An Australian Government Initiative

Joint Venture Agroforestry Program

Rural Industries Research & Development Corporation

Forest & Wood Products Australia

Land & Water Australia

Reviews of High Priority Species for Woody Biomass Crops in Lower Rainfall Southern Australia

FLORASEARCH 3B

FUTURE FARM INDUSTRIES CRC

An Australian Government Initiative

Reviews of High Priority Species for Woody Biomass Crops in Lower Rainfall Southern Australia

FloraSearch 3b

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

August 2009

RIRDC Publication No 09/044
RIRDC Project No UWA-98A

ISBN 1 74151 847 4
ISSN 1440-6845

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Publication No. 09/044
Project No. UWA-98A

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Electronically published by RIRDC in August 2009
Print-on-demand by Union Offset Printing, Canberra at www.rirdc.gov.au
or phone 1300 634 313

Foreword

The dryland agricultural regions of southern Australia face many natural resource management challenges. Following a long history of widespread vegetation clearance for the development of annual crops and pastures these landscapes now experience significant environmental issues including dryland salinity, soil erosion and other losses of ecosystem function. Broadscale restoration of deep-rooted perennial vegetation to these landscapes can help to address many of these problems and provide opportunities for more sustainable and resilient farming systems in a world of diverse markets and variable climate.

Since 2002, the FloraSearch project has researched selection and development of new crop species to supply feedstock for large-scale markets, including wood products, renewable energy, carbon sequestration and fodder. It has investigated a range of Australian native species with potential for domestication as new biomass industry crops, and evaluated the economic and spatial feasibility of these new crops and industries across southern Australia.

FloraSearch 3 presents the findings of the latest phase of this research, focussing on a suite of Australian native species suited to new broadscale woody crops and their associated commercial industries. The report is presented in three volumes, with the first providing in-depth information on the productive potential and agronomy of prospective new crops, the second (this volume) enlarging on the domestication potential of three high priority species, and the third analysing of regional industry potential for woody biomass crops in southern Australia.

This report (FloraSearch 3b) identifies native species Koojong Wattle (*Acacia saligna*), Old Man Saltbush (*Atriplex nummularia*) and Flooded Gum (*Eucalyptus rudis*) as having particular potential for development as broadscale commercial woody biomass crops in the dryland agricultural regions of southern Australia. It provides detailed species reviews and considers taxonomy, ecology, biology and agronomy in evaluating their potential for domestication as woody biomass crops for Australian dryland farming systems.

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; NSW Department of Primary Industries; and Vic. Department of Primary Industries.

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

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

Acknowledgments

The editors acknowledge the Joint Venture Agroforestry Program, Future Farm Industries Cooperative Research Centre (FFI CRC) and CRC for the Plant-based Management of Dryland Salinity for funding and supporting this project. We recognise the significant support of our parent organisations - SA Department of Water, Land and Biodiversity Conservation and WA Department of Environment and Conservation.

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, Wayne O'Sullivan, Daniel Huxtable, Nicholas George, David McKenna, Richard Mazanec, Craig Neumann, Graeme Olsen, Peter Jessop, Brendan George, Alan Humpries, Daniel Real, Hayley Norman, Jason Emms, Steve Hughes, Dean Revell, George Freischmidt, Des Stackpole, Malem McLeod, Isla Grundy, Olivia Kemp, Peter Butler, Andrew Fisher and Joe Landsberg. We greatly appreciate the research and administrative support of Merv Tucker, Gary Brennan, Julie Dean and Ligita Bligzna.

For the *Acacia saligna* review we especially thank Maurice McDonald and Bruce Maslin for permitting the reproduction of information and pictures relating to species taxonomy. Richard Bennett for producing GIS datasets of the climatic, physiography, substrates and species associations of *Acacia saligna*. Margaret Byrne for providing information regarding geneflow in the species. Bob Wilson for sharing his knowledge of utilization of *Acacia saligna* in grazing systems. Lynley Stone for providing advice regarding weed issues. Alasdair Grigg for providing advice on plant-water relations. Peter Hutton for providing information regarding the biological activity of secondary compounds from *Acacia saligna*. Lex Thompson for providing us with the collection of *Acacia saligna* literature assembled by CSIRO. Peter White and Andrew Thamo for their assistance with locating wild populations of *Acacia saligna* and provision of other valuable field observations. Melissa Millar for contributing to the work on geneflow, as well as proof reading the manuscript and providing editorial input. Henry Le Houerou for providing information and pictures of *Acacia saligna* in the Mediterranean, Charalambos Christodoulou for information and use of photographs of *Acacia saligna* in Cyprus, and Jean-Marc Dufour-Dror for pictures of *Acacia saligna* in Israel.

In the *Atriplex nummularia* review the editors thank Ed Barrett-Lennard, Hayley Norman, Enrique Correal, Daniel Real and Dean Revell for valuable and enlightening discussions on the nutritional aspects and development potential of Old Man Saltbush. Julie Dean for collation and maintenance of the reference data base. Merv Tucker and Craig Neumann for assistance in collection of field data. Lynley Stone for providing advice regarding weed issues.

For the *Eucalyptus rudis* review the editors thank Sarah Van Gent for conducting the germination tests, data synthesis, and preparation of that section of the report; and Peter White, Andrew Thamo, David Bright and Bob Gretton for sharing their observations of the species in its natural environment.

We also thank Tony Shelbourne for his detailed commentary and formal review of this work, and David McKenna and Craig Neumann for detailed proofing of this report.

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Executive Summary

What the report is about

This report identifies Australian woody crop 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 species reviews of Koojong Wattle (*Acacia saligna*), Old Man Saltbush (*Atriplex nummularia*) and Flooded Gum (*Eucalyptus rudis*) with a focus on their taxonomy, ecology, biology, agronomy and potential for domestication as woody biomass crops for Australian dryland farming systems.

Who is the report targeted at?

This report is intended to inform potential crop developers, researchers and plant breeders with the background information required to promote the development of new woody crops for 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 suit integration with existing annual cropping and grazing systems providing a range of natural resource benefits, including improved dryland and stream salinity. They need to improve resilience of agricultural systems in response to climate variability, and form 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 two 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** (Hobbs *et al.* 2009a);
- **FloraSearch 3b - Domestication potential of high priority species** (*Acacia saligna*, *Atriplex nummularia* and *Eucalyptus rudis*) **for woody biomass crops** (this report, 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 key objective of this report (FloraSearch 3b) is to provide a comprehensive overview of knowledge to support future crop development of three key woody crop species identified in the species evaluation report (FloraSearch 3a).

Methods used

This compilation of this report is based on extensive literature reviews, field surveys, trial site data and consultations with numerous plant and farm forestry researchers, taxonomists and rural industry practitioners. The extensive information gathered has been refined and consolidated for three targeted high priority species.

Results/key findings

This series of reviews provides the most up-to-date knowledge on Koojong Wattle (*Acacia saligna*), Old Man Saltbush (*Atriplex nummularia*) and Flooded Gum (*Eucalyptus rudis*), and detailed evaluations of the key issues and characteristics of each species as they progress towards domestication as commercially viable woody biomass crops. The information presented here provides the basis for future plant breeding and crop development of three key woody crop species suited to lower rainfall regions of southern Australia. Each candidate species identified in these reviews is strongly suited to further domestication work and has the potential to contribute to the future sustainability of farming systems in regions of Australia.

Koojong Wattle (*Acacia saligna*) has many desirable attributes that make it a candidate for domestication in Western Australia. It is easy to establish from seed and has the potential for rapid growth rates. The reproductive biology of the species suits it for plant improvement, while extensive wild populations and recently updated understanding of the species taxonomy provide a large and diverse genetic base to underpin this task. From an agronomic standpoint, Koojong Wattle is suited to integration into dryland farming systems where it could make a substantial contribution to landscape and enterprise sustainability. The wood in the form of chip is suitable for products such as panel board or for use in energy from biomass production. Although the foliage has potential for animal feed it has poorer forage value than Old Man Saltbush and is less suited to *in situ* utilisation due to taller plant height. Separated foliage as a side stream from mechanical biomass harvesting could be utilised for livestock feeds.

The review of **Old Man Saltbush (*Atriplex nummularia*)** suggests that this species will play a significant role in the development of resilient grazing systems, particularly in lower rainfall and marginal parts of the agricultural zone. There is significant potential for plant improvement programs to develop cultivars that are more palatable and productive, and having higher feed value for livestock. The wide geographic distribution and evaluation of variability suggest that there is a good likelihood of improvement of many of these aspects through selection and breeding. Old Man Saltbush is a valuable supplementary feed source particularly when pastures are depleted in late summer and autumn, easy to establish, drought and salt tolerant, and provides a range of environmental and financial benefits when incorporated into agricultural systems.

The product strengths of **Flooded Gum (*Eucalyptus rudis*)** lie in the utilisation of the woody fraction of the biomass. As a candidate for domestication in WA it has desirable attributes such as ease of establishment, potential for rapid growth rates, and a wide genetic base to underpin breeding selection. Although prone to some insect attack it appears to maintain an acceptable growth rate compared to other species in difficult environments. More information is required regarding the agronomy of *E. rudis* and the factors that impact upon its productivity.

Implications for relevant stakeholders

This research forms the backbone of Australian plant breeding and woody crop development for three species and select regions of the Australia's dryland agriculture zone. It provides a solid base from which research is being developed within the Future Farm Industries Cooperative Research Centre and aims to engage 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 and research is required to develop these species and associated industries in Australia. Plant selection, trials, agronomic experimentation and breeding will improve woody crop performance and profitability in agricultural lands.

