14.2	416	8.54	11.70	9.95
Eucalyptus globulus	506	16.9	14.0	416	8.65	11.82	10.05
Eucalyptus globulus	506	16.9	13.6	380	8.77	11.95	10.17
Eucalyptus globulus	506	16.9	14.3	390	8.89	12.08	10.28
Eucalyptus globulus	506	16.9	14.7	421	8.90	12.09	10.29
Eucalyptus globulus	510	16.7	16.0	863	7.29	10.29	8.75
Eucalyptus globulus	510	16.7	15.0	870	7.78	10.85	9.23
Eucalyptus globulus	511	14.2	13.4	702	7.09	10.35	8.80
Eucalyptus globulus	511	14.2	12.9	739	7.21	10.49	8.93
Eucalyptus globulus	540	27.1	26.8	770	16.47	18.55	15.78
Eucalyptus globulus	554	18.7	18.2	829	8.38	11.31	9.62
Eucalyptus globulus	554	18.7	18.5	878	9.21	12.23	10.41
Eucalyptus globulus	566	20.8	21.2	1641	8.02	10.71	9.12
Eucalyptus globulus	566	20.8	21.4	1617	8.73	11.48	9.77
Eucalyptus globulus	569	16.3	19.9	911	15.14	18.89	16.07
Eucalyptus globulus	569	16.3	19.9	928	15.61	19.37	16.48
Eucalyptus globulus	583	14.1	14.0	1059	7.26	10.56	8.98
Eucalyptus globulus	583	14.1	14.0	963	7.52	10.87	9.25
Eucalyptus globulus [APP]	625	9.8	12.2	1200	11.97	17.01	14.47
Eucalyptus globulus [APP]	625	9.8	13.0	800	13.07	18.29	15.56
Eucalyptus globulus [APP]	659	9.7	11.4	1600	7.10	11.07	9.42
Eucalyptus globulus [Culburra cult. (P05)]	460	10.7	12.5	898	12.26	16.40	13.95
Eucalyptus globulus [Flinders Island]	497	13.3	14.7	924	11.14	15.19	12.92
Eucalyptus globulus [Flinders Island]	497	13.3	14.5	973	12.44	16.63	14.15
Eucalyptus globulus [Flinders Island]	625	9.8	12.6	1600	12.03	17.07	14.53
Eucalyptus globulus [Flinders Island]	625	9.8	11.0	1200	12.12	17.18	14.62
Eucalyptus globulus [Flinders Island]	625	9.8	12.7	1600	13.17	18.40	15.66
Eucalyptus globulus [Flinders Island]	659	9.7	11.3	1600	7.47	11.54	9.82
Eucalyptus globulus [Flinders Island]	659	9.7	11.7	1600	7.70	11.82	10.06

Species and Provenance	Av. Annual Rainfall [mm]	Age [years]	Height [m]	Trees Per Hectare	MAI Stemwood Volume (x1000) [m³/plant/yr]	MAI Green Biomass [t/plant/yr]	MAI CO_2 equiv. [t/plant/yr]
Eucalyptus globulus [Jeeralang]	659	9.7	10.9	1600	7.23	11.23	9.56
Eucalyptus globulus ssp. *globulus* [cult. Worrolong]	659	9.7	11.8	1600	7.74	11.88	10.11
Eucalyptus globulus ssp. *globulus* [cult.]	606	4.9	18.0	1143	42.78	54.54	46.40
Eucalyptus globulus ssp. *globulus* [cult.]	606	4.9	19.2	1136	43.03	54.89	46.71
Eucalyptus globulus ssp. *pseudoglobulus*	659	9.7	11.8	1600	7.01	10.95	9.31
Eucalyptus globulus ssp. *pseudoglobulus*	659	9.7	11.7	1600	7.23	11.23	9.55
Eucalyptus gomphocephala [Culburra cult. (P23B)]	460	12.0	12.4	500	60.85	60.63	54.42
Eucalyptus gomphocephala [Ludlow CS12308]	559	8.4	9.5	355	33.52	40.88	35.95
Eucalyptus gracilis [Karoonda GA_1992.02]	364	10.3	2.7	139	0.40	1.60	1.55
Eucalyptus grandis	492	15.7	10.8	445	4.81	7.38	6.49
Eucalyptus grandis	492	15.7	11.2	498	5.05	7.68	6.75
Eucalyptus grandis	583	14.1	12.2	995	4.63	7.29	6.41
Eucalyptus grandis	583	14.1	12.2	995	4.63	7.29	6.41
Eucalyptus grandis	583	14.1	11.3	712	4.87	7.61	6.69
Eucalyptus grandis	583	14.1	11.3	712	4.87	7.61	6.69
Eucalyptus grandis [Coffs Harbour CS13020]	698	7.4	9.5	1600	9.94	15.33	13.48
Eucalyptus grandis [Shepparton]	492	6.8	10.6	945	13.20	19.44	17.45
Eucalyptus incrassata	374	8.0	3.7	1120	1.68	5.19	5.20
Eucalyptus incrassata [Culburra cult. (P37A)]	460	12.7	3.6	712	1.49	7.24	7.25
Eucalyptus kondininensis [FTx37079]	671	3.4	3.5		0.68	2.25	1.98
Eucalyptus kondininensis [Varley FTI_1999.03]	559	4.3	2.3	118	0.16	0.92	0.81
Eucalyptus largiflorens [Renmark CS16528]	492	9.3	6.2	598	2.42	4.62	4.06
Eucalyptus largiflorens [Renmark CS16528]	559	7.4	3.3	592	0.34	1.11	0.98
Eucalyptus largiflorens [Renmark CS16528]	613	7.4	3.4	928	0.16	0.70	0.61
Eucalyptus leptophylla [Lameroo GA_1993.02]	348	10.3	3.5	370	0.14	0.77	0.75
Eucalyptus leptophylla [Lameroo GA_1993.02]	364	10.3	2.9	46	0.28	1.23	1.20
Eucalyptus leucoxylon [Williamstown]	492	10.7	8.6	1088	6.75	10.03	9.68
Eucalyptus leucoxylon ssp. *leucoxylon* [Kangaroo Island CS13046]	492	9.3	12.7	684	22.18	28.54	27.54
Eucalyptus leucoxylon ssp. *leucoxylon* [Kangaroo Island CS13046]	559	8.4	7.6	710	11.84	17.30	16.69
Eucalyptus leucoxylon ssp. *leucoxylon* [Kangaroo Island CS13046]	613	10.3	12.2	580	33.66	39.58	38.20
Eucalyptus leucoxylon ssp. *leucoxylon* [Kangaroo Island CS13046]	698	10.4	13.4	1200	35.30	41.11	39.68
Eucalyptus leucoxylon ssp. *leucoxylon* [Kangaroo Island CS13046]	698	10.4	13.1	1600	37.33	43.06	41.56
Eucalyptus leucoxylon ssp. *leucoxylon* [Naracoorte CS16527]	492	9.3	12.1	684	21.65	27.97	27.00
Eucalyptus leucoxylon ssp. *leucoxylon* [Rushworth CS09608]	364	11.4	9.1	370	5.60	8.86	8.55
Eucalyptus leucoxylon ssp. *leucoxylon* [Rushworth CS09608]	364	11.4	9.7	370	6.27	9.71	9.37
Eucalyptus leucoxylon ssp. *leucoxylon* [Wirrabara CS16012]	320	7.3	3.9	469	0.20	0.79	0.76
Eucalyptus leucoxylon ssp. *leucoxylon* [Wirrabara CS16012]	364	11.4	8.2	370	5.88	9.22	8.90

Species and Provenance	Av. Annual Rainfall [mm]	Age [years]	Height [m]	Trees Per Hectare	MAI Stemwood Volume (x1000) [m³/plant/yr]	MAI Green Biomass [t/plant/yr]	MAI CO_2 equiv. [t/plant/yr]
Eucalyptus leucoxylon ssp. *megalocarpa* [Nelson CS12456]	364	13.1	6.8	500	7.80	11.35	10.95
Eucalyptus obliqua [Smithton CS13156]	613	7.4	7.9	928	5.97	10.08	8.86
Eucalyptus occidentalis	492	9.9	10.5	1198	9.06	13.14	12.04
Eucalyptus occidentalis [Bremer Bay CS13640]	509	10.3	9.8	256	27.88	33.88	31.04
Eucalyptus occidentalis [Bremer Bay CS13640]	509	10.3	11.3	85	29.17	35.17	32.22
Eucalyptus occidentalis [Bremer Bay CS13640]	559	8.4	10.8	828	25.45	32.55	29.82
Eucalyptus occidentalis [Broomehill CS13634]	509	10.3	14.2	598	27.97	33.97	31.12
Eucalyptus occidentalis [Culburra cult. (P18A)]	460	5.7	9.8	708	19.13	27.20	24.49
Eucalyptus occidentalis [Culburra cult. (P34A)]	460	6.7	8.2	828	7.31	11.90	11.09
Eucalyptus occidentalis [Culburra cult. (P34A)]	460	6.5	12.1	1111	18.93	26.44	24.22
Eucalyptus occidentalis [Culburra cult.(P34A)]	460	6.7	10.2	1133	13.32	19.42	17.79
Eucalyptus occidentalis [Genotype 45]	509	10.3	8.3	250	9.37	13.77	12.62
Eucalyptus occidentalis [Grass Patch CS13647]	364	11.4	11.4	231	16.35	21.42	19.63
Eucalyptus occidentalis [Jerramungup CALM A92122]	492	9.3	13.6	342	46.50	52.64	48.23
Eucalyptus occidentalis [Jerramungup CALM A92122]	559	8.4	11.7	473	27.00	34.18	31.31
Eucalyptus occidentalis [Pallerup Rock CS15406]	320	7.3	6.4	469	1.86	3.92	3.59
Eucalyptus occidentalis [Prov. 11]	494	5.5	3.0	889	0.61	1.81	1.66
Eucalyptus occidentalis [Prov. 11]	509	5.5	2.1	672	0.15	0.79	0.73
Eucalyptus occidentalis [Prov. 12]	509	5.5	2.4	594	0.17	0.83	0.76
Eucalyptus occidentalis [Prov. 20]	494	5.5	3.0	848	0.63	1.85	1.69
Eucalyptus occidentalis [Prov. 20]	509	5.5	2.1	547	0.17	0.84	0.77
Eucalyptus occidentalis [Prov. 9]	494	5.5	2.9	892	0.61	1.80	1.65
Eucalyptus oleosa	387	6.8	3.0	1585	1.36	4.44	5.04
Eucalyptus ovata [Willunga FTI_1999.01]	559	4.3	2.8	828	0.30	1.25	1.10
Eucalyptus ovata [Yundi BSC_1994.01]	492	9.3	10.1	598	12.08	17.27	15.19
Eucalyptus ovata [Yundi BSC_1994.01]	698	7.4	8.5	1600	8.83	13.91	12.24
Eucalyptus porosa [cult. (Cattle)]	387	6.7	3.9	1522	3.43	9.79	8.46
Eucalyptus porosa [Tailem Bend FR FTI_JF_1992.01]	348	10.3	5.8	370	1.62	4.86	4.20
Eucalyptus porosa [Tailem Bend FR FTI_JF_1992.01]	364	11.4	7.0	324	4.47	11.36	9.82
Eucalyptus saligna	492	6.8	9.1	880	10.00	15.40	13.83
Eucalyptus saligna	583	14.1	12.2	995	4.63	7.29	6.41
Eucalyptus saligna	583	14.1	12.2	995	4.63	7.29	6.41
Eucalyptus saligna	583	14.1	11.3	712	4.87	7.61	6.69
Eucalyptus saligna	583	14.1	11.3	712	4.87	7.61	6.69
Eucalyptus saligna [Relligen CS13015]	698	7.4	9.8	1600	11.00	16.67	14.66
Eucalyptus tereticornis ssp. *tereticornis* [Lochsport CS13302]	698	9.3	6.0	800	5.67	9.28	8.16
Eucalyptus tereticornis ssp. *tereticornis* [Yurrammie SF CS17768]	509	9.4	13.3	598	23.26	29.66	26.08
Eucalyptus tereticornis ssp. *tereticornis* [Yurrammie SF CS17768]	559	4.3	2.9	237	0.60	1.91	1.68
Eucalyptus tereticornis ssp. *tereticornis* [Yurrammie SF CS17768]	613	9.4	13.8	696	22.96	29.35	25.81
Eucalyptus viminalis	497	13.3	9.6	827	3.54	5.91	4.66
Eucalyptus viminalis	554	18.7	20.1	594	11.78	14.99	11.83

Species and Provenance	Av. Annual Rainfall [mm]	Age [years]	Height [m]	Trees Per Hectare	MAI Stemwood Volume (x1000) [m³/plant/yr]	MAI Green Biomass [t/plant/yr]	MAI CO_2 equiv. [t/plant/yr]
Eucalyptus viminalis	554	18.7	20.2	532	13.01	16.28	12.85
Eucalyptus viminalis [Culburra cult. (P47A)]	460	5.7	10.0	526	20.58	28.24	22.29
Eucalyptus viminalis ssp. *cygnetensis*	492	9.9	11.1	855	15.02	20.31	16.03
Eucalyptus viminalis ssp. *cygnetensis* [Tintinara FTI_J_1994.01]	492	9.3	8.6	256	14.84	20.47	16.16
Melaleuca *cuticularis* [Stirling Range CALM P9088]	492	9.3	3.4	598	0.84	1.75	1.44
Melaleuca *cuticularis* [Stirling Range CALM P9088]	509	9.4	1.5	598	0.04	0.05	0.05
Melaleuca *uncinata* [Karoonda GA_1993.03]	348	10.3	1.6	278	0.003	0.004	0.003
Melaleuca *uncinata* [Keith SFMB_1994.01]	492	9.3	1.5	171	0.003	0.004	0.003