Old Man Saltbush (*Atriplex nummularia*) has significant immediate potential for development. It has already been widely used as fodder source in southern Australia, does not require the development of new industries, has wide application due to its ranging climatic suitability, and is not greatly restricted spatially by weed risk potential.

Koojong Wattle (*Acacia saligna*) also has some potential as a fodder source to livestock industries, but is limited to use in Western Australia (due to weed risks in eastern Australia). However, Koojong Wattle does provide the opportunity for valuable multiple-product streams (eg. fodder / wood fibre / bioenergy) and is readily and cheaply established for crop production.

Flooded Gum (*Eucalyptus rudis*) is fast growing relative of River Redgum (*E. camaldulensis*) and is suited to Western Australian medium-low rainfall regions where it has strong potential for future sources of biomass for bioenergy and wood fibre.

Future research and development priorities for these three species:

Koojong Wattle (*Acacia saligna*) - increase the uptake and utilisation of this multipurpose crop species in Western Australia and allow the selection and development of new improved cultivars and breeding populations by:

- Utilising the existing comprehensive germplasm planting to assess performance of existing progeny and extend plant improvement strategies;
- Building on information from the existing progeny experiments, developing new knowledge about sprouting/coppicing ability, and about genetic resistance to, or cultural practices to control gall rust; and
- Undertaking tests of wood properties and phyllodes nutritive value in progeny experiments, and operational tests of panel manufacture and fodder value.

Old Man Saltbush (*Atriplex nummularia*) - enhance uptake and utilisation of this valuable fodder plant across Australia, especially in lower to medium rainfall regions by:

- Completing the estimation of genetic versus environmental variation and associated genetic parameters in the new family/provenance trials for a number of traits relating to nutrition and productivity;
- Defining breeding objectives and selection criteria by better understanding of nutritional components and how they relate to animal performance, developing more reliable rapid assessment techniques for nutritional assessment of native shrub species, and examining the

complementary benefits of mixed species grazing systems in which Old Man Saltbush is an integral part;

- Initiating a plant improvement program utilising selection and breeding to develop improved cultivars and breeding populations; and

- Developing more effective direct seeding techniques in order to reduce the cost of establishment.

Flooded Gum (*Eucalyptus rudis*) - better understand this potential woody fibre and biomass crop species and its likely utilisation of in Western Australia by:

- Establishing a range of progeny trials to assess variability of key characteristics (e.g. wood properties for fibre production) and support plant improvement strategies;

- Establishing small-scale field experiments to develop knowledge about site selection, yield potential, coppicing ability and insect control; and

- Establishing small scale operational planting by farmers to evaluate practical field establishment, management options, harvest operations and operational tests of panel manufacture.

1. Introduction and Overview

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

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Interest in the domestication of native woody, perennial plants suited to Australian dryland farming systems has steadily gathered momentum since the early 1990's. The impetus for this has been the recognition that farming systems based solely on annual plants are not sustainable in many parts of the Australian continent. The FloraSearch project has integrated scientific investigations of attributes of Australian plant species with new crop development and demonstrates that novel production systems are a real option for dryland agricultural regions (Bennell *et al.* 2008, Hobbs *et al.* 2008c). FloraSearch provides the latest available information on species targeted for biomass supply for a range of products including bioenergy, extractives, fodder and wood products. The information collected will also provide the reader with the opportunity of identifying the species best suited to the climate and soil conditions of a particular location together with estimates of the productive potential. Consequently, adaptable woody species can provide robust and reliable crop options in landscapes with variable soils and climates where they may be able to compete on economic returns with existing annual crops or be productive on land units that are poorly suited to annual crops and pastures (Bartle *et al.* 2007, Hobbs *et al.* 2008c).

Deep-rooted shrub and tree species can buffer seasonal and annual variations in climatic conditions that cannot be fully or reliably utilised by annual crops alone. Therefore, by increasing the mix of functional plant types in the landscape we are able to improve risk management and long-term economic sustainability of farming systems. Landscape and farm-scale benefits include decreasing recharge and the threat of salinisation, reduced wind erosion, biodiversity enhancement, and climate change adaptation (see Fig. 1).

Fig. 1. A typical Australian dryland farming landscape - cropland with little remnant native vegetation, high recharge rates and erosion-prone light textured soils (Dalwallinu, WA, Photo: D.Huxtable).

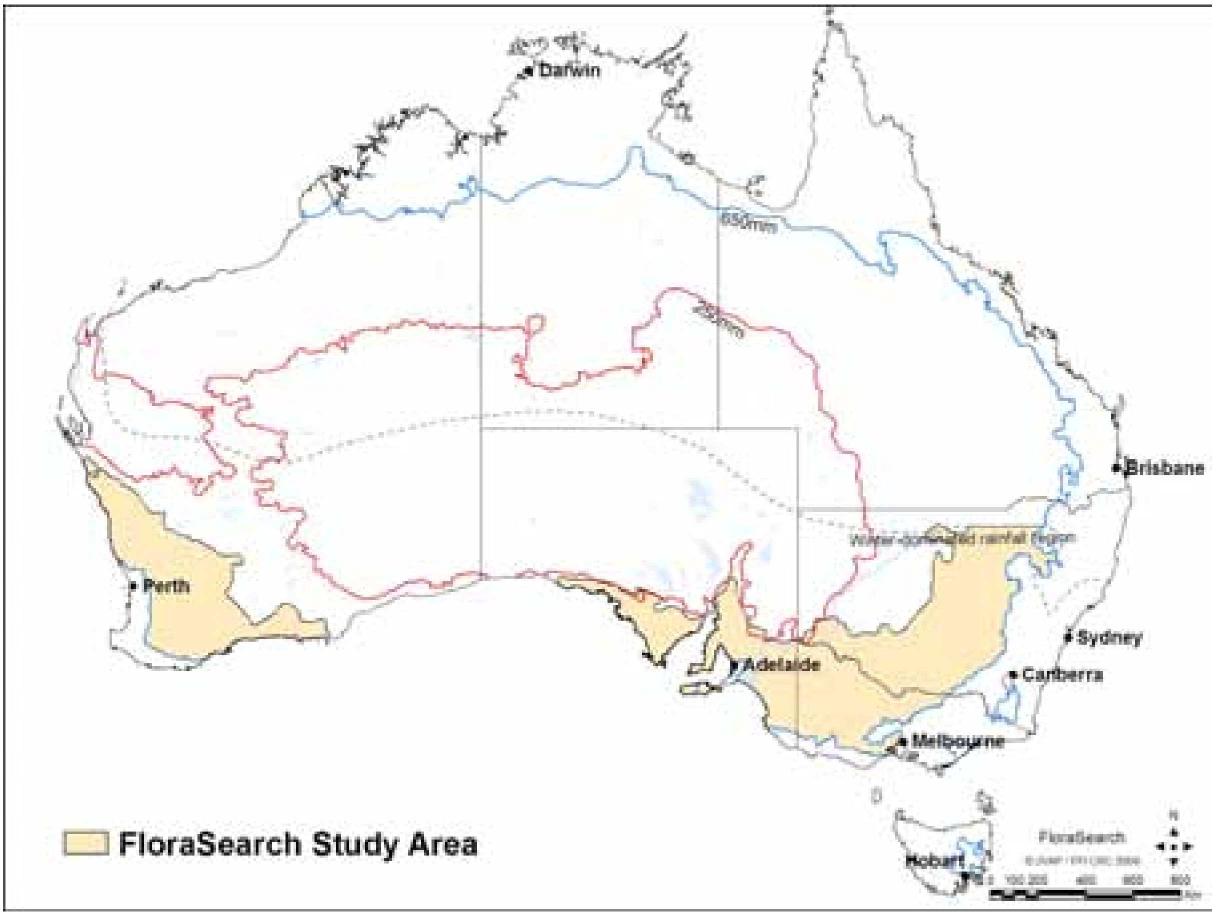
The impacts of dryland salinity and the need to control recharge were the main motivations for the early work on developing deep rooted woody crops (see Fig. 2). The extent of perennial plant cover necessary to contribute to salinity control is substantial and species described are adaptable, productive, and are able to supply feedstock for emerging large-scale industries. FloraSearch has focused on short production cycle woody crops; an agroforestry system that economic analysis indicates is most likely to be viable across the wheatbelt areas of southern Australia (Fig. 1). New agroforestry designs include short-cycle woody crops based on belt plantings or blocks of coppice and phase crops. Coppicing plants that can regrow after each phase of successive harvest cycles are receiving immediate attention in the ongoing evolution of research and development of prospective species. The ability to get several harvests from a single planting phase and in a relatively short time after establishment provides for better economic returns on current economic analysis.

Fig. 2. An example of land degradation caused by secondary salinity (Narrogin, WA, Photo: D. Huxtable).

The focus on short cycle harvest of coppicing species, and the move away from timber products, has focused attention on the development of new products and engagement in new industry development has become a critical part of the project. The recognition of carbon emissions as an important national issue has added to the potential importance of perennial woody crops as part of the agricultural landscape. Carbon sequestration and climate change issues are now equally as relevant as salinity and control of recharge. 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. The availability of technology for clean second-generation transport fuels is still constrained by the need to develop economically competitive industrial scale processes, the subject of huge investment particularly in North America and Europe. Consequently, 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. In the short-term, 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. Biosequestration currently forms a major component in national and state climate-change policies for reducing net greenhouse gas emissions and for landholders, carbon investment provides the prospect of financing revegetation to increase farm sustainability.

Fig. 3. 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.



The interest in short cycle crops was stimulated by the development of mallee in WA. This initially led to investment in the WA Search project (Olsen *et al.* 2004) followed by support from JVAP for the FloraSearch projects (Bennell *et al.* 2008, Hobbs and Bennell 2008, Hobbs 2008a, Hobbs *et al.* 2008c) to look generically at the potential of native woody species and their products. Native species only were considered due to the vast range of genetic variability available, the diminished risk of cultivated species becoming environmental weeds, and the ease of accessing genetic material to underpin plant improvement programs.

The project aims to be relevant over the whole of the southern Australian wheat-sheep zone and the abundant diversity of woody germplasm is such that every climatic and edaphic niche could potentially be used for future woody crops. In order to make the project nationally relevant, selection and development of species includes prospects potentially suitable for use in all major regions. This has been achieved by including species selection criteria that relate to regional adaptability of germplasm and regional relevance of products. The regional spread of opportunity is critical in achieving the objective of gaining broad national consensus for the project.

The WA Search (Olsen *et al.* 2004) and FloraSearch Stage 1 and 2 (Bennell *et al.* 2008, Hobbs and Bennell 2008, Hobbs 2008a, Hobbs *et al.* 2008c) reports describe in detail the methods and results of surveys to assess the potential within the native plant communities of southern Australia. The process describes the laborious step-by-step process of screening the vast number of plant species 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. The species were considered from a western and eastern perspective due to large differences in conditions in the two regions and the two lists were then prioritised so that a few key species could be drawn into a process of commercial development.

This process led to a decision at the conclusion of Stage 2 to undertake more detailed species development of Old Man Saltbush (*Atriplex nummularia*), Koojong Wattle (*Acacia saligna*) and Flooded Gum (*Eucalyptus rudis*). This work was taken in collaboration with mallee plant improvement work being undertaken by the WA Department of Environment and Conservation. 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.

This report presents in-depth reviews of existing knowledge on the FloraSearch Phase 3 focus species. This information is comprehensive in the case of Old Man Saltbush reflecting 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, Koojong Wattle has been recognised as a productive and adaptable species and has been the subject of many prior studies. Flooded Gum however has not been widely recognised as a potential commercial species in the past and there is a smaller amount of background information. These reviews provide an important recourse for ongoing research into the commercial development of these species and will shape the approach to plant improvement and agronomic studies planned in the Woody Crop Program being developed as part of the Future Farm Industries CRC.

This document, “Domestication potential of high priority species (*Acacia saligna*, *Atriplex nummularia* & *Eucalyptus rudis*) for woody biomass crops in lower rainfall southern Australia. FloraSearch 3b.” (Hobbs *et al.* 2009b), is part of a series of FloraSearch Stage 3 reports produced in 2008. The other volumes in this series include: “Developing species for woody biomass crops in lower rainfall southern Australia. FloraSearch 3a.” (Hobbs *et al.* 2009a) which focuses on species selections, woody crop performance, priorities for crop development, plant improvement and breeding strategies; and “Regional industry potential for woody biomass crops in lower rainfall southern Australia. FloraSearch 3c.” (Hobbs 2009b) that 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.

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2. Review of *Acacia saligna* (Koojong Wattle) and its Potential for Domestication for Western Australian Dryland Farming Systems

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Introduction

Acacia saligna (Labill.) H.L. Wendl. is a native woody shrub that has been selected for domestication for use as a multiple-purpose woody crop in the wheatbelt agricultural region of the south-west of Western Australia (WA). *A. saligna* has many attributes that favour its development as a crop plant including a long history of use in Australia and other parts of the world, but has so far attracted little investment in scientific development. It is easy to propagate and establish, is capable of rapid growth in a wide range of environments and has considerable genetic diversity and potential for improved crop cultivars. It could produce woody biomass as feedstocks for various industrial products and its foliage has some fodder value.

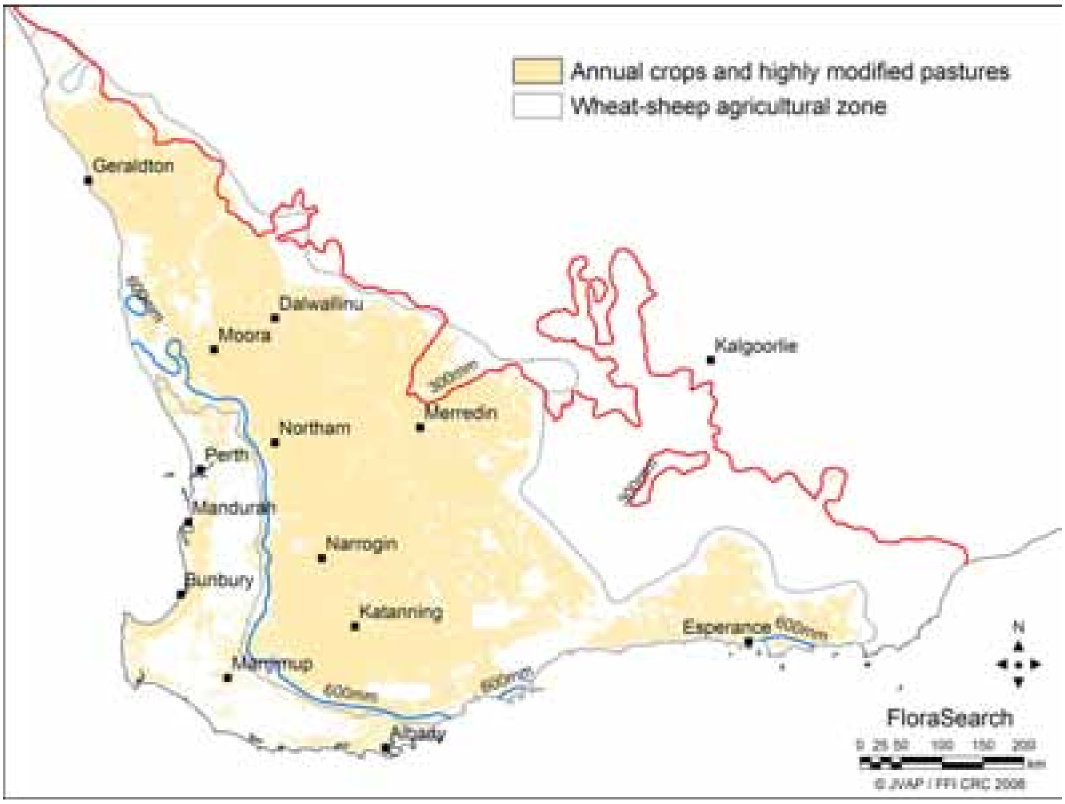
The purpose of this report is to review and synthesise all available knowledge on *A. saligna* relevant to its development as a crop plant. It will focus on potential for use in the farming systems in the south west of WA but may also be useful to land managers in other parts of the world where *A. saligna* has been introduced. The principal source of information is the scientific literature supplemented with knowledge gained by the authors and other practitioners who have worked on the species. The report briefly outlines the WA land-use context for domesticating *A. saligna* before addressing its taxonomy and ecology, historical and prospective uses and development of its agronomic potential. It concludes with a summary of findings and directions for future research and development.

Background

Dryland farming in Western Australia

The WA wheatbelt region comprises some 15 million ha of farm land between the latitudes 29 and 34 degrees south (Fig. 4). It has a Mediterranean type climate with an annual rainfall range of 300 to 600 mm. It consists of an ancient deeply weathered (~25 m) granite plateau of low relief and elevation of ~300 m above sea level. The native woodland and shrublands display exceptional biodiversity. Development for agriculture occurred during the twentieth century and farms have typically retained ~10% of the native vegetation. The agricultural plant species are all introduced and winter growing annuals.

Fig. 4. The wheat-sheep agricultural zone of Western Australia, as demarcated by cleared native vegetation and rainfall isohyets.



The conversion of native woodlands and shrublands to annual plant agriculture reduces evapotranspiration by a small amount. The low relief and generally deep, permeable weathered profile means that most of this water infiltrates into the profile and slowly accumulates as stored soil water and groundwater. The groundwater mobilises previously stable salt storages (built up over many millennia from trace inputs via rain and dry fallout) and forms saline discharge areas in low landscape positions. This process not only damages land and water supply on farms (see Fig. 1 and Fig. 2), but on a regional scale, it changes the hydrological characteristics of whole river systems, causing loss of water resources, biodiversity and amenity, increased flood risk and damage to infrastructure. Agricultural salinity has recently been comprehensively reviewed in a series of reports from the National Dryland Salinity Program (Powell 2004, Robbins 2004, van Bueren and Price 2004).

Environmental benefits and services

In theory, revegetation with perennials, especially deep rooted woody species, could reverse or control salinity. However, the considerable human and physical infrastructure invested in wheat-sheep agriculture, its current profitability and the scale of the salinity problem will dictate that the bulk of revegetation be profitable and implemented in harmony with the current agriculture. These constraints mean that revegetation options for salinity control will need to be complemented by other methods e.g. perennial herbaceous pastures, productive salt tolerant pastures on salt affected areas and various engineering options to collect and safely dispose of saline discharge water. At present, commercially viable perennial plant options for the wheatbelt are limited (Lefroy *et al.* 2005).

Prior to clearing, these landscapes supported a mosaic of vegetation types, determined principally by available moisture and soil type (Fig. 5). Photos of natural *A. saligna* populations (Fig. 7 - Fig. 10, Fig. 15 - Fig. 17) give a good indication of the floristic structure of the Western Australian landscape.