Appendix C. – Weed Risk Assessments

Acacia saligna

Environmental Weed Risk Assessment

Species: *Acacia saligna*

Submitted by*:* Wayne O'Sullivan, Nic George

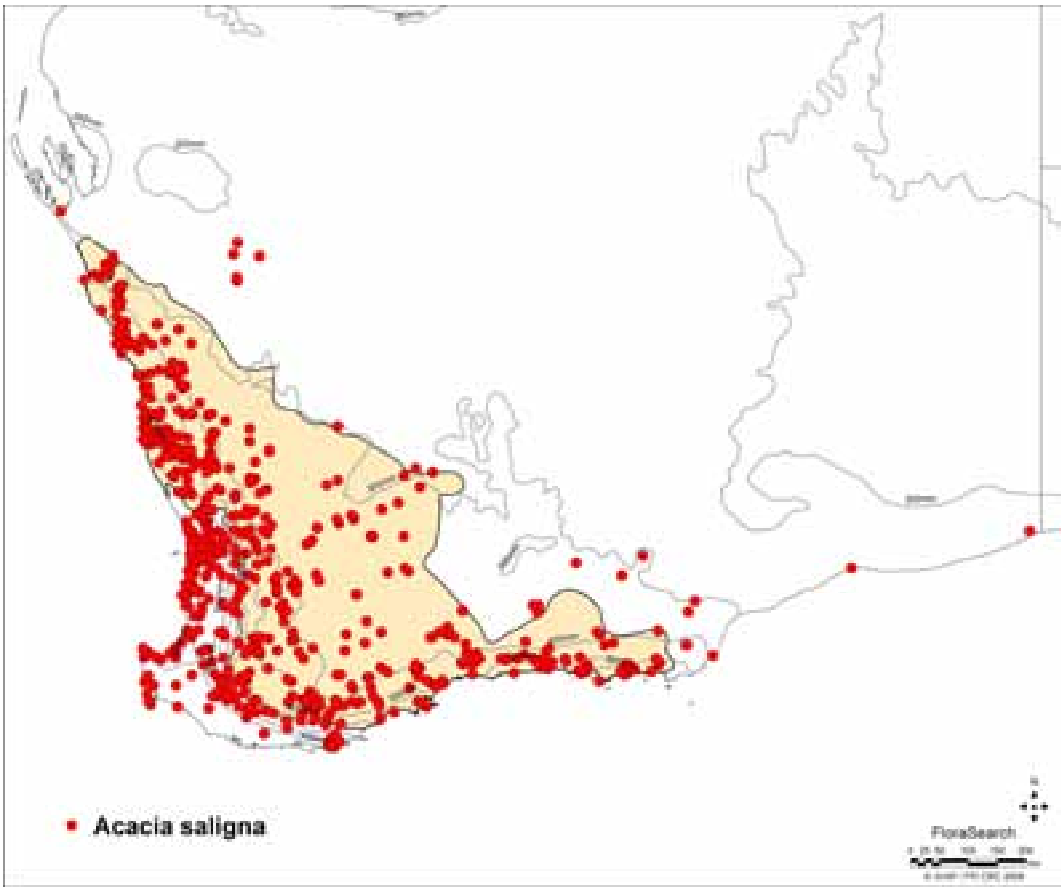
Reviewed by: Lynley Stone, John Virtue, Brian Dear

Species summary:

Acacia saligna has become an invasive weed both within Australia and internationally. However, utilization of the species for dryland salinity management in the Wheatbelt will most likely pose a minimal weed risk because it is endemic to the south-west of Western Australia (Fig. 1), with it natural range encompassing the Wheatbelt region. The weed risk posed by *A. saligna* within the south-west may increase if traits such as increased pest and disease resistance, or tolerance to adverse environmental conditions, are selected for as part of the species domestication program. Problems may also arise if genetically differentiated provenances are moved around the landscape in the south-west. These issues are beyond the scope of this weed risk assessment but will need to be addressed as part of the domestication of *A. saligna*. Due to the differing weed risk posed by *A. saligna* in south-western Australia and the rest of the country we have attempted to give two separate answers to each of the questions in this assessment. One answer is for south-western Australia and one answer is for the rest of the country. WA – Answer for south-western Australia. EA – Answer for elsewhere in Australia.

Fig. 1. The natural distribution of *Acacia saligna* in Western Australia.

Compiled from herbaria records. Shaded region indicates the FloraSearch study zone.



Section 1: Invasiveness

1. Does the species have a *documented* environmental weed history?

- [x] a) Is an environmental weed in Australia
- [ ] b) Is an environmental weed overseas
- [ ] c) Species not known to be an environmental weed but there are environmental weed species in the genus
- [ ] d) Genus has no known environmental weeds

Comments: *Acacia saligna* has become a weed in many areas where it has been introduced (Blood 2001; Muyt 2001; Swarbrick and Skarratt 1994). The species is naturalized in all states of Australia and all regions of the world which experience a Mediterranean-like climate (Fox 1995; Muyt 2001). It is a problematic weed in South Australia, where it is widespread in the south of the state and out-competes native vegetation (Virtue and Melland 2003). It is reportedly not as problematic in Victoria or New South Wales, although John Hosking believes it has the potential become more problematic in New South Wales.

Until the mid 1990's *A. saligna* was considered one of South Africa's most problematic 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 biological-control (Morris 1999).

2. What is the species' ability to establish in competition with other plant competitors and pests, such as weeds or native species, in trial plots or other situations?

- ☐ a) Establishment superior to other plant species (90 - 100% establishment, other plants suppressed)
- ☑ b) Establishment relatively unimpeded (50 - 89% establishment) (EA)
- ☑ c) Establishment impeded (10 - 49% establishment) (WA will be affected by degree of disturbance)
- ☐ d) Establishment impeded significantly (<10% establishment)
- ☐ e) Don't know

Comments: I have not found information relating to the establishment of *A. saligna* in competition with weeds in Western Australia. Wayne O'Sullivan, Dan Huxtable and I have discussed this and cannot reach an agreement regarding the species alibility to compete in mixed plots. Dan believes there is substantial observational experience to suggest that *A. saligna* is unlikely to establish from seed in plots on agricultural land without significant intervention (i.e. control of annual weeds or protection from grazing). Although, in South Australia *A. saligna* has been observed establishing in vegetation, including both dense native groundcover and weeds, apparently from both sucker and seedling growth (Virtue and Melland 2003). It is also used extensively in direct seeding work on the Yorke Peninsular in South Australia, because of its vigour (J. Virtue pers comm.). I have observed individual plants establishing in Banksia woodland in Kings Park. I believe we can conclude that the ability of *A. saligna* to establish under competition from pre-existing vegetation is low, but it will be highly competitive if it germinates at the same time as other vegetation, such as following a fire or heavy grazing. John Virtue has suggested the answer to this question could be 50 - 89% survival after disturbance. John Hosking independently made a similar claim. The competitiveness of *A. saligna* is due to its aggressive growth, extensive root system and tolerance of poor environmental conditions (Morris 1999; Witkowski 1991). In addition, the fast growth and broad canopy of *A. saligna* is reported to suppress weed growth.

3. To what degree can the species tolerate herbivory pressure?

- ☐ a) Is not palatable and is rarely grazed
- ☐ b) Will tolerate continuous grazing for an extended period of time
- ☑ c) Will tolerate rotational grazing all year round(WA/EA) (when established)
- ☐ d) Will tolerate some grazing at particular times of the year
- ☐ e) Has low tolerance to grazing, plants are easily killed
- ☐ f) Don't know

Comments: Mature plants of *A. saligna* will tolerate regular (although not continuous) grazing all year round. Kangaroos and rabbits have been observed to graze and kill recently planted *A. saligna*, sometimes preferentially in mixed species plantings (Wayne O'Sullivan pers. comm.). Mature *A. saligna* can probably tolerate regular grazing by re-sprouting from the roots and trunk (Morris 1999; Witkowski 1991). Observations support the notion that there is significant variation in suckering and coppicing ability within the species (Dan Huxtable pers. comm.). There is probably a significant genetic component underpinning these traits.

4. What is the species' ability to persist as a long-term sward or stand without management?

- ☐ a) Plant numbers increase substantially with successive reproductive cycles to form a near monoculture
- ☑ b) Plant numbers remain at a steady level, persisting as a significant component of a mixed sward/stand
- ☐ c) Plant numbers decline slowly over successive years so that it becomes a minor component of the vegetation
- ☐ d) Plant numbers decline rapidly over successive years so that only occasional plants can be found
- ☐ e) Don't know

Comments: Information regarding the rate of seedling survival of *A. saligna* in Western Australia has not been found. Dan believes that if the seedlings of *A. saligna* are able to survive the first 12 months from germination, they are likely to survive and persist. A study conducted in New South Wales found that 56 % of *A. saligna* seedlings, that emerged when a fire stimulated germination, died after 1 week (Tozer 1998). I think this indicates that persistence is probably average, with only 10 - 50% of established seedlings surviving more that 2 years. Individuals of *A. saligna* planted on farmland in Western Australia typically persist for 5-15 years (Dan Huxtable pers. comm.). The weediness of *A. saligna* is partially attributed to the species large seed set, the persistence of seed-bank and high germination rates (Morris 1999; Witkowski 1991). So even though seedling establishment may only be low this may be compensated for by large seed production.

5. Is the plant likely to rapidly colonise a site?

- ☐ a) At least 30 plants are found growing > 5 m from the original plots in the second or third years after planting for annuals, or within 10 years for perennials
- ☐ b) At least 30 plants are found growing > 1 m from the original plots in the second or third years after planting for annuals, or within 10 years for perennials
- ☑ c) At least 5 plants are found growing > 1 m from the original plots in the second or third years after planting for annuals, or within 10 years for perennials (WA/EA once plants are of reproductive age)
- ☐ d) No plants are found outside the plot, or plants are found growing within 1m of the original plots in the second or third years after planting for annuals, or within 10 years for perennials
- ☐ e) Don't know

Comments: In South Africa most seed from *A. saligna* falls directly below the canopy (Holmes *et al.* 1987; Milton and Siegfried 1981). It seems likely that the situation will be similar in Western Australia. The primary biotic dispersal mechanism for *A. saligna* seed in Western Australia is unknown, although in South African ants and birds are reported to disperse seeds (Fox 1995). Muyt (2001) states that in south-eastern Australia *A. saligna* is spread long distances by birds. In general, Acacia seed with large red arils is bird dispersed, and seed with smaller colourless arils is ant dispersed (New 1984). The arils of *A. saligna* are small and colourless, suggesting ants may be the primary biotic dispersal agent in Western Australia. This is the conclusion reached by Virtue and Melland (2003). Long distance transport by ants will probably be uncommon, although I have not read any studies that discuss it. John Majer from Curtin University says that the aril-type of *A. saligna* has evolved as an ant attractant. He has recorded ants from the genera *Rhytidoponera* and *Melophrous* rapidly removing seed from under trees. The seed is taken into nest where the arils are removed. The seed is undamaged and will create a buried seed store.

6. Will the species establish and reproduce in low-nutrient Australian soils?

- [ ] a) Establishment and reproductive ability uninhibited in low-nutrient soils
- [x] b) Establishment and reproductive ability reduced in low-nutrient soils (WA/EA)
- [ ] c) Establishment and reproductively severely diminished in low-nutrient soils
- [ ] d) Establishment and reproduction not likely in low-nutrient soils without soil additives
- [ ] e) Don't know

Comments: The environmental niches most commonly occupied by *Acacia saligna* are relatively nutrient rich, even within the generally nutrient poor environment of its natural range, for example streamlines, lake margins and edges of granite rocks. This has been exaggerated since clearing and the development of agriculture across much of its range, with increased disturbance and high nutrient runoff collecting in these zones, and the reduction in competition, stockpiling of topsoil and improved drainage in areas such as road verges. While some diminution of reproductive ability is observed with poor soils, the availability of water is a much more significant determinant of growth and seed production. In literature from elsewhere, *Acacia saligna* can reportedly tolerate nutrient poor soils (El-Lakany 1987), however the growth performance of the species is better on nutrient rich substrates (El-Baha *et al.* 2003; El-Lakany 1987; Jasper *et al.* 1989; Koreish *et al.* 1997). One of the factors that strongly influences the weedy distribution of *A. saligna* is South Africa was found to be soil nutrients (Higgins *et al.* 1999). No literature was found that dealt with the impact of additional soil nutrients on the reproductive potential of the species, although I have observed the species to flower and set large seed crops in unfertilized sandy soils.

Acacia saligna forms symbiotic associations with nitrogen-fixing bacteria and mychorizzal fungi. Studies show that, depending on soil conditions, biomass productivity of *A. saligna* is increased substantially by inoculation with root-nodule bacteria (Hatimi 1999; Koreish *et al.* 1997) and mycorrhizal fungi (Hatimi 1999; Hatimi *et al.* 1997; Jasper *et al.* 1989; Quatrini *et al.* 2003). *Acacia saligna* does not display specificity for root symbionts and instead can form associations with a large range of species native to soil both in Western Australia and elsewhere, including root-nodule bacteria of other commonly grown crop plants. We regularly find root-nodules on *A. saligna* seedlings growing in previously sterilized potting mix. Root-nodule bacteria and mychorrizal fungi, that are able to form associations with *A. saligna*, will therefore probably be present in the soil of most parts of south-western Australia. Once again, the impact of root symbionts on reproductive potential is unknown.

7. I. How likely is long-distance dispersal (>100m) by birds?

- ☐ a) Common
- ☑ b) Occasional
- ☐ c) Unlikely
- ☐ d) Don't know

Comments: I don't know how often bird transport of seed will occur. As already discussed above, some references suggest birds will move seed, but we have not observed it to occur (i.e. we have not observed birds actively foraging under *A. saligna* or seen Acacia seed in bird droppings). The majority of seed from *A. saligna* appears to fall directly beneath the parent tree, and the primary dispersal agent appears to be ants, which would not be expected to transport seed long distances. I believe *A. saligna* seed could survive passage through a bird gut because work has shown the *A. saligna* seed can survive treatment with concentrated acid, at high temperatures, for a number of hours (Shaybany and Rouhani 1976).

7.II. How likely is long-distance dispersal (>100m) by wild animals?

- ☐ a) Common
- ☑ b) Occasional
- ☐ c) Unlikely
- ☐ d) Don't know

Comments: The seed of African Acacia can survive passage through the gut of some mammals (New 1984). As discussed above, *A. saligna* seed can survive treatment with acid, so such dispersal is therefore possible. *Acacia saligna* seed is large and does not have characteristics that will lead to it adhering to the hair or skin of animals.

7.III. How likely is long-distance dispersal (>100m) by water?

- ☐ a) Common
- ☑ b) Occasional
- ☐ c) Unlikely
- ☐ d) Don't know

Comments: In my experience viable seed of *A. saligna* does not float readily, but Milton and Hall (1981) claim that *A. saligna* seed is transported by water in South Africa, as does Muyt (2001). The species shows a preference for riparian habitats, occasionally growing in the bed of ephemeral streams. It is likely that rapidly flowing water of sufficient volume could transport *A. saligna*. In the Jerdacuttup River area *A. saligna* was spread along a road verge for several kilometres after sand that contained seed was quarried from the bed of river for use as road base (Wayne O'Sullivan pers. comm.).

7.IV. How likely is long-distance dispersal (>100m) by wind?

- ☐ a) Common
- ☐ b) Occasional
- ☑ c) Unlikely
- ☐ d) Don't know

Comments: The seed of *A. saligna* is large and does not have the morphology to facilitate wind transport.

8. I. How likely is long-distance dispersal (>100m) accidentally by people and vehicles?

- ☐ a) Common
- ☑ b) Occasional
- ☐ c) Unlikely
- ☐ d) Don't know

Comments: Due to the morphology of *A. sali*gna seed I believe it is unlikely that it could be accidentally transported by people or vehicles by adhering to clothes or in dirt. However, large volumes of seed can build up in the soil under *A. saligna* trees. Seed densities of around 1400 to 3600 seed per m2 have been reported for populations of *A. saligna* growing in New South Wales (Tozer 1998), and densities of 5000 seed per m2 have been reported in South Africa, with most seed in the top 8 cm, although in loose sandy soil some seed was found at 35 cm (Milton and Siegfried 1981). I believe this makes it likely that the seed can be accidentally moved in soil from earth-works. Muyt (2001) reports that seed is moved by grading.

The species can reproduce via root suckers, although as I have already noted above sucking propensity appears to vary depending on provenance. Fox (1995) cites an example of plants being harvested by uprooting in winter and leaving a hollow that becomes surrounded by a ring of root shoots. We have observed dense populations of *A. saligna* distributed down road verges that may be the result of suckering following grading. The accidental movement of root fragments via earth-works is therefore also a possibility.

8.II. How likely is long-distance dispersal (>100m) accidentally by contaminated produce?

- ☐ a) Common
- ☐ b) Occasional
- ☑ c) Unlikely
- ☐ d) Don't know

Comments: *Acacia saligna* produces seed in November to January (Fox 1995) which coincides with grain harvesting in south-western Australia. However, we believe it is highly unlikely that *A. saligna* seed could become a contaminant of agricultural crops. These crops are harvested above ground level, either directly by taking grain from upright stems or by picking up material that has been piled in rows to facilitate moisture loss prior to harvest.

8.III. **How likely is long-distance dispersal (>100m) accidentally by domestic/farm animals?**

- ☐ a) Common
- ☑ b) Occasional
- ☐ c) Unlikely
- ☐ d) Don't know

Comments: The seed of African *Acacia* can survive passage through the gut of some mammals (New 1984), is therefore possible if could be transported in the gut of livestock. This would need to be confirmed. *Acacia saligna* seed is large and does not have characteristics that will lead to it adhering to the hair or skin of livestock.

9. I. What is the species' minimum generation time?

- ☐ a) ≤ 1 year
- ☑ b) 2-3 years
- ☐ c) >3 years/never
- ☐ d) Don't know

Comments: *Acacia saligna* has been observed to flower when 15 months old (Ryan and Bell 1989) and flowers heavily after 2 to 3 years (Maslin *et al.* 1998).

9.II. What is the species' average seed set?

- ☑ a) High (>1000 m-2/year for woody species, >5000 m-2/year for herbaceous species)
- ☐ b) Low
- ☐ c) None
- ☐ d) Don't know

Comments: Seed densities of around 1400 to 3600 seed per m^2 have been reported for populations of *A. saligna* growing in New South Wales (Tozer 1998), and densities of 5000 seed per m^2 have been reported in South Africa (Milton and Siegfried 1981). The higher seed set of *A. saligna* in South Africa compared to New South Wales is attributed to a lack of seed predation. It is possible that seed predation in Western Australia may be even higher than New South Wales.

9.III. What is the species' seed persistence in the soil seedbank?

- ☑ a) > 5 years
- ☐ b) 2-5 years
- ☐ c) < 2 years
- ☐ d) Don't know

Comments: Information regarding the potential longevity of *A. saligna* seed is not available. Other Acacia are known to persist for more than five years (perhaps up to a century?) (New 1984). Work conducted in New South Wales found that only 12 % of the total seed bank of *A. saligna* emerged after a fire simulated germination, the remaining seed were viable (Tozer 1998). In South Africa there may have been some viable seed seven years after clearing of adult plants (Holmes *et al.* 1987). Holmes (1988) found 100 % and 95 % seed viability in soil for *A. saligna* after six and eight years. Muyt (2001) claims that seed can remain viable for over a decade.

9.IV. Can the species' reproduce vegetatively?

- ☑ a) Yes (with disturbance)
- ☐ b) Slow (Under normal circumstances)
- ☐ c) No
- ☐ d) Don't know

Comments: Certain variants of the species, notably subspecies *stolonifera*, have the propensity to sucker more aggressively than other variants. Environmental factors, such as fire, are also likely to affect suckering.

Section 2: Impacts

1. Could the species reduce the biodiversity value of a natural ecosystem, either by reducing the amount of biodiversity present (diversity and abundance of native species), or degrading the visual appearance?

- ☐ a) The species could significantly reduce biodiversity such that areas infested become low priorities for nature conservation and/or nature-based tourism
- ☑ b) The species could have some effect on biodiversity and reduce its value for conservation and/or tourism (EA)
- ☐ c) The species would have marginal effects on biodiversity but is visually obvious and could degrade the natural appearance of the landscape
- ☑ d) The species would not effect biodiversity or the appearance of natural ecosystems (WA)
- ☐ e) Don't know

Comments: It is probable that in Western Australia *A. saligna* will not impact the products or services obtained from natural vegetation. It is even likely to enhance biodiversity, as is discussed in the following sections. However, the species' high fecundity, aggressive growth, extensive root system, and tolerance of poor environmental conditions (Morris 1999; Witkowski 1991) suggest outside its natural range it has a potential for invading and out-competing natural vegetation. In South Australia and South Africa it was found to replace indigenous vegetation (Melland and Virtue 2002; Morris 1999). John Virtue has observed thickets of *A. saligna* to establish in parts of South Australia. These thickets out-compete native vegetation and will persist for prolonged periods of time, perhaps over a decade, and will re-sprout if cleared.

2. Does the species have a history of, or potential to in your view, of reducing the establishment of other plant species?

☑ a) The species can significantly inhibit the establishment of other plants (e.g. regenerating native vegetation) by preventing germination and/or killing seedlings, and/or the species forms a monoculture (EA)

☐ b) The species can inhibit the establishment of other plants and/or does/will become dominant.

☑ c) The species can cause some minor displacement by inhibiting establishment, but will not become dominant. (WA)

☐ d) The species does not inhibit the establishment of other plants.

☐ e) Don't know

Comments: As noted above, it is unlikely that in Western Australia *A. saligna* will exclude the establishment of natural vegetation, although it will compete strongly for nutrients and other resources (particularly water) after disturbance, especially fire. It is a pioneer species (Fox 1995) and may actually facilitated the establishment of other plants in disturbed environments as part of a species succession, such as through the provision of shelter or nutrients via litter-fall.

The research literature shows that outside it natural range it will out-compete natural vegetation. For example, Virtue and Melland (2003) report that in the upper South-East and on the Eyre Peninsula of South Australia, *A. saligna* forms thickets and out-competes local native species. These authors also suggest that after a fire rapid seedling growth combined with rapid suckering growth from adult plants may significantly interfere with regeneration of native woody species in South Australia. In a case study from southern Cyprus, Christodoulou (2003) shows that invasion by *Acacia saligna* into the Akrotiri salt marshes has resulted in significant environmental damage. There has been a reduction in species richness, with the degree of reduction directly related to the density of *A. saligna*. There have been changes in plant community structure and species composition, reduced species richness, and local extinctions. Studies have found that the crops growing in the vicinity of *A. saligna* plantings exhibited depressed growth (Droppelmann *et al.* 2000a; Knight *et al.* 2002; Unkovich *et al.* 2003).

3. Could the species alter the structure of any native ecosystems at risk of invasion from this species by adding a new strata level?

☐ a) Will add a new strata level, and could reach medium to high density

☐ b) Will add a new strata level, but at low density

☑ c) Will not add a new strata level

☐ d) Don't know

Comments: Unlikely to add a new stratum, there is already a shrub level present in areas where the species may naturalise.

4. Could or does the species restrict the physical movement of people, animals, and/or water?

- ☐ a) Species infestations could become impenetrable throughout the year, preventing the physical movement of people, animals and/or water
- ☑ b) Species infestations could significantly slow the physical movement of people, animals and/or water throughout the year
- ☐ c) Species infestations could slow the physical movement of people, animals and/or water at certain times of the year or provide a minor obstruction throughout the year.
- ☐ d) Species infestations have no effect on physical movement
- ☐ e) Don't know

Comments: *Acacia saligna* is a shrub to small tree, the species is not prickly, which will allow people and animals to 'push through' stands. Research from South Africa suggests that heavy germination and suckering can form dense stands (Morris 1999). I envisage these could act as a physical barrier to the movement of people, animals, vehicles and machinery. John Virtue says that in South Australia he has only ever observed the species to form isolated clumps or thickets, not large impenetrable stands.

5. Is the species toxic to animals, have spines or burrs, or host other pests or diseases that could impact on native fauna and flora?

- ☐ a) Yes
- ☑ b) No

Comments: There are no known ill-effects on native fauna or flora from this species.

6. Does the species have, or show the potential to have, a major effect on fire regime?

- ☐ a) Major effect on frequency and/or intensity (in some situations overseas)
- ☑ b) Minor impact on frequency and/or intensity (EA)
- ☑ c) No effect (WA)
- ☐ d) Don't know

Comments: The foliage of *A. saligna* has a high moisture content and does not burn readily, the dry litter-layer does burn but this decomposes readily and provides only a small quantity of combustible biomass at any one time (Wilgen and Richardson 1985). Models show that fire intensity and spread is lower in *A. saligna* than South African fynbos, under most climatic conditions (Wilgen and Richardson 1985). Given these characteristics, it is conceivable that planted areas of *A. saligna* could act as barriers to grass fires in farming landscapes. Elsewhere however, the situation may be different, for example in the semi arid zone of Cyprus, Kyriacou (2006) reports that invasion by *A. saligna* increases the accumulation of flammable leaf litter. This build up of flammable material, and the accumulation of a large, dormant fire-stimulated seedbank, combines with the species fast growth rate to allow a dominance over native vegetation after fire. It is unlikely to have any impact on fire in WA as it is already a part of the ecosystem across a wide area.

7.I. Could the species provide food or shelter for pest animals?

☑ a) Yes (EA)

☑ b) No (WA)

☐ c) Don't know

Comments: In south-western Australian I believe *A. saligna* will provide food and shelter for fauna. The species is not to support a diverse range of insects, along with other insects and arachnids that predate them (Berg 1980a; Berg 1980b; Berg 1980c; Majer 1979). The use of *A. saligna* for agroforestry in Western Australia is may therefore have a positive impact on biodiversity, although this would need to be confirmed.

In the rest of Australia *A. saligna* is likely to reduced food and shelter due to its propensity for out-competing native vegetation. I have not read reports that claim it harbours pest species. John Virtue does not believe the characteristics of *A. saligna* thickets favours vertebrate pest such as rabbits.

7.II. Does the species have, or show the potential to have, a major effect on nutrient levels?

☑ a) Will significantly increase soil nutrient levels

☐ b) Will significantly decrease soil nutrient levels

☐ c) Will have minimal effect on soil nutrient levels

☐ d) Don't know

Comments: *Acacia saligna* does impact the nutrient content of soil. In South Africa litter fall from *A. saligna* increases soils fertility relative to indigenous vegetation, increasing N, Ca, Mg, K, Mn and B, whilst decreasing Fe (Musil 1993; Musil and Midgely 1990). Since it is nitrogen-fixing *Acacia saligna* will probably lead to net nitrogen inputs into soil.

7.III. Could the species reduce water quality or cause silting of waterways?

☐ a) Will significantly reduce water quality or cause silting of waterways

☐ b) May have some effect on water quality or silting of waterways in a small number of ecosystems

☑ c) Minor or no effect on water quality

☐ d) Don't know

Comments: *Acacia saligna* is able to produce an extensive root system, penetrating to a vertical depth of up to 3.5 meters, and to a lateral extent of 12 meters (El-Lakany and Mohamed 1993a; El-Lakany and Mohamed 1993b; Nasr *et al.* 2005). The highest density of roots is in the top 100 cm of soil (El-Lakany and Mohamed 1993a; El-Lakany and Mohamed 1993b). I have not found work that specifically discusses the impact of *A. saligna* on soil stability, but I think that the species will increase soil stability. *Acacia saligna* has been planted to stabilise sand blow outs on the Swan coastal plain north of Perth. Rapid growth and ease of establishment enhance the usefulness of the species for this purpose (D. Huxtable *pers. comm.*).

7.IV. Does the species have, or show the potential to have, a major effect on the soil water table?

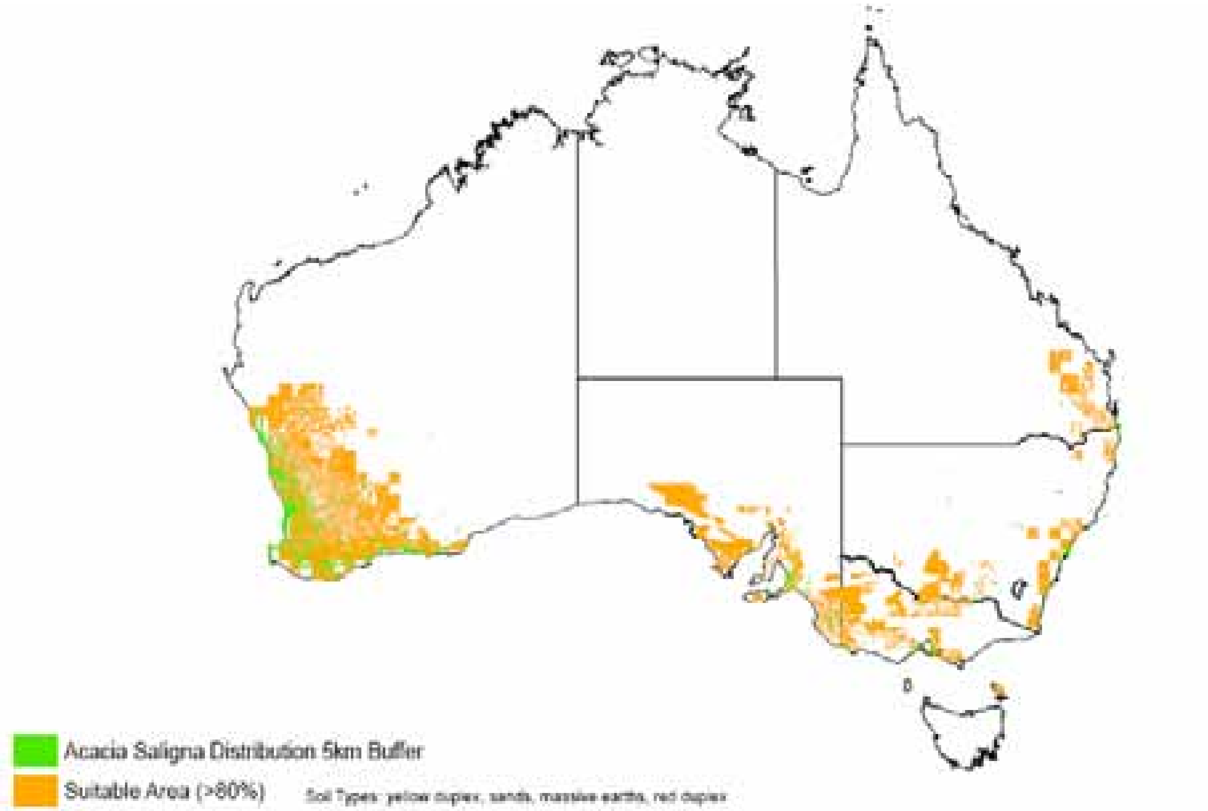
- ☐ a) Will significantly lower the water table
- ☑ b) Will have no effect
- ☐ c) Don't know

Comments: In Western Australia the species grows in a variety of habitats, although it shows a preference for habitats with greater soil moisture availability, and it is considered to be highly responsive to supplemental irrigation (El-Lakany 1987; Maslin 2001). *Acacia saligna* uses more water than annual crops, studies have shown that it can de-water the soil profile to a depth of 6 meters (Droppelmann *et al.* 2000b; Knight *et al.* 2002). Its water use will therefore probably be little different to native ecosystems containing woody, perennial plants.