Fig. 5. Examples of remnant vegetation in the Western Australian wheat-sheep agricultural zone.

(A) Remnant vegetation on sandplain in northern Wheatbelt showing emergent shrubs in a species rich heath (B) *A. saligna* in remnant heath with emergent mallee species in the south-western Wheatbelt (C) Remnant mallee and woodland species on heavier soils of the central western Wheatbelt, west of Wongan Hills (D) Remnant *Eucalyptus wandoo* woodland at Arthur River in the wetter south western Wheat-sheep belt.

Acacia saligna as a domestication candidate

The standing of *Acacia* as a prospective genus for investigation is based on its prominence in the Australian flora and its history of utilisation. It is a large genus comprising over 1500 species occurring on five continents, with approximately 950 from Australia, 130 from Africa, 100 from

Madagascar, 270 from the Americas and 55 from the Asia-Pacific (Orchard and Wilson 2001). South-western Australia has the world's highest diversity of *Acacia*, and a secondary centre of diversity occurs on the Great Dividing Range in eastern Australia (Hopper and Maslin 1978).

Australian *Acacia* species are already utilised in some 70 countries (Orchard and Wilson 2001). They are grown for fuel wood, timber, tannins, livestock feed, livestock shelter and land rehabilitation (El-Lakany 1987, Fox 1986, New 1984, Orchard and Wilson 2001, Wickens *et al.* 1995, Zhigang and Minquan 1986). Australian *Acacia* species introduced into Africa in the second half of the 19^{th} century are now an important resource for rural communities, providing essential feed for livestock and fuel for cooking (Le Houerou 2000). The ability of *Acacia* to survive in harsh conditions and produce large quantities of edible seed has resulted in their use for human food in sub-Saharan Africa (Harwood *et al.* 1999, Rinaudo *et al.* 2002).

Historically there has been minimal development of *Acacia* or other native species as crop plants for temperate climatic zones in Australia.

Serious endeavour to develop woody crop species for the wheatbelt in WA began in the 1980s, with the exploration of mallee eucalypts for short cycle coppice crops (Bartle and Shea 2002). Mallee development commenced in earnest in 1993, culminating in the establishment of some 12,000 ha of mallee crops by more than 20% of wheatbelt farmers, and the operational testing of a processing option (Enecon 2001). Work towards making mallee a commercially competitive crop option is ongoing. Mallee established a new woody crop paradigm of short harvest cycles (3 to 6 years), low cost continuous harvest systems and regionally based industries producing industrial products from biomass (Bartle *et al.* 2007, Bartle 2006).

The progress in mallee domestication led to the obvious question of whether there were other native species that might be suitable candidates for short cycle crop development. Native species were seen as having several advantages for crop development: notably their evolutionary adaptation to target landscapes and their low risk of becoming weeds. This gave rise to the Search Project, sponsored by the Natural Heritage Trust (NHT), to screen the WA flora for potential commercial species. The project was implemented during 1999-2003. Large scale, bulk industrial products were the target: including reconstituted wood products, chemical feed stocks and bio-energy. The project included the manufacture of sample products as part of its assessment and specified a priority list of 20 species for domestication, based on product feed stock attributes and agronomic factors. *A. saligna* was ranked highly in this project (Bartle *et al.* 2002, Olsen *et al.* 2004).

During the same period, the Joint Venture Agroforestry Program (JVAP), a consortium of national research and development organisations, commissioned a study called AcaciaSearch to look nationally at potentially commercial *Acacia* species. Of the 462 *Acacia* species endemic to the dryland farming regions of southern Australia, 35 were identified as having development potential based on subjective assessment of plant form, growth, wood quality, weediness, soil preference, taxonomy, distribution, reproductive biology and agronomy (Maslin and McDonald 2004). Of these, *A. saligna* was rated as the most prospective species.

In 2001, JVAP decided to support a national scale project called FloraSearch in conjunction with the Cooperative Research Centre for Plant-based Management of Dryland Salinity (CRC PBMDS). The continuing work on the domestication of *A. saligna*, which includes this review, is part of the FloraSearch Project.

Taxonomy and Ecology

Species description

Taxonomy and species description

Sound taxonomic resolution is a prerequisite to domestication. If taxa are poorly defined, or if the names applied to them are incorrect, the information that is assembled and disseminated is likely to be erroneous or of diminished value (Maslin 2002). In the absence of clear taxonomic boundaries, useful traits may be overlooked as being environmentally driven rather than genetically derived and heritable (Byrne and Broadhurst 2002). Genetic structuring, particularly if it reflects different taxa, can also have significant impacts on domestication and breeding programs, especially if different lineages have different traits of commercial value (Byrne and Broadhurst 2003). Recent work on *A. saligna* has shown that traits which are potentially important in the domestication process, such as growth form and suckering propensity, vary between newly described subspecies (Maslin and McDonald, 2004, McDonald and Maslin, in review).

A. saligna belongs to the subgenus *Phyllodineae*s section *Phyllodineae* (Maslin 2001) which are characterised by having '1-nerved' phyllodes and flowers arranged in globular heads (Maslin and McDonald, 2004). This somewhat artificially defined section of about 408 species is largely confined to the Australian continent. It is unclear whether *A. saligna* is closely related to other *Acacia* taxa, however it does share taxonomic similarities with the *A. bivenosa* group, *A. blakelyi* and *A. scirpifolia* (Maslin and McDonald, 2004).

The history of *A. saligna* taxonomy is reviewed in McDonald and Maslin (in review). Of note is that collections of *A. saligna* from the Perth region were at one stage recognized as a separate species, *Acacia cyanophylla* Lindl. (1839), but the two species were later unified under the name *A. saligna* (Maslin 1974). Some literature (cited in this review) published since Maslin's revision, continued to use the name *A. cyanophylla* (for example, Atti *et al.* 2003, Ben Salem *et al.* 2002a, Ben Salem *et al.* 2002b, Ben Salem *et al.* 1997, Ben Salem *et al.* 1999, Ben Salem *et al.* 2005b, Dumancic and Le Houerou 1981, Laamouri *et al.* 2002, Michaelides 1979, Quatrini *et al. 2*003, Reed 1995). Throughout this report no distinction is made between historic studies of *A. saligna* and *A. cyanophylla*. The current relationship between these entities is detailed below.

A. saligna exhibits highly variable morphology, and earlier work assumed that the species was genetically variable (Fox 1995, Maslin 2001, Maslin *et al.* 1998). In a review of the species ecology, Fox (1995) posited a link between morphological variation and provenance. Morphologically distinct 'cultivars' of *A. saligna* are apparently recognized internationally (see Fig. 6). For example, workers in the Mediterranean region recognize two different forms of *A. saligna*; one arborescent with broad phyllodes, said to be more suitable for firewood production, and another with a bushy habit and narrow phyllodes, considered more suitable for livestock forage (Le Houerou 2002). It is uncertain how this variation relates to the recent taxonomic revision, and may be an example of local exotic landrace development. *A. saligna* is endemic to south-western Australia, where plant species often exhibit taxonomic complexity, and many species are known to contain distinct genetic lineages (Coates 2000, Hopper 1992). It was therefore suspected that the variation within *A. saligna* might have been the result of unresolved taxonomic complexity or differentiation between provenances. The existence of a distinct entity confined to the Swan coastal plain was posited by McCabe (1997) using allozyme analysis, with a possible link to populations on the Esperance sandplain hypothesised using morphometric analysis.

The greater extent of the morphological variation within *A. saligna* was revealed by a systematic examination of the species (Maslin and McDonald 2004), when four major variants, with somewhat separate natural distributions, were identified (Fig. 12). These included: the "cyanophylla" variant on the Swan coastal Plain in the vicinity of Perth, the "typical" variant in inland areas approximating the wheatbelt region, the "forest" variant in a zone between the previous two and the "Tweed River" variant in a smaller geographic area between Bridgetown and Kojonup. A genetic study using RFLP molecular markers by George *et al.* (2006a) provided strong evidence that the "typical" and "forest" variants were distinct, however "cyanophylla" and "Tweed River" forms were unable to be separated.

A subsequent study has been conducted using microsatellite molecular markers that were developed specifically for *A. saligna,* and show greater levels of polymorphism than RFLP markers (Millar and Byrne 2007, Millar *et al.* 2008a). This study produced greater resolution between the "cyanophylla' and "Tweed River" variants and did resolve the species complex into four distinct genetic entities. Although a level of genetic affinity was still evident for the "cyanophylla' and "Tweed River" variants, the authors of the study support the recognition of four distinct subspecies within the species complex.

The cryptic morphological variation (i.e. growth form, phyllode morphology) that was known to exist within the species has now been substantially resolved through the recently completed taxonomic revision by McDonald and Maslin (in review). Four subspecies are now formally recognised. These are *A. saligna* ssp. *saligna* (formerly 'cyanophylla'), *A. saligna* ssp. *lindleyi* (formerly 'typical'), *A. saligna* ssp. *stolonifera* (formerly 'forest'), and *A. saligna* ssp. *pruinescens* (formerly 'Tweed Blue'). These entities were assigned the rank of subspecies because their similarities were considered greater than the differences between them. The review shows there is a strong taxonomic basis to the morphological variation observed in the species. McDonald and Maslin's (in review) revision considers a range of morphological characters, including bark (texture, colour), growth phases (degree of heterophylly and neotony), foliage (colour, form, lustre, size, arrangement), inflorescence (development, arrangement, size, colour) and fruit (size, colour). It takes account of the distribution, habitat, and affinities of the variants. It discusses the variation within each subspecies, and the occurrence of hybrids. There is some discussion about the potential usefulness of each of the subspecies. The information presented in this report takes account of this taxonomy, although segregation of historic data to this level is difficult in the majority of cases.

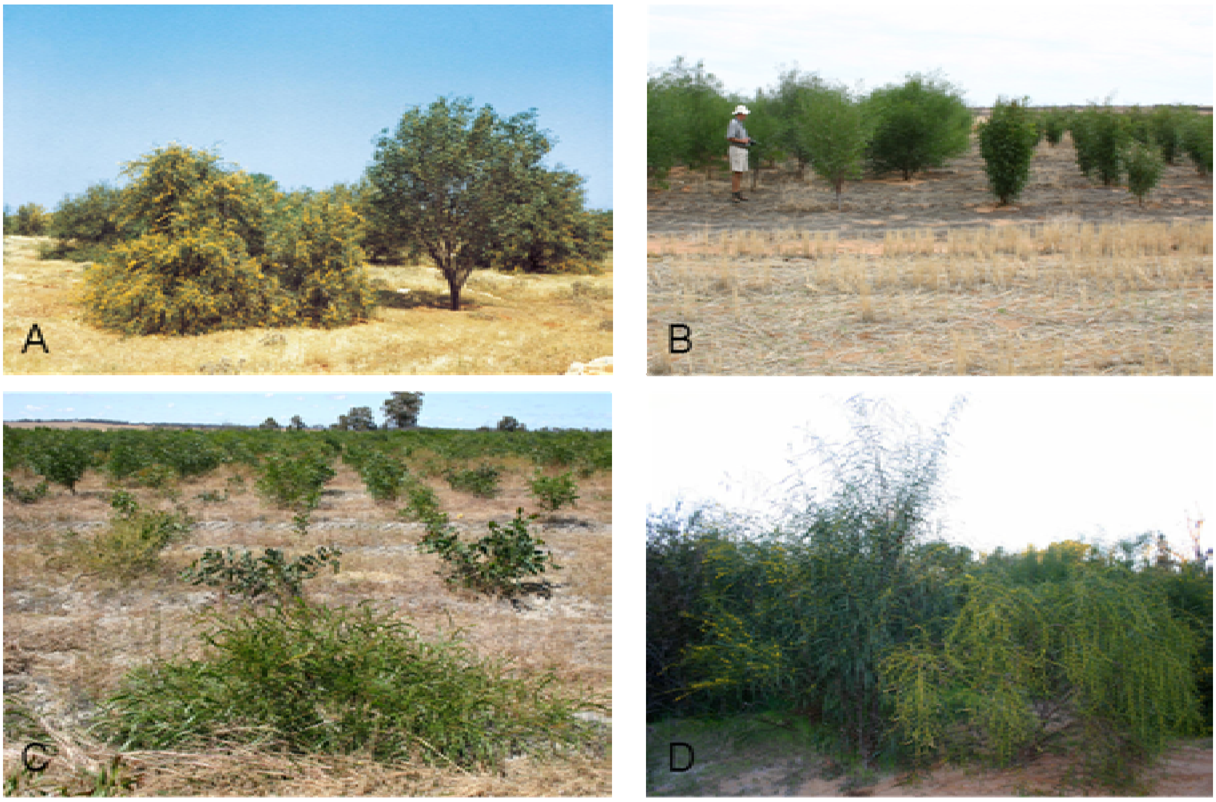
To avoid confusion the use of Latin species names is generally preferred to the use of common names, however, common names can also be useful for communicating information about plant species, especially amongst non-specialists. *A. saligna* has several colloquial common names including Orange Wattle, Black Wattle, Golden Wreath Wattle, Blue-Leafed Wattle, Western Australian Golden Wattle and Port Jackson Willow (Fox 1995). To avoid ambiguity, it is preferable to use one standard common name. Abbott (1983) proposed the name *Cujong* be adopted for *A. saligna,* which was the name for the species being used by the aboriginal people in the Albany region. Authors since then have used variations on this name, for example: *Koojong* and *Coojong* (Keighery and Huston 1994, McDonald *et al.* 2001). The most appropriate spelling for the name is purportedly *Koojong* (Whitehurst 1992). As such, we recommend that the name and spelling *Koojong* is used to refer to *A. saligna*. A similar logic applies to assigning common names to subspecies. Traditional names for *A. saligna* subspecies may have existed but we have no record of them. The following common names for the subspecies are therefore proposed (Table 1).

Table 1. Recommended common names for *Acacia saligna* subspecies.

A. saligna subspecies (McDonald and Maslin in review)	Suggested common name	Variant name used in Maslin and McDonald (2004)
A. saligna (in the broad sense)	Koojong	
A. saligna ssp. *lindleyi*	Inland Koojong	Typical
A. saligna ssp. *Pruinescens*	Blue Koojong	Tweed
A. saligna ssp. *Saligna*	Coastal Koojong	Cyanophylla
A. saligna ssp. *Stolonifera*	Forest Koojong	Forest

Fig. 6. Examples of variation in *Acacia saligna*.

(A) Morphological differences between ten-year-old plants at Cyrenaica, Eastern Libya. Form on left is used for fodder, form on right is used for fuelwood. (Photo: Reproduced with permission from Le Houerou). (B & C) Morphologically different plants growing on trial sites at Dalwallinu, (B) and Bolgart (C), WA. (D) Variation in form of *A. saligna* in a natural population, Mimegara Rd, WA (Photos: W. O'Sullivan).



Distribution, ecology and biology

Species distribution

A. saligna is endemic to the south-west of WA. The natural distribution of the species, derived from herbarium collection data, is shown in Fig. 11 and Fig. 12. (Note that what is considered to be the natural distribution of subsp. *pruinescens* has now contracted from that shown on the map here. The eastern occurrences around Esperance are now regarded as subsp. *saligna* and the northern population near Perth is considered to be a recent introduction.) The species has a widespread distribution extending from Wilgiamia Pool, 30 km north east of Kalbarri, to Ponier Rock 65 km south of Balladonia, but also occurring 230 km east-north-east of Kalbarri on Meka, Murgoo and Jingemarra Stations (Maslin 2001). Single collections of the species from isolated locations in the east and north east may represent remnant populations from a period when the species had a wider distribution, as is evident in other plant species in south-WA (Hopper and Gioia 2004). Alternately, the collections may represent individual plants or populations that have arisen due to historical or recent movement of the species by humans.

Fig. 7. *Acacia saligna* ssp. *saligna*.

(A, B) Bark, (C) Adolescent plant, (D) Seedling, (E) Habit Perry Lakes, (F) Habit near Fremantle, (G) Inflorescence bud, (H) Inflorescence, (I) Pods (Photos: M. McDonald).

Fig. 8. ***Acacia saligna*** **ssp.** ***lindleyi*.**

(A) Habit near Jerramungup, (B) Habit near Eneabba, (C) Seedling, (D) Inflorescence bud with emerging raceme, (E) Habit N of Gingin, (F) New growth showing shiny phyllodes, (G) Inflorescence, (H) Bark (Photos: M. McDonald).