Section 3: Potential Distribution

The potential distribution was determined by digitally overlaying climate and soil layers to find the areas of Australia where the species is most likely to grow (Fig. 2). This output is a broad indicator only.

Fig 1. Potential distribution for *Acacia saligna* based on analysis of climate and soil data.



The information used for CLIMATE analysis (a climate-matching software package) was: Where is the species found in Australia? Where does the species originate? Where else in the world has the species naturalised? (Maps and GPS coordinates where possible)

The information required for the soil analysis was: What soil type does the species grow in? Where available, the soil types where the species originated, and where it has naturalised around the world were included.

The soil type must be classified according to broad Northcote descriptions (Table 1).

Table 1. Northcote soil classifications to be used in estimation of potential distribution

☑ Sands (Uc)	☐ Brown duplex (Db)
☑ Loams (Um)	☑ Yellow duplex (Dy)
☐ Non-cracking clay (Uf)	☐ Black duplex (Dd)
☐ Cracking clay (Ug)	☐ Grey duplex (Dg)
☐ Calcareous earths (Gc)	☐ Organic (O)
☑ Massive earths (Gn)	☐ Rock
☑ Red duplex (Dr)	☐ Lakes

The distribution analysis was done on a state-by-state basis.

The climate and soils maps were digitally overlayed, and areas where the climate and soils match to within 80% of the mean was used to estimate the potential distribution of the species. The number of hectares that are suitable for the species was estimated for each state. The size of each output square in CLIMATE is approx 250,000ha, therefore the smallest match for any species, other than no match, is 250,000ha.

For Western Australia, hectares suitable for the species was calculated SOUTH of the Tropic of Capricorn only. This was to eliminate bias against species that may be suitable to the northern parts, but show little suitability in the regions where they are intended for planting. A whole-of-state calculation can be easily calculated if necessary.

How many hectares are suitable for the species is then converted to a score (Table 2).

Table 2. Scoring system from potential distributions

Million ha	SCORE
> 50	10
≤ 50	9
≤ 20	8
≤ 10	7
≤ 5	6
≤ 3	5
≤ 2	4
≤ 1	3
≤ 0.5	2
≤ 0.25	1
0	0.5

Potential distribution scores were 8, 6, 4, and 6 for WA, SA, Vic, and NSW respectively.

Section 4: Weed Risk Score

To calculate the weed risk score, the scores for invasiveness and impacts are adjusted to range from 0 to 10 (potential distribution is already a score ranging between 0 and 10).

To adjust the scores for Invasiveness and Impacts to range between 0 and 10:

Invasiveness: Divide raw score by 27 and multiply by 10. Round off to one decimal place.

Impacts: Divide raw score by 15 and multiply by 4. Round off to one decimal place.

The adjusted scores for each section are then multiplied together.

WEED RISK = Invasiveness x Impacts x Potential Distribution

The possible scores have been divided into bands of 20% to provide cut-offs for classes of weed risk (Table 3).

Table 3. Weed risk classification categories

FREQUENCY BAND	WEED RISK SCORE	WEED RISK
80-100% (top 20% of possible scores)	≥ 196	Very High
60-80%	< 196	High
40-60%	< 116	Medium
20-40%	< 55	Low
0-20% (bottom 20% of possible scores)	< 22	Negligible

Multiplying the scores for each section is logical, as it acknowledges the interactions between the criteria, and gives a broader spread of scores.

A panel of experts comprised of Lynley Stone, John Virtue, and Brian Dear have calculated the weed risk score for *Acacia saligna.* Invasiveness and Impact scores were 5.9 and 2.0 in WA and 6.3 and 5.5 in the eastern states. Overall results indicate a medium weed risk category in Western Australia and a high weed risk category in the eastern states (Table 4).

Table 4. Weed risk summary for *Acacia saligna* in Australia

State	Score	Risk Caregory
Weed risk for WA	94	**medium**
Weed risk for SA	208	**high**
Weed risk for VIC	139	**high**
Weed risk for NSW	208	**high**

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FUTURE FARM INDUSTRIES CRC

Environmental Weed Risk Assessment

Species: *Atriplex nummularia*

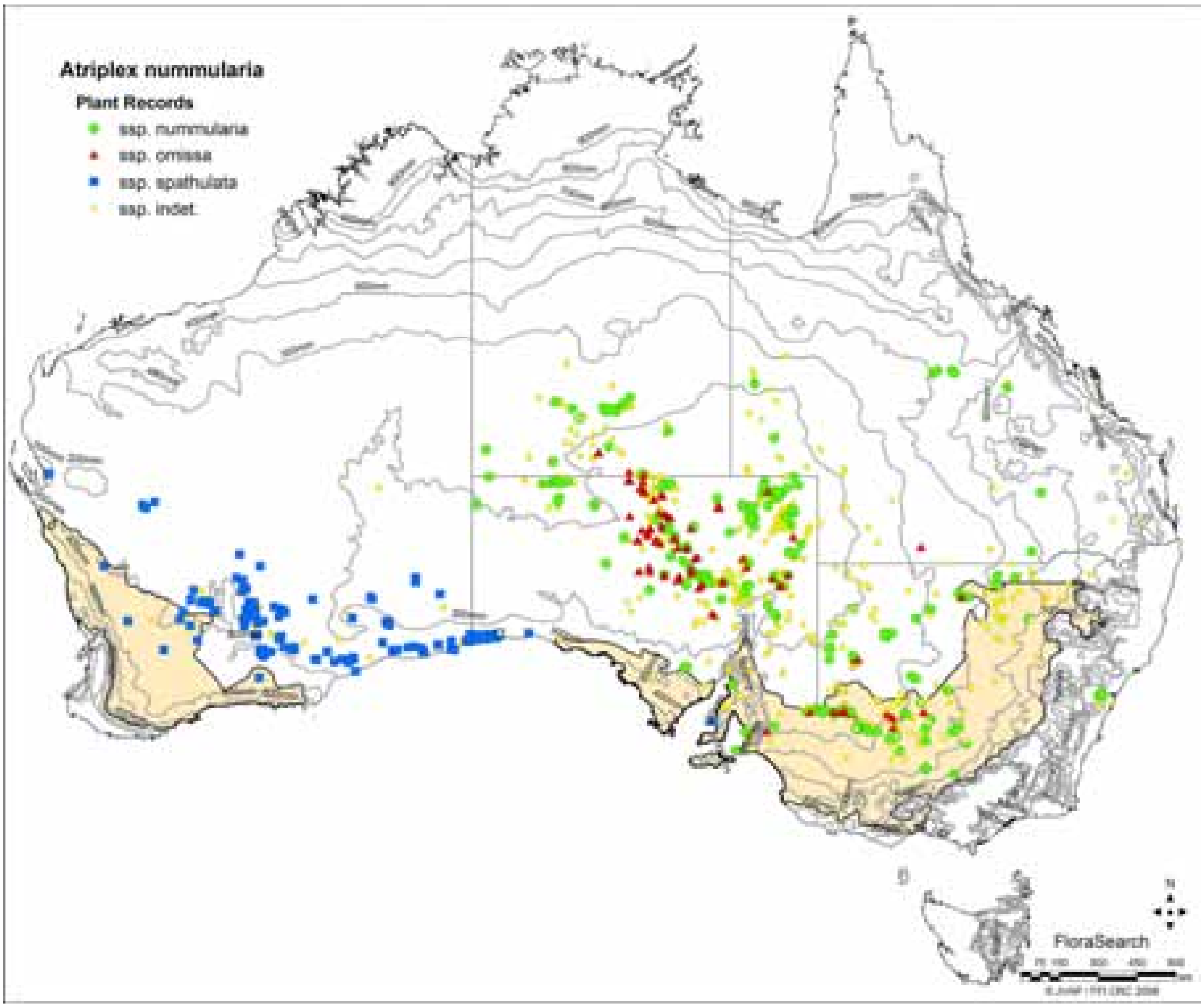
Submitted by*:* Wayne O'Sullivan

Reviewed by: Lynley Stone, John Virtue, Hayley Norman

Species summary:

Atriplex nummularia, commonly known as Old Man Saltbush, has a wide natural distribution across the southern half of the Australian continent (Fig. 1). There are three recognised subspecies: *Atriplex nummularia* subsp. *nummularia*, *Atriplex nummularia* subsp. *spathulata* and *Atriplex nummularia* subsp. *omissa*. *Atriplex nummularia* (seldom with a distinction made between subspecies) has been widely planted in low rainfall, broad acre farming systems as a perennial pasture species on salt affected land. There is strong interest in further developing the species for use in livestock production systems, including selection and breeding for improved domestication traits. The weed risk posed by *A. nummularia* in southern Australia may increase if traits such as improved pest and disease resistance, or tolerance to adverse environmental conditions, are selected for as part of the species domestication program. Problems may also arise if genetically differentiated provenances are moved around the continent. These issues are beyond the scope of this weed risk assessment but will need to be addressed as part of the domestication of *A. nummularia*.

Fig. 1. Known distribution of the different subspecies of Old Man Saltbush compiled from herbaria records. Shaded region indicates the FloraSearch study zone.



Section 1: Invasiveness

1. Does the species have a documented environmental weed history?

☐ a) Is an environmental weed in Australia

☑ b) Is an environmental weed overseas

☐ c) Species not known to be an environmental weed but there are environmental weed species in the genus

☐ d) Genus has no known environmental weeds

Comments: Virtue and Melland (2003) say that neither Lazarides *et al.* (1997), Carr *et al.* (1992) or Hussey *et al.* (1997), list *A. nummularia* as a weed within Australia, however, citing N. Mallen as a pers. comm., they say that at Alice Springs the species has been observed to spread and become dominant in a revegetation area, and there are several other minor incidents of spread within SA described in the same report. It has also been observed to spread locally from plantings within the Western Australian Wheatbelt (W. O'Sullivan pers. comm.).

Saltbush are widely used for forage production on saline land (Lefroy *et al.* 1992). Internationally *A. nummularia* has been planted for fodder in South Africa (Henderson 1998) and has naturalised across wide areas of the country. It occurs in a number of vegetation types, mainly low rainfall <300 mm, succulent Karoo which is rocky hill country with succulents and dwarf shrubs and trees, savannah with steep slopes and low dense vegetation, and strandveld with low growing mostly succulent plants between coastal fynbos and succulent karoo (Henderson 1998). Personal communications cited by Zalba *et al.* (2000), says the species is establishing in California and Hawaii.

2. What is the species' ability to establish in competition with other plant competitors and pests, such as weeds or native species, in trial plots or other situations?

- ☐ a) Establishment superior to other plant species (90 - 100% establishment, other plants suppressed)
- ☐ b) Establishment relatively unimpeded (50 - 89% establishment)
- ☐ c) Establishment impeded (10 - 49% establishment)
- ☑ d) Establishment impeded significantly (<10% establishment)
- ☐ e) Don't know

Comments: Virtue and Melland (2003) say that *Atriplex nummularia* will not compete well with established vegetation. In South Africa and California where the species is naturalized, natural establishment is associated with major disturbance to existing vegetation. These authors conclude that the species will only establish in natural vegetation at a very low density.

In Western Australia, revegetation of farmland with *Atriplex nummularia* requires effective weed control for successful establishment. The species is recognised as having a poor ability to produce volunteer seedlings in saltland pasture systems (Barrett-Lennard and Malcolm, 1995).

3. To what degree can the species tolerate herbivory pressure?

- ☐ a) Is not palatable and is rarely grazed
- ☐ b) Will tolerate continuous grazing for an extended period of time
- ☐ c) Will tolerate rotational grazing all year round
- ☑ d) Will tolerate some grazing at particular times of the year
- ☐ e) Has low tolerance to grazing, plants are easily killed
- ☐ f) Don't know

Comments: While no specific information has been found regarding this, commercial experience has shown that saltbush and bluebush pastures can be used to maintain the condition of sheep over summer and autumn as a substitute to grain feeding (Lefroy *et al.* 1992). Livestock are observed to exhibit a preference for grazing this species, and are therefore likely to actively graze them. In areas where grazing is controlled the plants are able to recover rapidly when the grazing animals are excluded. The plant is able to grow to above the height of sheep, and plants in heavily grazed areas have been observed setting seed on occasional branches above the height of stock (W. O'Sullivan pers. comm.).

It has been observed not to persist in areas where the plants have been overgrazed (Virtue and Melland 2003). Mitchell and Wilcox (1994) state that the species declines under heavy grazing in the

Murchison and Gascoyne, and its presence here indicates good range condition. In the Goldfields, where the plant is relatively common, they say that the plant increases under heavy grazing, and its dominance indicates poor range condition. This supports personal observation, that there are gaps in the distribution of the species in Western Australia, especially in overgrazed western areas (Gascoyne and Murchison regions). Anecdotal and herbarium records suggest the species may have been more wide spread in the past than is currently observed. Plants colonise road verge areas and mine disturbance areas of the Goldfields (pers obs).

4. What is the species' ability to persist as a long-term sward or stand without management?

☐ a) Plant numbers increase substantially with successive reproductive cycles to form a near monoculture

☑ b) Plant numbers remain at a steady level, persisting as a significant component of a mixed sward/stand

☐ c) Plant numbers decline slowly over successive years so that it becomes a minor component of the vegetation

☐ d) Plant numbers decline rapidly over successive years so that only occasional plants can be found

☐ e) Don't know

Comments: The plant shows high rates of survival in revegetation work in Australia, both from direct seeding and seedling planting. Such work, involving site preparation, seed treatment and timing to ensure growing conditions are optimised may present a different picture to what happens in the natural environment (see below). Less success is reported from overseas, for example Abdul-Halim *et al.* (1990) found quite low survival rates (19 %) for 7-8 month old seedlings, although salinity in surface soil was 46-54 ds/m which may have caused the high plant death.