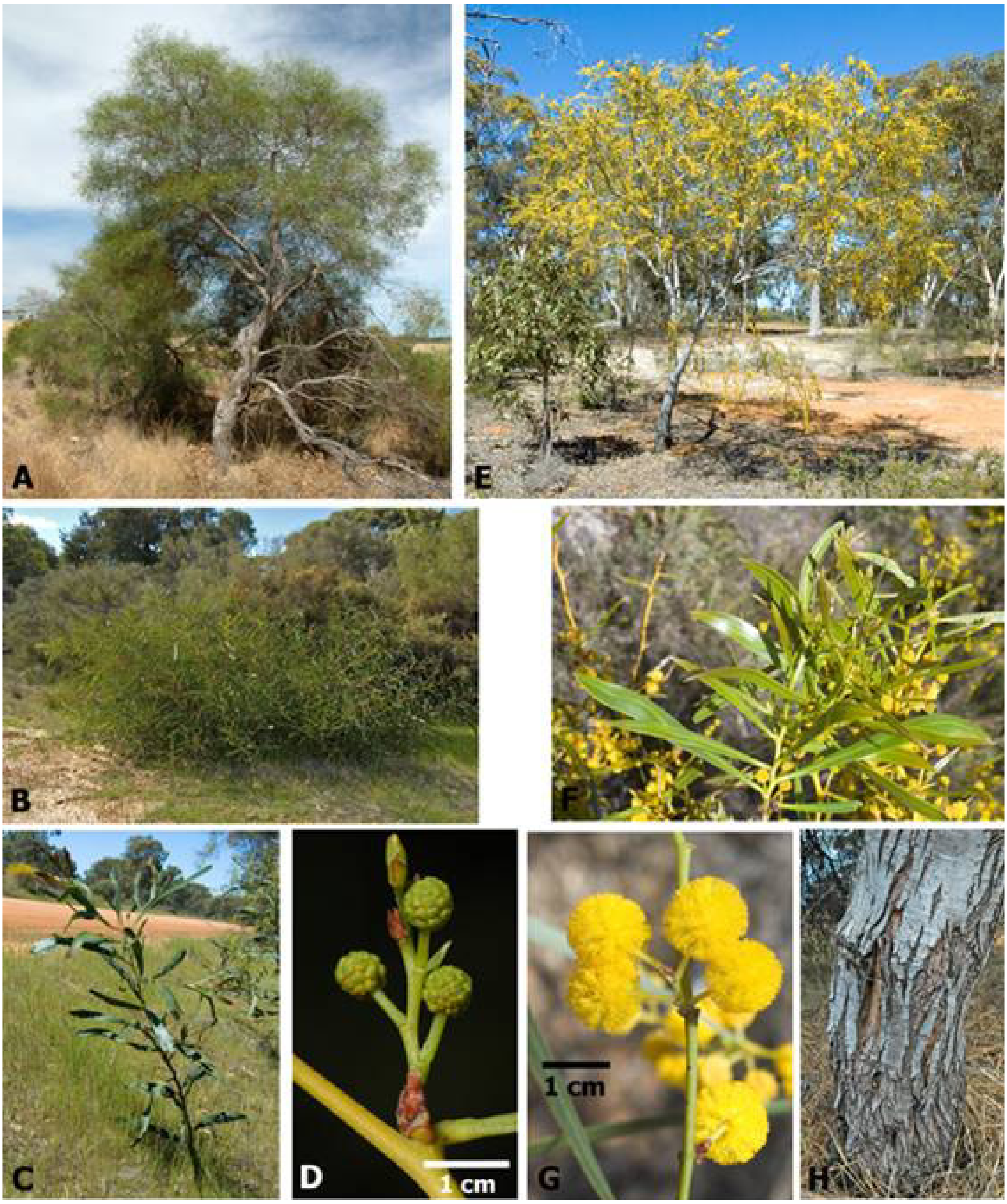


Fig. 9. ***Acacia saligna*** **ssp.** ***pruinescens*.**

(A, D) Bark, (B) Seedling, (C) Adolescent plant, (E) Inflorescence bud, (F) Inflorescences, (G) Habit near Frankland, (H) Habit near Collie (Photos: M. McDonald).

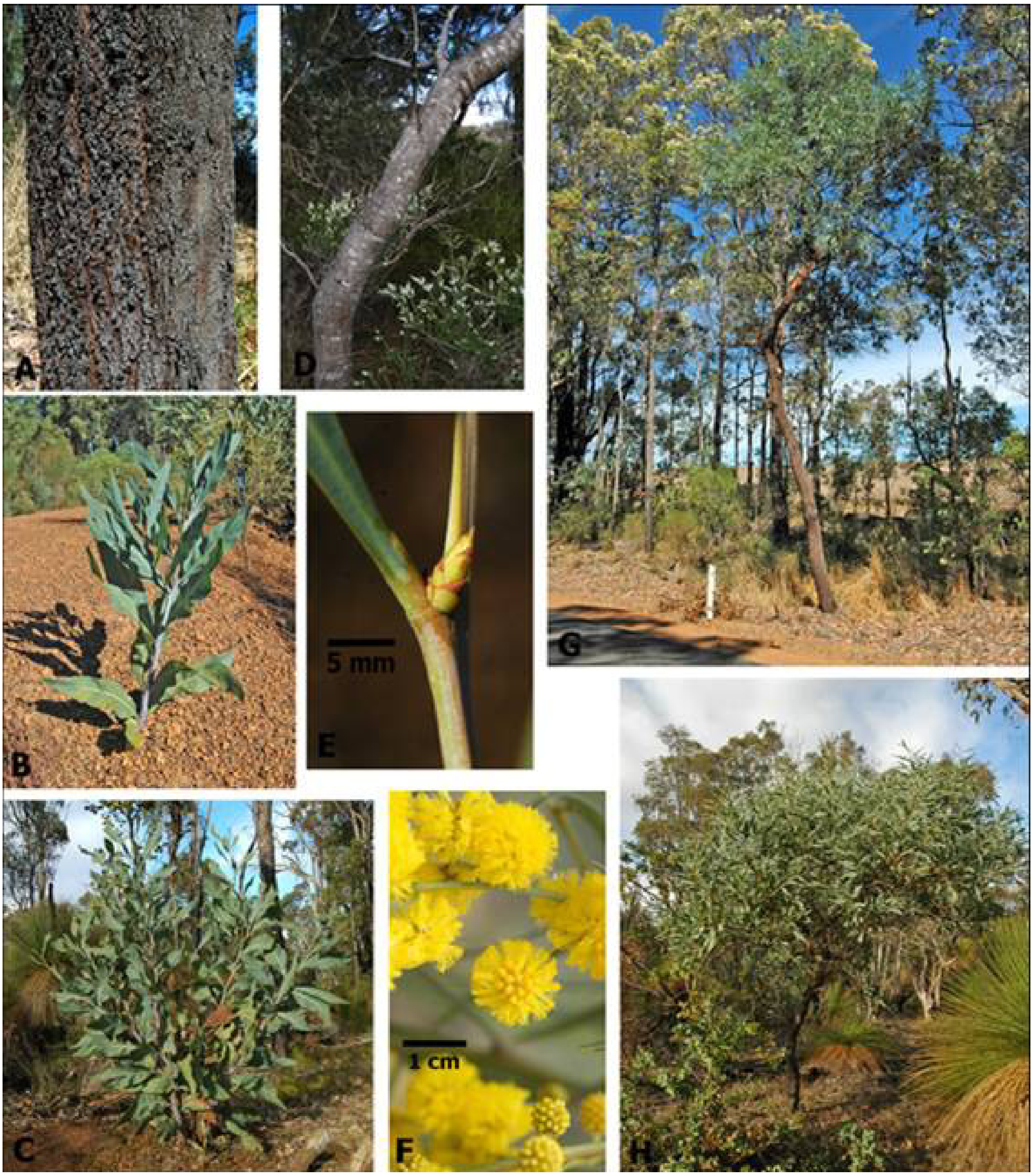


Fig. 10. ***Acacia saligna*** **ssp.** ***stolonifera.***

(A, B) Bark, (C) Habit near Niokia, (D) Seedlings, (E) Inflorescence bud, (F) Habit East Augusta, (G) Root suckering clump, (H) Inflorescences (Photos: M. McDonald).

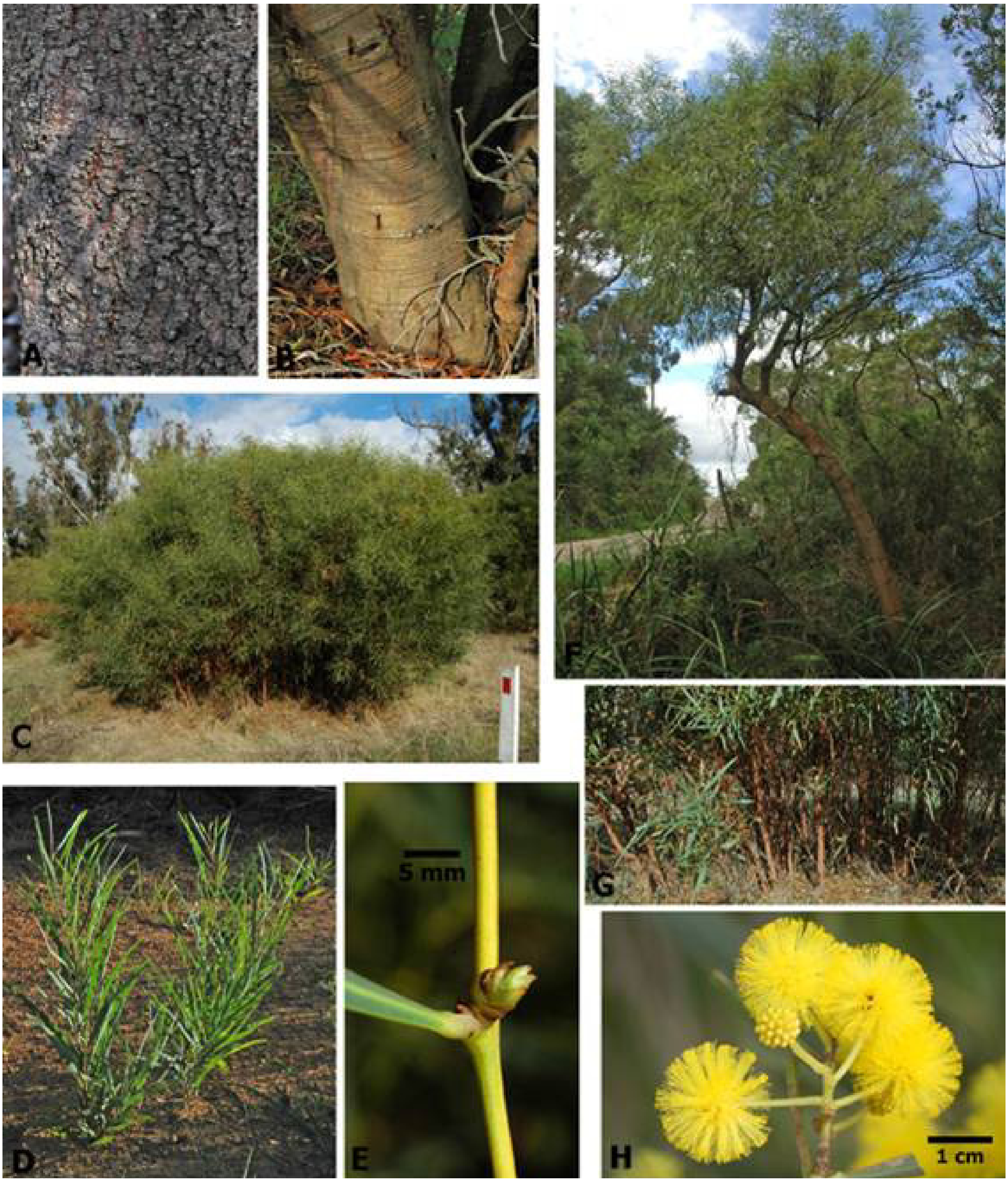
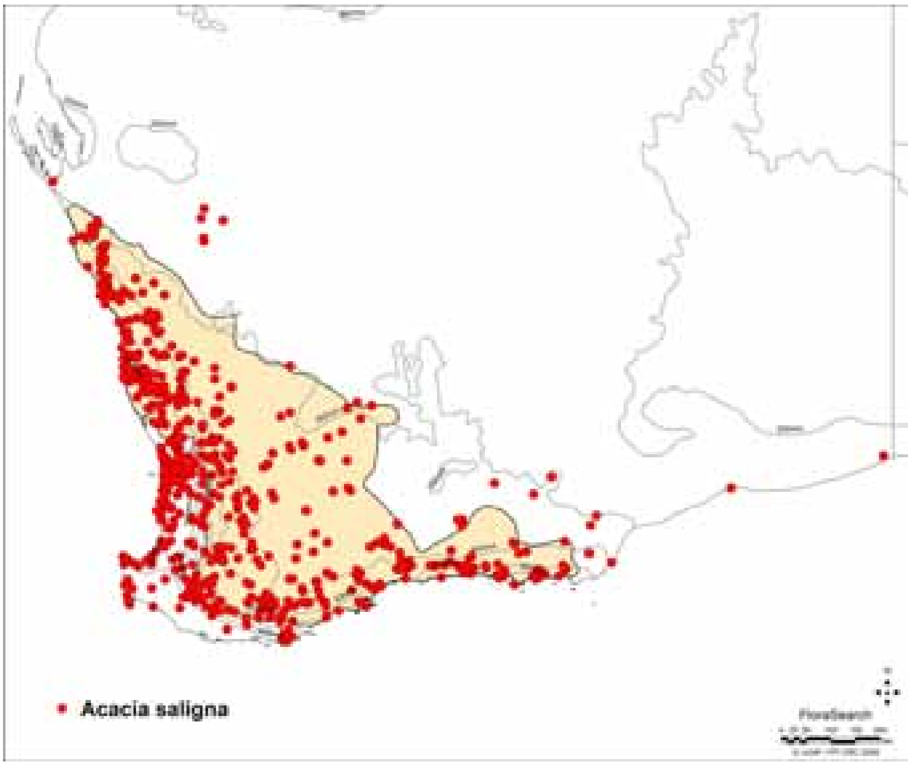