Salt inhibits the germination of plants. Halophytes and cereals have approximately the same soil salt requirement for germination. Germination requirements are more exacting than the growth requirements for mature plants, for example, plants can be raised in the nursery and planted out into more saline conditions (Malcolm 1991). The bracteoles that encase the Atriplex seed inhibit germination, and their removal from the seed results in a rapid and high germination of the naked seeds (Donaldson 1990; Beadle 1952). This was validated by germination testing performed for the Search Project in Western Australia (Pat Ryan, pers. Comm.). Donaldson (1990) found the seeds of Atriplex germinated equally well in the dark and in the light, and over a wide range of pH. It was determined that seeds are sensitive to deficient aeration, although waterlogging is not harmful to the seeds and they germinate when removed from the water-logged environment. All the Atriplex species germinated over a wide range of temperatures but germination was usually best at low temperatures with optima of between 20 and 25 deg C, with germination readily increased by soaking seeds in water.

In the wild, seed is more likely to germinate as bracteoles are leached by successive showers of rain. Beadle (1952) says that mats of dead Atriplex seedlings, usually in the cotyledon stage, are commonly seen especially in dry and drought years. These result from germination after rain that has been insufficient to support the continued growth of the plants. If such dry conditions continue for 10 years or more, the supply of seed in a local area is likely to be exhausted.

In Pakistan, Mahmood *et al.* (1991) found the establishment of *A. amnicola* to vary with season, with the higher survival in winter than summer attributed to drought stress. This supports observations within the low rainfall natural range of the species in Western Australia, where regeneration of seedlings is more common in moisture gaining areas, such as runoff zones and spoon drains. Mahmood *et al.* (1991) also report survival was adversely affected by waterlogging. As *A. nummularia* is considered to have less waterlogging tolerance than *A. amnicola* (Barrett-Lennard and Malcolm, 1995), it is likely be at least as susceptible. This is supported by a study by Zalba *et al.* (2000) in Argentina, which concluded that *A. nummularia* would be capable of establishing itself in those places (within the studied reserve) subjected to sporadic floods, and on an old marine plain, but not in frequently flooded environments.

5. Is the plant likely to rapidly colonise a site?

- ☐ a) At least 30 plants are found growing > 5 m from the original plots in the second or third years after planting for annuals, or within 10 years for perennials
- ☐ b) At least 30 plants are found growing > 1 m from the original plots in the second or third years after planting for annuals, or within 10 years for perennials
- ☐ c) At least 5 plants are found growing > 1 m from the original plots in the second or third years after planting for annuals, or within 10 years for perennials
- ☑ d) No plants are found outside the plot, or plants are found growing within 1m of the original plots in the second or third years after planting for annuals, or within 10 years for perennials
- ☐ e) Don't know

Comments: No specific reference on the phenology of flowering and seed production for the species has been found. A small number of plants have been observed to flower in the first year after planting, in particular male plants (R. Mazanec, Personal Communication) although seed production is unlikely to be significant .

Wind dispersal of seed in its bracteole has been observed (W. O'Sullivan Pers. Obs), but this will not result in an even or particularly predictable distribution. Bracteoles accumulate in large numbers in hollows, roadside drains, and against obstacles such as branches and rocks. These may represent favourable niche environments, which can enhance survival i.e. lower, wetter, nutrient accumulating, sheltered.

6. Will the species establish and reproduce in low-nutrient Australian soils?

- ☑ a) Establishment and reproductive ability uninhibited in low-nutrient soils
- ☐ b) Establishment and reproductive ability reduced in low-nutrient soils
- ☐ c) Establishment and reproductively severely diminished in low-nutrient soils
- ☐ d) Establishment and reproduction not likely in low-nutrient soils without soil additives
- ☐ e) Don't know

Comments: Lal (2001) reports that *Atriplex nummularia* in India can produce 5-5 t dry matter /ha/yr under adverse conditions, and can grow well with only 150-200 mm annual rainfall.

The species has a wide distribution across much of semi-arid Australia. Observations made at the time of the germplasm collections for the FloraSearch program showed it to occur on a wide range of soil types, including low nutrient dune fields.

Low salinity levels do not appear to have a deleterious effect on the growth of Atriplex spp and may actually stimulate growth. High salinity levels however may cause a reduction in total growth of Atriplex spp especially in leaf biomass. Species of Chenopodiaceae commonly accumulate glycine betaine in the cytoplasm which acts as an osmoprotectant and can offset the high salinity concentration in the vacuole (Khan *et al.* 2000).

Atriplex nummularia shows increased growth with Mychorriza (Asghari *et al.* 2005; Asghari 2004; Plenchette and Duponnois 2005).

7. I. How likely is long-distance dispersal (>100m) by birds?

- ☐ a) Common
- ☐ b) Occasional
- ☑ c) Unlikely
- ☐ d) Don’t know

Comments: The bracteole is not attractively coloured or flavoured, and is not fleshy to attract the interest of birds. No instances of the seeds surviving the passage through the digestive tract of a bird or animal have been reported.

7.II. How likely is long-distance dispersal (>100m) by wild animals?

- ☐ a) Common
- ☐ b) Occasional
- ☑ c) Unlikely
- ☐ d) Don’t know

Comments: The seed of *Atriplex nummularia* is encased in a smooth bracteole that will not stick to, and is unlikely to lodge in feathers, or fur.

7.III. How likely is long-distance dispersal (>100m) by water?

- ☑ a) Common
- ☐ b) Occasional
- ☐ c) Unlikely
- ☐ d) Don’t know

Comments: Seed of this species is adapted to spread by water (Virtue and Melland 2003). Additionally, the leaching of salts from the bracteole will potentially assist germination. The bracteole is light weight, easily moved by water. Additionally, wind will concentrate them into watercourses to facilitate this type of dispersal.

7.IV. How likely is long-distance dispersal (>100m) by wind?

- [x] a) Common
- [ ] b) Occasional
- [ ] c) Unlikely
- [ ] d) Don't know

Comments: The morphology of the bracteole encasing *A. nummularia* seed facilitates ready dispersal by wind. Seed was observed being dispersed by strong winds across the flat plains of the Nullarbor by the FloraSearch germplasm collectors (W.O'Sullivan pers obs.).

8. I. How likely is long-distance dispersal (>100m) accidentally by people and vehicles?

- [ ] a) Common
- [ ] b) Occasional
- [x] c) Unlikely
- [ ] d) Don't know

Comments: The seed is enclosed in a bracteole which is smooth, with no hooks, barbs or sticky coatings. While in the bracteole the seed is large and lightweight and unlikely to accidentally lodge in clothing or vehicles.

8.II. How likely is long-distance dispersal (>100m) accidentally by contaminated produce?

- [ ] a) Common
- [ ] b) Occasional
- [x] c) Unlikely
- [ ] d) Don't know

Comments: Areas targeted for revegetation with this species are generally treated as a separate land unit, developed for perennial grazing and separated from cropping areas. Although waterlogging mitigation earthworks will be common in these areas, disturbance of soil is generally localised, with material rarely removed from the site.

8.III. How likely is long-distance dispersal (>100m) accidentally by domestic/farm animals?

- [ ] a) Common
- [ ] b) Occasional
- [x] c) Unlikely
- [ ] d) Don't know

Comments: The seed of *Atriplex nummularia* is encased in a smooth bracteole that will not stick to, and is unlikely to lodge in feathers, fur or wool. This type of dispersal problem has never been reported despite several decades of use in low rainfall perennial pasture systems.

9. I. What is the species' minimum generation time?

- ☐ a) ≤ 1 year
- ☑ b) 2-3 years
- ☐ c) >3 years/never
- ☐ d) Don't know

Comments: No specific reference on the phenology of flowering and seed production for the species has been found. Virtue and Melland (2003) say seed set is likely to occur within three years. Personal observations suggest that although some limited seed production occurs in the first and second years, it is not significant.

9.II. What is the species' average seed set?

- ☐ a) High (>1000 m-2/year for woody species, >5000 m-2/year for herbaceous species)
- ☑ b) Low
- ☐ c) None
- ☐ d) Don't know

Comments: Fifty percent of plants in a population are male, producing no seed. The seed production on female plants is highly variable. Once ripe the seed, in its bracteole falls to the ground, but its retention close to the parent plant is determined by the local conditions. If there is significant trash, or the site is sheltered, large quantities may accumulate. If the ground is bare and or exposed, little seed will accumulate.

9.III. What is the species' seed persistence in the soil seedbank?

- ☑ a) > 5 years
- ☐ b) 2-5 years
- ☐ c) < 2 years
- ☐ d) Don't know

Comments: Beadle (1952) tested seed viability of a number of Atriplex species over an eight year period. *Atriplex nummularia* started with 92% viability when collected (year zero), had 62% viability at age five, and fell to 10% viability at age eight. It had the longest seed life of five Australian Atriplex species examined.

9.IV. Can the species' reproduce vegetatively?

- ☐ a) Yes
- ☑ b) Slow
- ☐ c) No
- ☐ d) Don't know

Comments: In Zalba et al's (2000) work in Argentina, evaluations of habitat quality were done considering seed dispersion, though they state that *A. nummularia* is capable of successful propagation through vegetative mechanisms. Variables such as floatability of propagules and direction and strength of currents are often decisive in the dispersion of salt marsh species. Knowledge about them would allow a concentration of effort on the detection of possible invasions selecting those areas of suitable habitat that are accessible to colonisation by seed and vegetative shoots.

The species is commonly propagated from cuttings, which are very easy to strike.

Section 2: Impacts

1. Could the species reduce the biodiversity value of a natural ecosystem, either by reducing the amount of biodiversity present (diversity and abundance of native species), or degrading the visual appearance?

- ☐ a) The species could significantly reduce biodiversity such that areas infested become low priorities for nature conservation and/or nature-based tourism
- ☐ b) The species could have some effect on biodiversity and reduce its value for conservation and/or tourism
- ☐ c) The species would have marginal effects on biodiversity but is visually obvious and could degrade the natural appearance of the landscape
- ☑ d) The species would not effect biodiversity or the appearance of natural ecosystems
- ☐ e) Don't know

Comments: The impact of revegetation programs with this species is likely to be positive, rather than negative. Some areas are rangelands within the natural distribution of the species, many of which have suffered from over grazing. Of the areas proposed for revegetation outside the endemic range of the species, most are cleared and declining farmland which are degraded in terms of biodiversity services and visual amenity.

2. Does the species have a history of, or potential to in your view, of reducing the establishment of other plant species?

- ☐ a) The species can significantly inhibit the establishment of other plants (e.g. regenerating native vegetation) by preventing germination and/or killing seedlings, and/or the species forms a monoculture
- ☐ b) The species can inhibit the establishment of other plants and/or does/will become dominant.
- ☑ c) The species can cause some minor displacement by inhibiting establishment, but will not become dominant.
- ☐ d) The species does not inhibit the establishment of other plants.
- ☐ e) Don't know

Comments: Virtue and Melland (2003) suggest that at a low density *A. nummularia* would have marginal effects on establishment, biomass and diversity of local native plant species.

Work in Chile showed an increase in nutrients, potentially available to other plants, close to the plant, but a decrease immediately adjacent to the *Atriplex nummularia* (Torres 1999). A thesis by Aliaga (1982), cited in Figeroa *et al.* (2004), also working in Chile, reports an allelopathic effect from *Atriplex nummularia* inhibiting annual species in natural grasslands in arid northern Chile.

3. Could the species alter the structure of any native ecosystems at risk of invasion from this species by adding a new strata level?

- ☐ a) Will add a new strata level, and could reach medium to high density
- ☐ b) Will add a new strata level, but at low density
- ☑ c) Will not add a new strata level
- ☐ d) Don't know

Comments: Through most of the target range of the plant it will not add a new stratum, but there is a possibility in some areas, especially grasslands or woodlands with a grassy understorey, that they may add an additional shrub layer.

4. Could or does the species restrict the physical movement of people, animals, and/or water?

- ☐ a) Species infestations could become impenetrable throughout the year, preventing the physical movement of people, animals and/or water
- ☐ b) Species infestations could significantly slow the physical movement of people, animals and/or water throughout the year
- ☐ c) Species infestations could slow the physical movement of people, animals and/or water at certain times of the year or provide a minor obstruction throughout the year.
- ☑ d) Species infestations have no effect on physical movement
- ☐ e) Don't know

Comments: *Atriplex nummularia* is a non-spiny shrub, at a low density in native vegetation it would have negligible impacts on movement of fauna or people in comparison to local native shrubs (Virtue and Melland 2003).

5. Is the species toxic to animals, have spines or burrs, or host other pests or diseases that could impact on native fauna and flora?

- ☐ a) Yes
- ☑ b) No

Comments: The species is being regarded as a fodder plant, and is being developed for this purpose. It does not have spines or burrs, and it hosts very few insects, possibly because of the high salt content of the leaves.

6. Does the species have, or show the potential to have, a major effect on fire regime?

- ☐ a) Major effect on frequency and/or intensity
- ☐ b) Minor impact on frequency and/or intensity
- ☑ c) No effect
- ☐ d) Don't know

Comments: The low density of this species in its natural habitat, and low litter accumulation beneath the plants makes fire an uncommon occurrence (Barry Hooper pers. comm.). The high salt content of the foliage may also reduce the flammability of the plant.

7. I. Could the species provide food or shelter for pest animals?

- ☐ a) Yes
- ☑ b) No
- ☐ c) Don't know

Comments: Even where the species is recorded as spreading outside planted areas the density of plants is not great, meaning displacement of other species will be minimal. As a non-toxic shrub there will be some habitat and (minimal) food value to browsing animals, invertebrates and birds.

7.II. Does the species have, or show the potential to have, a major effect on nutrient levels?

- ☐ a) Will significantly increase soil nutrient levels
- ☐ b) Will significantly decrease soil nutrient levels
- ☑ c) Will have minimal effect on soil nutrient levels
- ☐ d) Don't know

Comments: Work in Chile showed an increase in nutrients, potentially available to other plants, close to the plant, but a decrease immediately adjacent to the *Atriplex nummularia* (Torres 1999). Sharma and Tongway (1973) report that the surface soil salinity beneath *A. nummularia* can be increased due to litter fall of leaves containing high concentrations of salt. This may impact on some species ability to utilize nutrients, but if plants maintain a low density in native vegetation as expected, this would be an insignificant impact at the ecosystem level.

7.III. Could the species reduce water quality or cause silting of waterways?

- ☐ a) Will significantly reduce water quality or cause silting of waterways
- ☐ b) May have some effect on water quality or silting of waterways in a small number of ecosystems
- ☑ c) Minor or no effect on water quality
- ☐ d) Don't know

Comments: The species does not persist in wet conditions, so will not invade permanent waterways. May establish in ephemeral water courses in low rainfall areas, but plant density will be low and unlikely to lead to silt accumulation. No reference to changes in water quality seen.

7.IV. Does the species have, or show the potential to have, a major effect on the soil water table?