Fig. 11. The natural distribution of *Acacia saligna* in Western Australia.

Compiled from herbaria records. Shaded region indicates the FloraSearch study zone.



A. saligna has been widely planted outside its natural range (Fig. 13 & Fig. 14). Within Australia the species has been introduced to South Australia, Queensland, New South Wales Victoria and Tasmania (AVH 2006, Muyt 2001). The species is also extremely widespread internationally. Greuter *et al.* (1989), report it growing in Algeria, Cyprus, France, Libya, Turkey, Corsica, Greece, Spain, Israel, Jordan, Italy, Portugal, Morocco, Sardinia, Sicily, Sinai, and Tunisia. It is recorded in Egypt and Palestine (Le Houerou 2002), Ethiopia, Kenya, Namibia, Tanzania, and South Africa (Lock 1989), the Middle East (Le Houerou 2002, Lock and Simpson 1991, Marcar *et al.* 1991, Townsend 1974), South America, where there is increasing usage in Chile (Izaguirre and Beyhaut 2003, Perret and Mora 1999), as well as plantings in Uruguay (Perret *et al.* 2001). It grows in the United States of America (USDA and NRCS 2006), Mexico (Perret *et al.* 2001), New Zealand (Pollock *et al.* 1986) and southern India (Chakrabarty and Gangopadhyay 1996).

Habitat and environmental adaptation

Habitat

A. saligna has an extensive but discontinuous range in south-western Australia, and it is often common in areas where it occurs (Fox 1995, Maslin and McDonald 2004, McDonald and Maslin in review). 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. Images showing some of the various habitats and vegetation communities are shown in Fig. 15 - Fig. 17.

Environmental adaptation

As part of this review, biophysical data was generated for all the collections of *A. saligna* lodged at the Western Australian Herbarium, current to April 2006, along with those lodged at other Australian herbaria accessible through Australia's Virtual Herbarium (AVH 2006). A total of 984 non-duplicated records were available, 847 from locations in WA and 137 from other Australian States. Of the collections taken within WA, approximately 196 were unduplicated collections made since 2001, largely as part of work done for the FloraSearch project. Environmental data for each site was created using the program ArcMap (ESRI 2002). Meteorological data was obtained from the Australian National Land and Water Resources Audit (NLWRA 2005), soil data from the Digital Atlas of Australian Soils (DAAS 1991), and vegetation data from the Australian Government Department of the Environment and Heritage (PMVG 2005).

Much of the latitude and longitude data for non-WA herbaria collections had a low precision (within 2.5 kilometres). It was found that removal of these collections did not greatly affect the averages obtained in the data analysis. However, this lack of resolution will need to be considered when interpreting the results for the non-WA collections. An attempt has also been made to summarize the habitat details of the individual subspecies of *A. saligna*. There were difficulties finding populations where the subspecies were unambiguously identified, because the revision of the taxonomic status of the species is so recent. For this reason the sample size for assessing some of the subspecies was limited.

Fig. 12. The distribution of described variants of *Acacia saligna.*

Mapping by Paul Gioia. Image used with permission of the WA Herbarium, Department of Conservation and Environment.

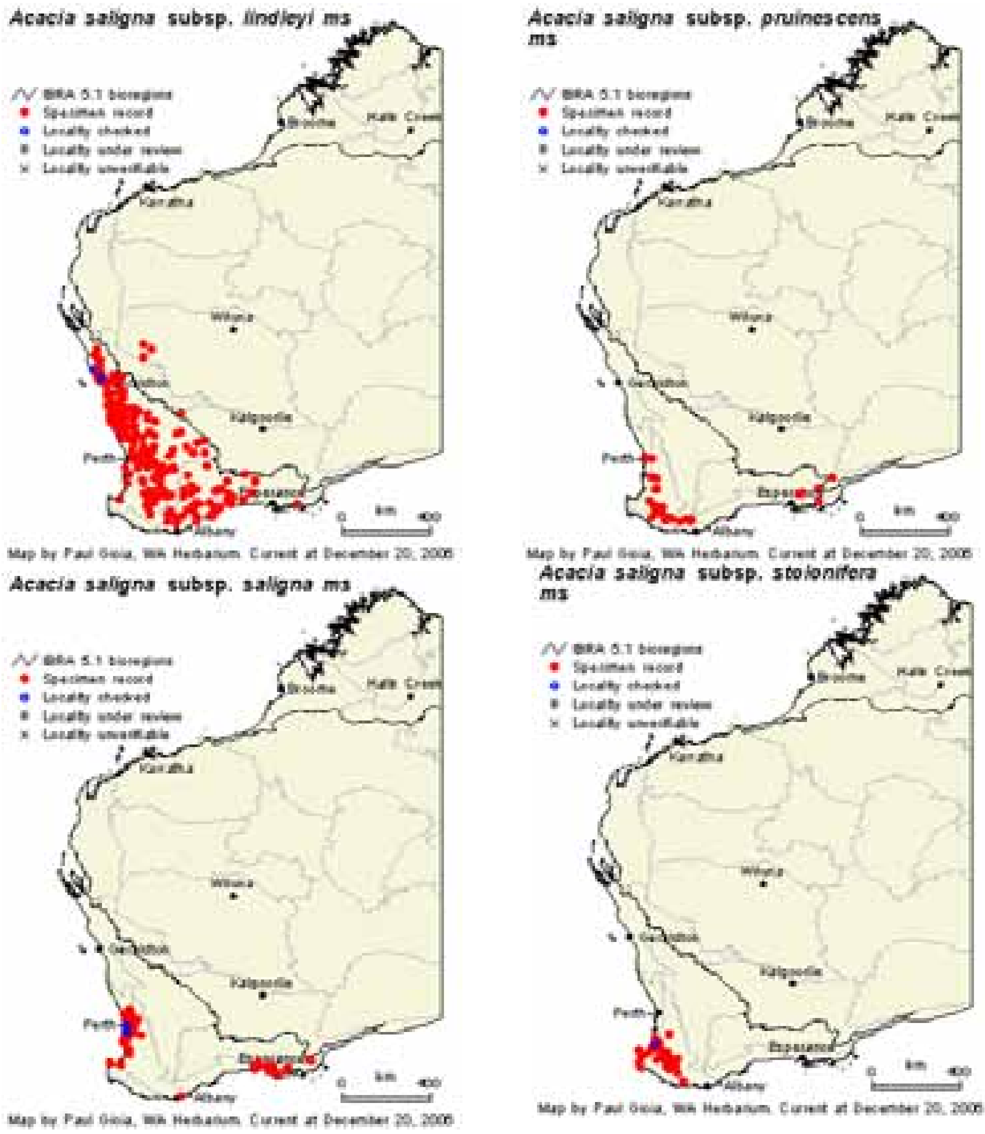


Fig. 13. *Acacia saligna* growing outside its endemic range in Australia.