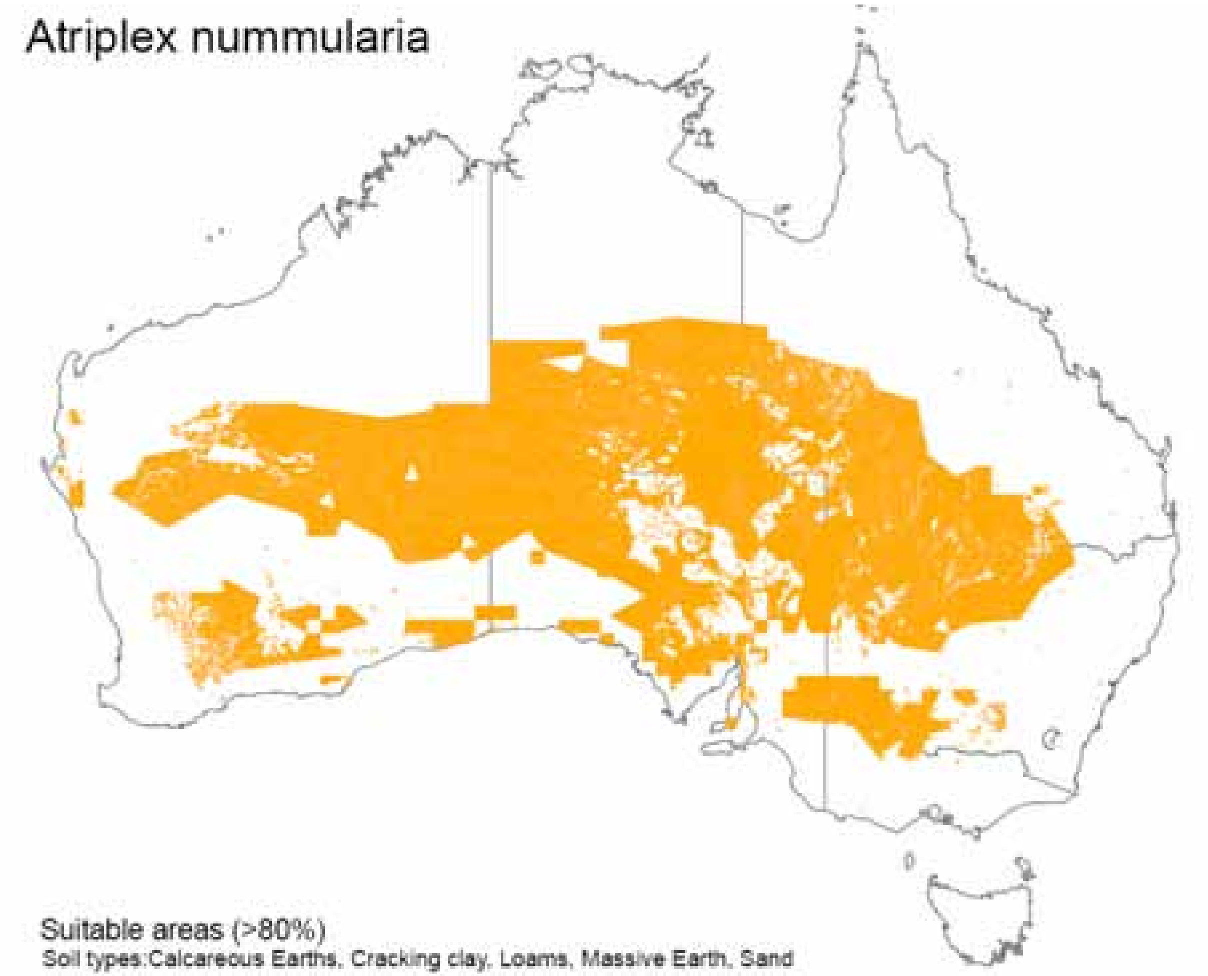
- ☐ a) Will significantly lower the water table
- ☑ b) Will have no effect
- ☐ c) Don't know

Comments: Knight *et al.* (2002) showed that belts of *Atriplex nummularia* and *Acacia saligna* planted across farmland dried the deep soil profile under the belts. It is not possible to say how much of this effect was attributable to the different species in the belt. Work by Jones and Hodgekinson (1969) showed the plant to be deep rooted, to at least 3.5m, but also capable of producing a very fine, probably ephemeral, shallow root system to take advantage of brief wet periods. The ability of *Atriplex nummularia* to lower water tables on salt affected farmland, thereby improving the ability of the land to support grazing systems, is a key reason for its use in farmland revegetation.

Section 3: Potential Distribution

The potential distribution was determined by digitally overlaying climate and soil layers to find the areas of Australia where the species is most likely to grow (Fig. 2). This output is a broad indicator only.

Fig 2. Potential distribution for *Atriplex nummularia* based on analysis of climate and soil data.



The information used for CLIMATE analysis (a climate-matching software package) was: Where is the species found in Australia? Where does the species originate? Where else in the world has the species naturalised? (Maps and GPS coordinates where possible)

The information required for the soil analysis was: What soil type does the species grow in? Where available, the soil types where the species originated, and where it has naturalised around the world were included.

The soil type must be classified according to broad Northcote descriptions (Table 1).

Table 1. Northcote soil classifications to be used in estimation of potential distribution of *Atriplex nummularia*

☑ **Sands (Uc)**	☐ Brown duplex (Db)
☑ **Loams (Um)**	☐ Yellow duplex (Dy)
☐ Non-cracking clay (Uf)	☐ Black duplex (Dd)
☑ **Cracking clay (Ug)**	☐ Grey duplex (Dg)
☑ **Calcareous earths (Gc)**	☐ Organic (O)
☑ **Massive earths (Gn)**	☐ Rock
☐ Red duplex (Dr)	☐ Lakes

The distribution analysis was done on a state-by-state basis.

The climate and soils maps were digitally overlayed, and areas where the climate and soils match to within 80% of the mean was used to estimate the potential distribution of the species. The number of hectares that are suitable for the species was estimated for each state. The size of each output square in CLIMATE is approx 250,000ha, therefore the smallest match for any species, other than no match, is 250,000ha.

For Western Australia, hectares suitable for the species was calculated SOUTH of the Tropic of Capricorn only. This was to eliminate bias against species that may be suitable to the northern parts, but show little suitability in the regions where they are intended for planting. A whole-of-state calculation can be easily calculated if necessary.

How many hectares are suitable for the species is then converted to a score (Table 2).

Table 2. Scoring system from potential distributions

Million ha	SCORE
> 50	10
≤ 50	9
≤ 20	8
≤ 10	7
≤ 5	6
≤ 3	5
≤ 2	4
≤ 1	3
≤ 0.5	2
≤ 0.25	1
0	0.5

The potential distribution scores for WA, SA, Vic, NSW are 10, 10, 4 and 9 respectively

Section 4: Weed Risk Score

To calculate the weed risk score, the scores for invasiveness and impacts are adjusted to range from 0 to 10 (potential distribution is already a score ranging between 0 and 10).

To adjust the scores for Invasiveness and Impacts to range between 0 and 10:

Invasiveness: Divide raw score by 27 and multiply by 10. Round off to one decimal place.

Impacts: Divide raw score by 15 and multiply by 4. Round off to one decimal place.

The adjusted scores for each section are then multiplied together.

WEED RISK = Invasiveness x Impacts x Potential Distribution

The possible scores have been divided into bands of 20% to provide cut-offs for classes of weed risk (Table 3).

Table 3. Weed risk classification categories

FREQUENCY BAND	WEED RISK SCORE	WEED RISK
80-100% (top 20% of possible scores)	≥ 196	Very High
60-80%	< 196	High
40-60%	< 116	Medium
20-40%	< 55	Low
0-20% (bottom 20% of possible scores)	< 22	Negligible

Multiplying the scores for each section is logical, as it acknowledges the interactions between the criteria, and gives a broader spread of scores.

A panel of experts comprised of Lynley Stone, John Virtue, and Hayley Norman have calculated the weed risk score for *Atriplex nummularia.* The Invasiveness and Impact scores were 4.8 and 0.5 respectively with overall results indicating a low weed risk category in WA, SA, and NSW and negligible for Vic (Table 4).

Table 4. Weed risk summary for *Atriplex nummularia* in Australia

State	Score	Risk Category
Weed risk for WA	24	low
Weed risk for SA	24	low
Weed risk for VIC	10	negligible
Weed risk for NSW	22	low

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FUTURE FARM INDUSTRIES CRC

Environmental Weed Risk Assessment

Species: *Eucalyptus rudis*

Submitted by*:* Wayne O'Sullivan

Reviewed by: Lynley Stone, John Virtue

Species summary:

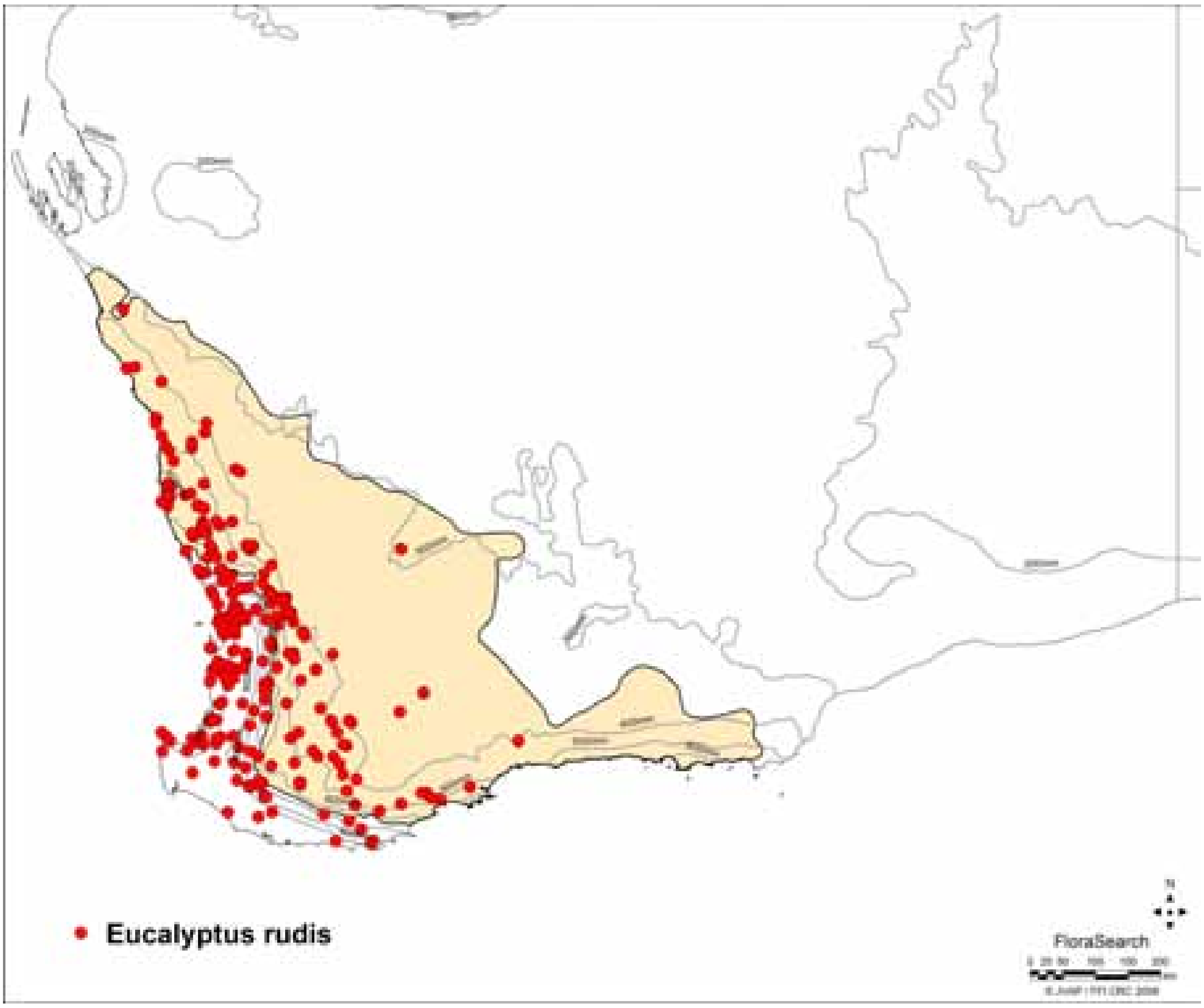
Eucalyptus rudis is not recorded as a weed species, within its range in southwestern Australia (Fig. 1) or elsewhere. Because the species is not widely planted and there is little material in the literature, much of the information in this assessment is based on the behaviour of eucalypts in general, and where possible on the specific behaviour of *Eucalyptus camaldulensis*, to which *Eucalyptus rudis* is closely related, and interbreeds.

Eucalyptus rudis is a variable species. It would be advantageous to better understand this variation prior to extensive revegetation within its native range, to give a greater understanding of the risk of genetic pollution. There are nominally two subspecies (*Eucalyptus rudis* subspecies *rudis* and *E. r.* subsp *cratyantha*), but this may not represent the entire diversity within the species. There appears to be some significant morphological variation in the south west part of its range, as well as a naturally occurring intergrade with *Eucalyptus camaldulensis* in the northeast part of the range (Maurice McDonald, pers comm.). The species is recorded as producing natural hybrids with *E. camaldulensis, E. drummondii, E. gomphocephala, E. loxophleba, E. occidentalis* and *E. wandoo* (Western Australian Herbarium 1998).

Eucalyptus rudis x *Eucalyptus camaldulensis* hybrid trees, a product of natural *E. rudis* populations crossing with garden *E. camaldulensis* plants, are showing greater vigour than the native *Eucalyptus rudis* around wetlands south of Perth (David Bright, pers comm.) Concern has been expressed about the recent introduction of *E. camaldulensis* material into the range of a naturally occurring *E. rudis/camaldulensis* intergrade in the Bolgart area of the WA Wheatbelt before the implications of such planting, or potential of the existing natural diversity is better understood. (Emmott 2002). Problems may also arise if genetically differentiated provenances are moved around the landscape in the south-west. These issues are beyond the scope of this weed risk assessment but will need to be addressed as part of the domestication of the species.

Fig. 1. The natural distribution of *Eucalyptus rudis* in Western Australia.

Compiled from herbaria records. Shaded region indicates the FloraSearch study zone.



Section 1: Invasiveness

1. Does the species have a *documented* environmental weed history?

- [ ] a) Is an environmental weed in Australia
- [ ] b) Is an environmental weed overseas
- [x] c) Species not known to be an environmental weed but there are environmental weed species in the genus
- [ ] d) Genus has no known environmental weeds

Comments: Within Australia the eucalypts are recognised as having weedy potential, but are generally considered a low weed risk, as they are relatively slow to spread, have non persistent seed and are easy to control (Virtue and Melland 2003). I have been unable to find any published reference to *Eucalyptus rudis* being recorded as a weed, either in Australia or overseas. The species has been observed spreading on farmland, including into areas away from its natural habitat (Andrew Thamo pers comm.). It has been seen invading cleared land adjacent to pine plantations (Andrew Thamo pers comm.), and self-seeding to dominate planted eucalypts in plantations (Peter White pers comm.). It has been observed expanding its range within its preferred natural environment (Bob Gretton, pers comm.).

The closely related *E. camaldulensis* occurs as a weed in the south west of Western Australia, (Andrew Thamo pers comm.), and in the Wheatbelt and adjoining Goldfields areas of WA (Peter White pers comm.). It is frequently mentioned as weedy in the literature from other parts of Australia (e.g. Groves, *et al.* 2005) and the world, for example South Africa (e.g. Alien Plant Invaders, 2006) and United States of America (e.g. Agricultural Research Council, 2006). Several other eucalypt species occur commonly on weed species lists in the literature, for example *Corymbia maculata, C. citriodora, Eucalyptus globulus, E. bicostata, E. occidentalis, E. cladocalyx and E. botryoides*. Caution should be exercised in suggesting that weediness will be restricted to these species or to species from these series within the eucalypts, or on such listings, as these lists represent the most commonly and widely planted species. In the SW of WA *Eucalyptus polyanthemos* has been observed self seeding aggressively into cleared areas at Balingup (Andrew Thamo pers comm.), *Eucalyptus grandis* can be seen colonising creek lines at Margaret river, and *Eucalyptus globulus* is invading bush on road verges at Denmark.

2. What is the species' ability to establish in competition with other plant competitors and pests, such as weeds or native species, in trial plots or other situations?

☐ a) Establishment superior to other plant species (90 - 100% establishment, other plants suppressed)

☐ b) Establishment relatively unimpeded (50 - 89% establishment) (EA, may be lower for WA)

☐ c) Establishment impeded (10 - 49% establishment) (will be affected by degree of disturbance)

☑ d) Establishment impeded significantly (<10% establishment)

☐ e) Don't know

Comments: *Eucalyptus rudis* commonly regenerates under and around established trees on farmland, in particular those that are low in the landscape. An accepted method of establishing this species is to control weeds in the proximity of existing trees with a herbicide and allow natural regeneration (Peter White, pers comm.). It this situation the ready emergence of seedlings in the sprayed areas, but not in adjacent areas with grassy weeds, suggests that they are impeded by the weeds even where there is sufficient moisture. The species commonly volunteers in sprayed areas adjoining revegetation areas, frequently in the gutters of mounds. Seedlings are commonly seen growing on firebreak areas subject to herbicide weed control. Whilst less common, they have been observed emerging in open paddock situations. Andrew Thamo (pers comm.) reports of his experience on farmland in the SW of WA that "For sure it is much happier colonising bare ground but there is some (limited) success in colonising pasture. Possibly as a result of summer rain where annuals may die off due to lack of follow up rain but the *E. rudis* gets a taproot down far enough to keep going. Longer term survival would tend to only occur on undergrazed pasture." Peter White (pers comm.) has observed seedlings emerging through long grass of an ungrazed paddock adjoining a line of 30 year old *E. rudis* in the Upper Great Southern region of WA.

3. To what degree can the species tolerate herbivory pressure?

- [ ] a) Is not palatable and is rarely grazed
- [ ] b) Will tolerate continuous grazing for an extended period of time
- [x] c) Will tolerate rotational grazing all year round
- [ ] d) Will tolerate some grazing at particular times of the year
- [ ] e) Has low tolerance to grazing, plants are easily killed
- [ ] f) Don't know

Comments: Seedlings are fast growing, so much so that unless they are sown late in nurseries they can be difficult to manage (Peter White pers comm.). Self sown or as planted seedlings they soon grow beyond the reach of grazing animals. Emergence of the seedlings is normally associated with times when stock is excluded, such as revegetation, or cropping. Sustained heavy grazing can eliminate young plants.

4. What is the species' ability to persist as a long-term sward or stand without management?

- [ ] a) Plant numbers increase substantially with successive reproductive cycles to form a near monoculture
- [x] b) Plant numbers remain at a steady level, persisting as a significant component of a mixed sward/stand
- [ ] c) Plant numbers decline slowly over successive years so that it becomes a minor component of the vegetation
- [ ] d) Plant numbers decline rapidly over successive years so that only occasional plants can be found
- [ ] e) Don't know

Comments: Stands establishment tends to be associated with episodic events, creating an opportunity for the species. In the natural range of the species, which is within the agricultural zone, this usually involves control of weed competition for sufficient time to allow germination and early growth. This is achieved by herbicides or mechanical control (such as firebreaks or new road construction), or may be associated with periods of inundation. The plant may establish at very high rates, and although competition between individuals is observed to reduce numbers with time, the relative site occupancy will remain more or less constant.

5. Is the plant likely to rapidly colonise a site?

- ☐ a) At least 30 plants are found growing > 5 m from the original plots in the second or third years after planting for annuals, or within 10 years for perennials
- ☐ b) At least 30 plants are found growing > 1 m from the original plots in the second or third years after planting for annuals, or within 10 years for perennials
- ☑ c) At least 5 plants are found growing > 1 m from the original plots in the second or third years after planting for annuals, or within 10 years for perennials (WA/EA once plants are of reproductive age)
- ☐ d) No plants are found outside the plot, or plants are found growing within 1m of the original plots in the second or third years after planting for annuals, or within 10 years for perennials
- ☐ e) Don't know

Comments: Although precocious for a eucalypt, plants are seldom flowering before age 3, and seed production is light for several years. Colonisation by seed of this species is associated with long established plants, and particular episodic circumstances creating a conducive environment.

6. Will the species establish and reproduce in low-nutrient Australian soils?

- ☐ a) Establishment and reproductive ability uninhibited in low-nutrient soils
- ☑ b) Establishment and reproductive ability reduced in low-nutrient soils
- ☐ c) Establishment and reproductively severely diminished in low-nutrient soils
- ☐ d) Establishment and reproduction not likely in low-nutrient soils without soil additives
- ☐ e) Don't know

Comments: The species has evolved in the generally low nutrient environment of the SW of Western Australia. Its natural range is mostly in low landscape areas in what is now an agricultural zone. This highly modified environment accumulates nutrients and water. Despite their ability to survive on low nutrient soils, eucalypts will respond to increased moisture and nutrients, particularly N and P (Pryor 1976). While increased leaf nitrogen has been correlated with insect attack (White 1984), neither Clay and Majer, (2001) or Yeomans (1999) found any difference in N levels between healthy and declining trees. Increased growth rates associated with access to increased nutrients and moisture may assist survival by growing trees beyond the reach of grazing animals. If insect attack is not sustained, accumulated reserves will allow faster recovery from attack. The conditions described here for the low landscape position of the agricultural zone occupied by and targeted for revegetation by this species are often a precursor to the development of severe waterlogging and salinity. The species has a recorded tolerance of saline conditions (Turnbull and Prior 1984). Beyond the tolerance of the species, however the health and vigour of the plants declines.

7. I. How likely is long-distance dispersal (>100m) by birds?

- ☐ a) Common
- ☐ b) Occasional
- ☑ c) Unlikely
- ☐ d) Don't know

Comments: I have never observed, nor heard or read reference to the capsules of this species being eaten or transported by birds.

7.II. How likely is long-distance dispersal (>100m) by wild animals?

- ☐ a) Common
- ☐ b) Occasional
- ☑ c) Unlikely
- ☐ d) Don't know

Comments: Seeds are smooth, and contained in a weighty, smooth capsule until shed by drying, at which point they fall close to the parent tree.

7.III. How likely is long-distance dispersal (>100m) by water?

- ☐ a) Common
- ☑ b) Occasional
- ☐ c) Unlikely
- ☐ d) Don't know

Comments: From my experience, it is common to see seed of this species germinate on the edge of areas that have been inundated, generally close to parent trees. There is a chance that flood waters will move the seed greater distances however, as this is a species of creek and river margins. Bob Gretton from Greenskills in Denmark reports that "I have seen it coming up like wheat from seed from a natural stand - after floods on the Blackwood a few years ago - but not from planted trees." (Bob Gretton, Pers. comm. 2006). Seedlings are reported as coming up in great numbers in detention basins in the Metropolitan area of Perth (Pers comm. David Bright), suggesting that flowing water is at least concentrating seed locally, if not transporting them great distances

7.IV. How likely is long-distance dispersal (>100m) by wind?

- ☐ a) Common
- ☑ b) Occasional
- ☐ c) Unlikely
- ☐ d) Don't know

Comments: The seed of *E. rudis* does not have the morphology to facilitate wind transport, but some drift of seed and branch material is possible, as reflected by these comments by Andrew Thamo about farmland in the SW of WA; "I'd say the main spread is wind drift which can freakily be quite far e.g. branchlets torn off by storm, but normally 1 x tree height for the majority of the seed. The patch that is spreading at our place is actually trending uphill- perhaps driven by nor-westerlies or nor-easterlies which may intensify travel up the steep gully whereas the stand may be in the wind shadow of the ridge for the opposite winds."

8. I. How likely is long-distance dispersal (>100m) accidentally by people and vehicles?

- ☐ a) Common
- ☐ b) Occasional
- ☑ c) Unlikely
- ☐ d) Don't know

Comments: Due to the morphology of *E. rudis* seed I believe it is unlikely that it could be accidentally transported by people or vehicles by adhering to clothes or in dirt. The seed viability in the wild is not great, so high volumes of seed will not build up in soil. Some fresh seed may be transported with sand quarried adjacent to river beds, but the most common use locally is for applications such as road building or concrete production, which minimises risk.

8.II. How likely is long-distance dispersal (>100m) accidentally by contaminated produce?

- ☐ a) Common
- ☐ b) Occasional
- ☑ c) Unlikely
- ☐ d) Don't know

Comments: The separation of the trees from agricultural land, and the need to remove and dry seed capsules to release seed make this very unlikely.

8.III. How likely is long-distance dispersal (>100m) accidentally by domestic/farm animals?

- ☐ a) Common
- ☐ b) Occasional
- ☑ c) Unlikely
- ☐ d) Don't know

Comments: *E. rudis* does not have characteristics that will lead to it adhering to the hair or skin of livestock. It is unlikely to be accidentally ingested by animals, and unlikely to survive passage through the gut of animals.

9. I. What is the species' minimum generation time?

- ☐ a) < 1 year
- ☐ b) 2-3 years
- ☑ c) >3 years/never
- ☐ d) Don't know

Comments: *Eucalyptus rudis* may produce a light flowering at age three under optimal conditions, with approximately another year to ripen seed. Significant flowering will not occur until at least five years old.

9.II. What is the species' average seed set?

- ☑ a) High (>1000 m-2/year for woody species, >5000 m-2/year for herbaceous species)
- ☐ b) Low
- ☐ c) None
- ☐ d) Don't know

Comments: The closely related *Eucalyptus camaldulensis* is reported as having a high percentage of viable seed compared to other eucalypts (Willan 1985). The germination data *E. camaldulensis* and *E. rudis* is comparable (Turnbull and Doran 1987). Periodicity varies between species of eucalypts, *E. camaldulensis* is recorded as bearing heavier seed crops every two to three years (Willan 1985). *Eucalyptus rudis* seed crops have been observed to vary significantly from year to year, which may reflect seasonal variation, for example 2005 was a particularly poor year for seed across much of its range.

9.III. What is the species' seed persistence in the soil seedbank?

☐ a) > 5 years

☐ b) 2-5 years

☑ c) < 2 years

☐ d) Don't know

Comments: Ordinarily *eucalyptus* seed is not considered to persist in the soil (Virtue and Melland 2003), this may be a result of predation, climatic conditions and other factors, rather than simple seed physiology, as Young and Young (1992) report seed germinating after 30 years of storage at room temperature. Young and Young (1992) and Willan (1985) suggest that eucalyptus seed can be stored at optimal conditions (low temperature and humidity in sealed containers) for up to 10 years. This is supported by Turnbull and Doran (1987), who add that seeds tend to be at their physiological peak at maturity, declining from that point on with age.

9.IV. Can the species' reproduce vegetatively?

☐ a) Yes

☐ b) Slow

☑ c) No

☐ d) Don't know

Comments: *Eucalyptus rudis* is lignotuberous and has been observed to reshoot from the root system after fire. The new growth is attached to the parent, and represents a very small increment in land occupied by the plant. Many eucalypts can be rooted from vegetative shoots that have juvenile leaves (Young and Young, 1992). This technique is used by DEC for propagation of some mallee species (Pat Ryan pers. comm.). I do not know if this applies to *Eucalyptus rudis*, and it is unlikely to be a means of propagation in a natural environment.

Section 2: Impacts

1. Could the species reduce the biodiversity value of a natural ecosystem, either by reducing the amount of biodiversity present (diversity and abundance of native species), or degrading the visual appearance?

- ☐ a) The species could significantly reduce biodiversity such that areas infested become low priorities for nature conservation and/or nature-based tourism
- ☐ b) The species could have some effect on biodiversity and reduce its value for conservation and/or tourism
- ☑ c) The species would have marginal effects on biodiversity but is visually obvious and could degrade the natural appearance of the landscape (EA)
- ☑ d) The species would not effect biodiversity or the appearance of natural ecosystems (WA)
- ☐ e) Don't know

Comments: It is unlikely that this species will adversely impact on biodiversity or landscape values in the south west of Western Australia. , but may have a minor effect in Eastern Australia where it is not native.

2. Does the species have a history of, or potential to in your view, of reducing the establishment of other plant species?

- ☐ a) The species can significantly inhibit the establishment of other plants (e.g. regenerating native vegetation) by preventing germination and/or killing seedlings, and/or the species forms a monoculture
- ☐ b) The species can inhibit the establishment of other plants and/or does/will become dominant.
- ☑ c) The species can cause some minor displacement by inhibiting establishment, but will not become dominant.
- ☐ d) The species does not inhibit the establishment of other plants.
- ☐ e) Don't know

Comments: Within the natural range of *Eucalyptus rudis*, the areas most readily colonised by new seedlings are degraded or marginal areas on farmland, where the major competition is with introduced grassy weed species. In this situation, the shading of, and competition with the weeds is more likely to assist in the creation of conditions favourable to other native species, rather than hinder them. Around Perth the species has been observed to die out on the floor of wetlands as a result of water table rise associated with development for housing. The species then re-establishes itself at a higher level, around the fringe of the wetland (David Bright, Pers. comm.). A potential effect of this shift is that species that would otherwise have occupied that zone are probably displaced.

3. Could the species alter the structure of any native ecosystems at risk of invasion from this species by adding a new strata level?

- ☐ a) Will add a new strata level, and could reach medium to high density
- ☑ b) Will add a new strata level, but at low density
- ☐ c) Will not add a new strata level (WA)
- ☐ d) Don't know

Comments: Around Perth the species has been observed to die out on the floor of wetlands as a result of water table rise associated with development for housing. The species then re-establishes itself at a higher level, around the fringe of the wetland (David Bright, Pers. comm.). This widening of the zone normally occupied by the species will be minor, and will be dependant on the lack of competition from other species. It is likely that any such establishment would be replacing other species of similar strata that have in turn succumb to the changing conditions.

4. Could or does the species restrict the physical movement of people, animals, and/or water?

- ☐ a) Species infestations could become impenetrable throughout the year, preventing the physical movement of people, animals and/or water
- ☐ b) Species infestations could significantly slow the physical movement of people, animals and/or water throughout the year
- ☐ c) Species infestations could slow the physical movement of people, animals and/or water at certain times of the year or provide a minor obstruction throughout the year.
- ☑ d) Species infestations have no effect on physical movement
- ☐ e) Don't know

Comments: *Eucalyptus rudis* is a small tree. The species is not prickly, and never regenerates so densely that people and animals cannot 'push through' stands. It may create something of a physical barrier to the movement of people, animals, vehicles and machinery when it colonises tracks or firebreaks, and may catch trash, which in turn will obstruct water when water levels rise.

5. Is the species toxic to animals, have spines or burrs, or host other pests or diseases that could impact on native fauna and flora?

- ☐ a) Yes
- ☑ b) No

Comments: While the species hosts a range of insect pests, these appear to be species specific.

6. Does the species have, or show the potential to have, a major effect on fire regime?

☐ a) Major effect on frequency and/or intensity (in some situations overseas)

☐ b) Minor impact on frequency and/or intensity

☑ c) No effect

☐ d) Don't know

Comments: In south-western Australia the lower landscape is often dominated by this species already, often in association with other myrtaceous plants (eg *Melaleuca*, *Agonis* and *Taxandria*), which all carry volatile oils. Increased numbers or density of this species is therefore unlikely to significantly increase fire risk. *Eucalyptus rudis* has a light canopy, and consequently a light leaf drop, compared to many other eucalypts. The bark is rough and retained on the tree. Where the trees occupy previously grassy sites, the reduction in wind speed, and the suppression of grassy weeds through shading and competition may reduce intensity of fires.

7. I. Could the species provide food or shelter for pest animals?

☐ a) Yes

☑ b) No

☐ c) Don't know

Comments: While the species hosts a range of insect pests, these appear to be species specific.

7.II. Does the species have, or show the potential to have, a major effect on nutrient levels?

☐ a) Will significantly increase soil nutrient levels

☐ b) Will significantly decrease soil nutrient levels

☑ c) Will have minimal effect on soil nutrient levels

☐ d) Don't know

Comments: The eucalypts are not nitrogen fixing, and they are unlikely to have much impact on nutrient levels beyond localised recycling of nutrients through uptake from soil and leaf drop.

7.III. Could the species reduce water quality or cause silting of waterways?

☐ a) Will significantly reduce water quality or cause silting of waterways

☐ b) May have some effect on water quality or silting of waterways in a small number of ecosystems

☑ c) Minor or no effect on water quality

☐ d) Don't know

Comments: The species is more likely to make a positive contribution to stabilising waterways and reducing erosion. *Eucalyptus rudis* has been observed to have a strong network of surface roots, which may be part of its adaptation to the waterlogged and/or the heavy clay soils where it naturally occurs, but this has the effect of binding together the soil along watercourses. Almost all natural regeneration and introduced plantings of this species occur on land that is otherwise occupied by grasses. In winter the grasses will afford good erosion protection, but at other times, such as summer or post-fire, this will be markedly reduced.

7.IV. Does the species have, or show the potential to have, a major effect on the soil water table?

- ☐ a) Will significantly lower the water table
- ☑ b) Will have no effect
- ☐ c) Don't know

Comments: In the southwest of Western Australia the species represents a key tree component of the lower landscape. These areas are vulnerable to waterlogging and increasing salinisation due to changes in land use across the landscape. This is one of the few native species of eucalypts in this region to withstand elevated levels of salinity and prolonged waterlogging without a substantially decreased growth performance. These trees will contribute to a lowering of the water table in areas where they are planted or where they regenerate, but in most cases this will be advantageous and more likely to contribute to the reversal or lessening of change, rather than a drying of wetlands.

In South Africa several eucalypt species are classed as Category 2 weeds (proven plant invaders under uncontrolled conditions outside demarcated areas) (Agricultural research Council 2006). While recognising that the trees are often beneficial, their planting will be controlled around wetland areas.

Section 3: Potential distribution

The potential distribution was determined by digitally overlaying climate and soil layers to find the areas of Australia where the species is most likely to grow (Fig. 2). This output is a broad indicator only.

The information used for CLIMATE analysis (a climate-matching software package) was: Where is the species found in Australia? Where does the species originate? Where else in the world has the species naturalised? (Maps and GPS coordinates where possible)

The information required for the soil analysis was: What soil type does the species grow in? Where available, the soil types where the species originated, and where it has naturalised around the world were included.

The soil type must be classified according to broad Northcote descriptions (Table 1).

Fig 2. Potential distribution for *Eucalyptus rudis* based on analysis of climate and soil data.

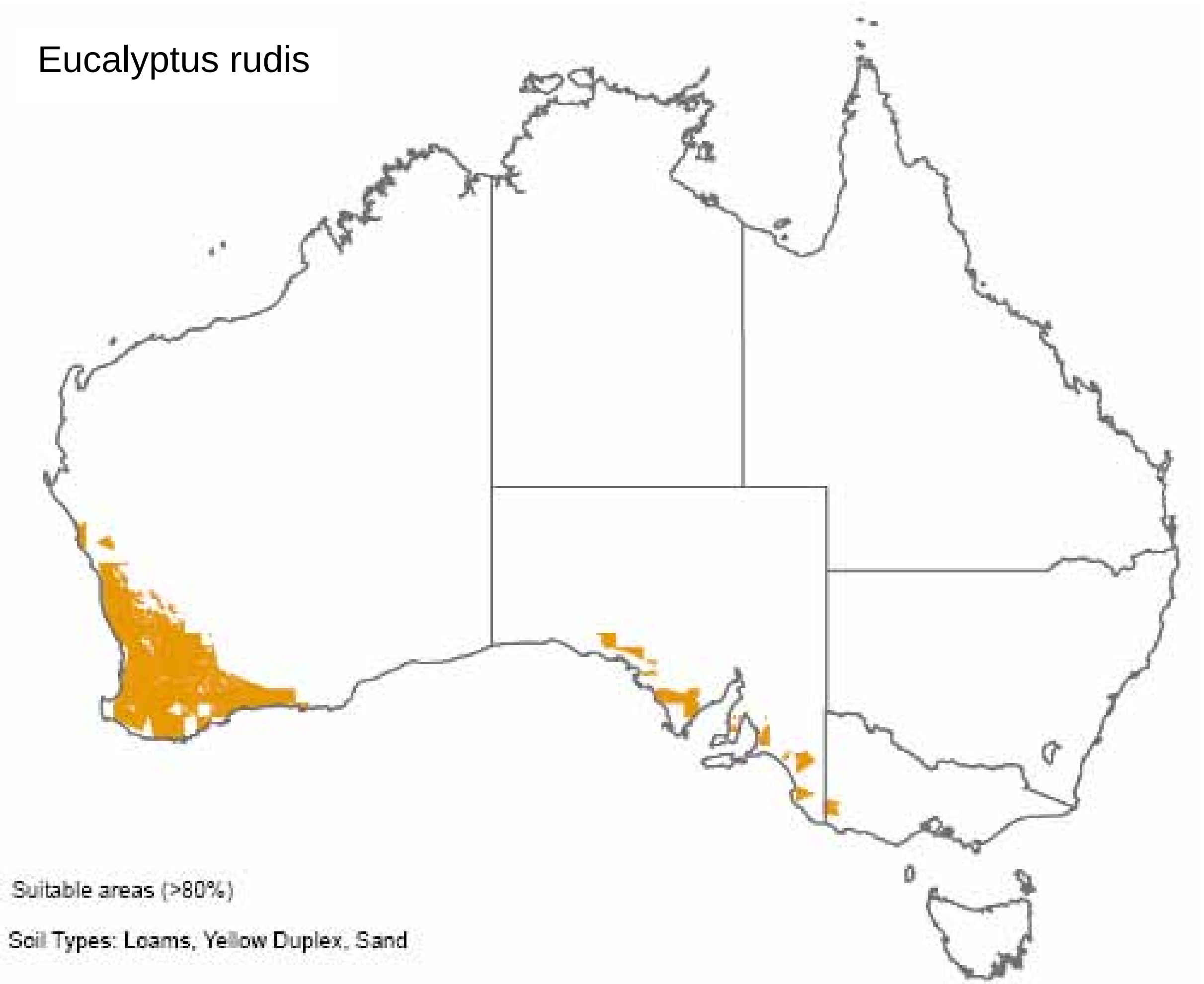


Table 1. Northcote soil classifications to be used in estimation of potential distribution

☑ Sands (Uc)	☐ Brown duplex (Db)
☑ Loams (Um)	☑ Yellow duplex (Dy)
☐ Non-cracking clay (Uf)	☐ Black duplex (Dd)
☐ Cracking clay (Ug)	☐ Grey duplex (Dg)
☐ Calcareous earths (Gc)	☐ Organic (O)
☐ Massive earths (Gn)	☐ Rock
☐ Red duplex (Dr)	☐ Lakes

The distribution analysis was done on a state-by-state basis.

The climate and soils maps were digitally overlayed, and areas where the climate and soils match to within 80% of the mean was used to estimate the potential distribution of the species. The number of hectares that are suitable for the species was estimated for each state. The size of each output square in CLIMATE is approx 250,000ha, therefore the smallest match for any species, other than no match, is 250,000ha.

For Western Australia, hectares suitable for the species was calculated SOUTH of the Tropic of Capricorn only. This was to eliminate bias against species that may be suitable to the northern parts, but show little suitability in the regions where they are intended for planting. A whole-of-state calculation can be easily calculated if necessary.

How many hectares are suitable for the species is then converted to a score (Table 2).

Table 2. Scoring system from potential distributions

Million ha	SCORE
> 50	10
≤ 50	9
≤ 20	8
≤ 10	7
≤ 5	6
≤ 3	5
≤ 2	4
≤ 1	3
≤ 0.5	2
≤ 0.25	1
0	0.5

The potential distribution scores for WA, SA, Vic, NSW are 5, 3, 1 and 0.5 respectively

Section 4: Weed Risk Score

To calculate the weed risk score, the scores for invasiveness and impacts are adjusted to range from 0 to 10 (potential distribution is already a score ranging between 0 and 10).

To adjust the scores for Invasiveness and Impacts to range between 0 and 10:

Invasiveness: Divide raw score by 27 and multiply by 10. Round off to one decimal place.

Impacts: Divide raw score by 15 and multiply by 4. Round off to one decimal place.

The adjusted scores for each section are then multiplied together.

WEED RISK = Invasiveness x Impacts x Potential Distribution

The possible scores have been divided into bands of 20% to provide cut-offs for classes of weed risk (Table 3).

Table 3. Weed risk classification categories

FREQUENCY BAND	WEED RISK SCORE	WEED RISK
80-100% (top 20% of possible scores)	≥ 196	Very High
60-80%	< 196	High
40-60%	< 116	Medium
20-40%	< 55	Low
0-20% (bottom 20% of possible scores)	< 22	Negligible

Multiplying the scores for each section is logical, as it acknowledges the interactions between the criteria, and gives a broader spread of scores.

A panel of experts comprised of Lynley Stone and John Virtue have calculated the invasiveness and impact scores for *Eucalyptus rudis* at 3.7 and 1.5 respectively for WA and 3.7 and 2.0 respectively for the eastern states, indicating a low weed risk for WA and SA and negligible weed risk for NSW and Vic (Table 4).

Table 4. Weed risk summary for *Eucalyptus rudis* in Australia

State	Score	Risk Category
Weed risk for WA	28	**Low**
Weed risk for SA	22	**Low**
Weed risk for VIC	7	**Negligible**
Weed risk for NSW	4	**Negligible**

References for Eucalyptus rudis weed risk assessment

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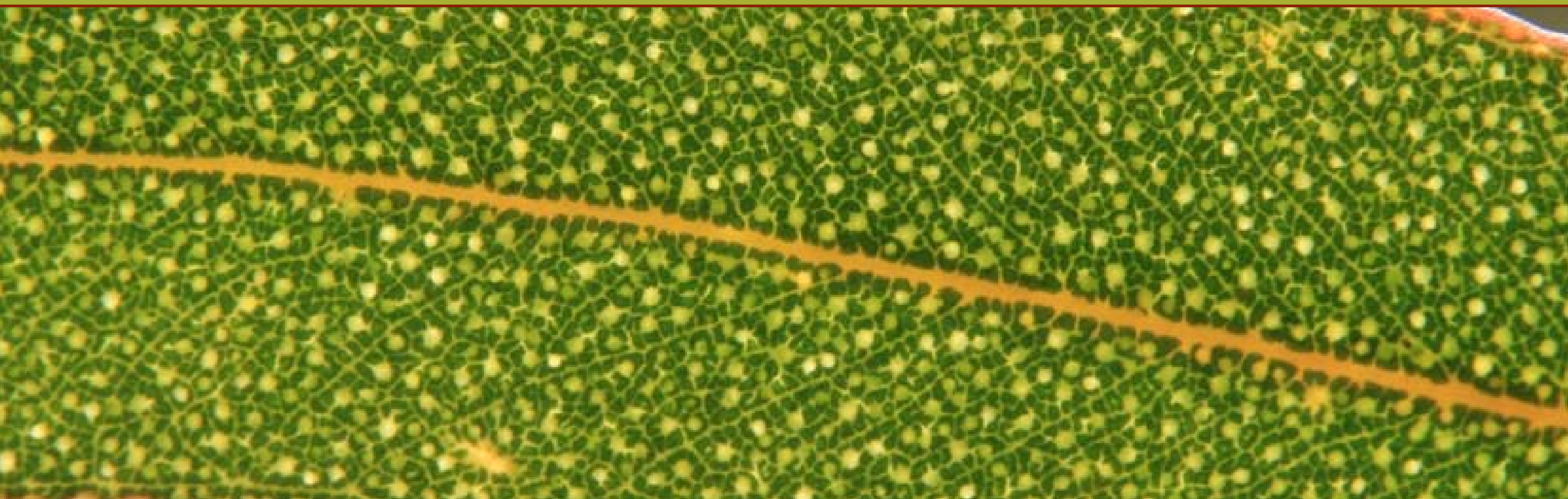
Joint Venture Agroforestry Program

by Trevor J. Hobbs, Mike Bennell and John Bartle (eds)

August 2009



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