(A) Growing in sandy soil in close proximity to the ocean, Yamba, New South Wales. (B) Growing in a weed-infested rail reserve, Glen Huntly, Victoria (Photos: N George). (C) Multiple generations growing in a sandy clay beside the Murray River at Swan Hill Victoria (Photo: W. O'Sullivan).

Fig. 14. ***Acacia saligna*** **growing as an environmental weed outside Australia.**

(A) *A. saligna* plants growing on a slope in the Judean Hills of Israel (Photo: J-M Dufour-Dror). (B) Invading the river bed at Kalavasos dam in Cyprus. (Photo: C. S. Christodoulou).

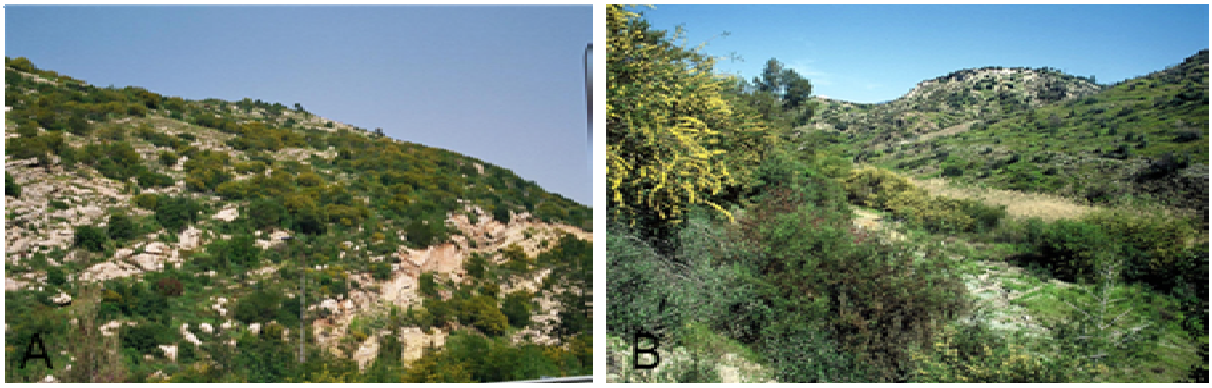


Fig. 15. Examples of the habitat of *Acacia saligna*: Water gaining sites.

Seasonal lakes north of Cranbrook (A) and south of Wagin (B), River margins at Arrowsmith River (C) and Murchison River (D), and seasonally inundated flats near Bridgetown (E) and near Frankland (F). (Photo: (E): N. George, all others W. O'Sullivan)

Fig. 16. Examples of the habitat of *Acacia saligna*: Soils and vegetation.

(A) In heath on coastal sand dunes at Esperance, (B) In *Banksia prionotes* woodland on deep sand at Wagin, (C) with *Corymbia calophylla* on shallow ironstone near Busselton, (D) In laterite sands with *Eucalyptus marginata* forest north east of Collie, (E) Among *Allocasuarina huegelliana* on shallow duplex soil at Katanning, and (F) shallow duplex with *Eucalyptus wandoo* and *Melaleuca* spp. near Cranbrook. (Photos: W. O'Sullivan)

Fig. 17. Roadside growth habit of *Acacia saligna*.

(A) Seed growth of ssp. *saligna* near Gingin, (B) ssp. *lindleyi* plants emerging from sucker growth on disturbed roadside east of Jurien bay, (C) Seed growth of ssp. *lindleyi*, Karakin, (D) Sucker growth of ssp. *stolonifera* on disturbed roadside west of Lake Muir, (E) Seed growth of ssp. *pruinescens* north east of Collie, and (F) Seed growth of narrow phyllode variant of ssp. *saligna* north of Badgingarra. (Photos: (A) M. McDonald, (B, D, E) W. O'Sullivan, (C, F) A. Rasmussen).

Climate

In its natural range within south-western Australia, *A. saligna* grows in a Mediterranean climate. Climatic conditions for this zone have been summarised in the literature, and have also been determined independently as part of the domestication program being undertaken by the authors of this report. The previously published data are summarised below (Table 2).

Table 2. A summary of the climatic characters to which *Acacia saligna* is adapted reported in the literature.

	Mean annual temperature range	Minimum	Maximum
Marcar *et al.* (1995)	13-21ºC	2-10 ºC	26-36 ºC
Maslin and McDonald (2004)	11-23ºC	4-9ºC	25-35ºC

Data collected for this review shows *A. saligna* occurs in areas with a mean minimum temperature of 12°C, with a range of 9°C to 16°C. The mean maximum temperature is 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. Across all the collection sites the rainfall averages 41% of evaporation, with a range of 12 to 95%. These climatic characteristics of the (Australian) collection sites are summarized in Table 3. They are similar to the previously published summaries above and indicate the potential climatic range of the species.

Table 3. Summary of the mean climatic characters of the collection sites of *Acacia saligna* in Australia.

(Standard deviation in parenthesis)

Climate Variable	WA collections	Non-WA collections	Overall
Maximum annual temperature	23.8 (1.9)	21.7 (1.9)	23.5 (2.0)
Minimum annual temperature	11.8 (1.5)	11.2 (2.1)	11.7 (1.6)
Maximum January temperature	30.9 (2.7)	27.4 (2.5)	30.4 (2.9)
Maximum July temperature	16.9 (1.5)	15.3 (2.2)	16.7 (1.7)
Minimum January temperature	16.2 (1.9)	15.9 (2.6)	16.2 (2.0)
Minimum July temperature	7.5 (1.4)	6.3 (1.8)	7.3 (1.5)
Annual rainfall	583 (188)	841 (425)	620 (253)
Maximum January rainfall	19 (6.8)	70 (49.9)	26 (26.4)
Maximum July rainfall	108 (43.4)	77 (22.6)	104 (42.5)
Maximum evaporation	1527 (188.8)	1308 (164.4)	1496 (200.4)
Aridity index (rainfall / evaporation)	0.4 (0.2)	0.7 (0.3)	0.4 (0.2)

These data show that *A. saligna* is an adaptable species, able to grow throughout most of the wheat-sheep agricultural zone region of WA. A notable observation is that the species does not grow in areas that regularly experience temperatures below freezing. Severe damage and mortality due to frost has been observed in containerised stock in the nursery within the endemic range of the species (Fig. 18). This is in agreement with a study that found that frosts of -6°C kill phyllodes and stems of *A. saligna* (Pollock *et al.* 1986). Reporting on the Mediterranean region, Michaelides (1979) confirms that the species does not tolerate frosts. Prospective growers need to assess the frost risk of any given site as a part of a species selection process.

Fig. 18. Frost damage to *Acacia saligna* ssp. *lindleyi* seedlings in a nursery at Kalannie, WA.

Plants will generally recover from foliage damage such as that shown here, but are vulnerable to damage to the apical meristem.

The majority of collection sites referred to above are in areas with a comparatively low annual rainfall, however many of these sites are known to be riparian habitats where the plants will have access to more water than rainfall alone. The species is also able to grow in higher rainfall regions, and its reduced incidence in the wetter regions of south-western Australia may be as a result of competition with tall tree species. In these regions it tends to be associated with open areas, such as those created by disturbance events or with site constraints such as shallow hardpans.

The mean annual rainfall for eastern Australian collection sites was 840mm, somewhat higher than the WA collections, although the standard deviation was so large that interpretation of this result is difficult. The aridity index also shows that on average the non-endemic eastern Australian sites had a slightly higher ratio of rainfall to evaporation.

Michaelides (1979) reported that the species commonly grows in the 750-1000 mm rainfall zone of the Mediterranean, but is able to grow in rainfall as low as 250 mm. In Chile, water is recognised as being a limiting factor to the growth of the species. While 250 mm is a preferred minimum rainfall, it is recorded growing in areas of less than 100 mm per annum. Proximity to the coast and the presence of maritime mists is recognised as an important adjunct to rainfall in this situation (Perret *et al.* 2001). The effect of environmental conditions, in particular rainfall, on the productivity of the species is discussed in later sections of the report.

Landform, soils and substrates

As a result of its wide natural distribution *A. saligna* grows in a variety of landscapes. The documented collections assessed for this review show the species commonly grows on coastal dunes, plains, valley plains with some sand-hills, gently undulating plains or plateau at low elevations, (frequently with small granitic hills), gently undulating to rolling terrain with some ridges and uneven slopes, dissected lateritic plateaus, stream valleys, broad valleys and undulating interfluvial terrain. The average elevation of collection sites was around 150 meters above sea level, with a range of approximately 0 to 600 meters above sea level. McDonald and Maslin (in review) provide a detailed account of associations between subspecies and landform, soils and substrates. The following summary is drawn largely from their work.

The WA collections of *A. saligna* are recorded as growing in a diverse range of soil types. Fig. 19 summarises the available records using the Northcote system of classification (Fig. 20, Northcote 1979). The most commonly recorded soil types were deep sandy soils of a uniform profile (Northcote Uc), and duplex soils with yellow-grey clayey sub soils (Northcote Dy). The first of these, the Uc Sands, are generally uniform and coarse textured, with little pedalogic organisation. They may be deep or have hardpans at varying depths, with a variable pH determined by the parent material. The Dy duplex soils vary in the depth and texture of their A horizon, which is incoherent or weakly structured, and can range from sandy or loamy soil through to clay loams. The B horizon is usually mottled clay overlying pallid zone clay. Both soil groups are common in south-western Australia. These data are assembled for the species as a whole, with more detailed information at subspecies level described below (Fig. 19).

Fig. 19. The proportion of *Acacia saligna* collections from different soil types.

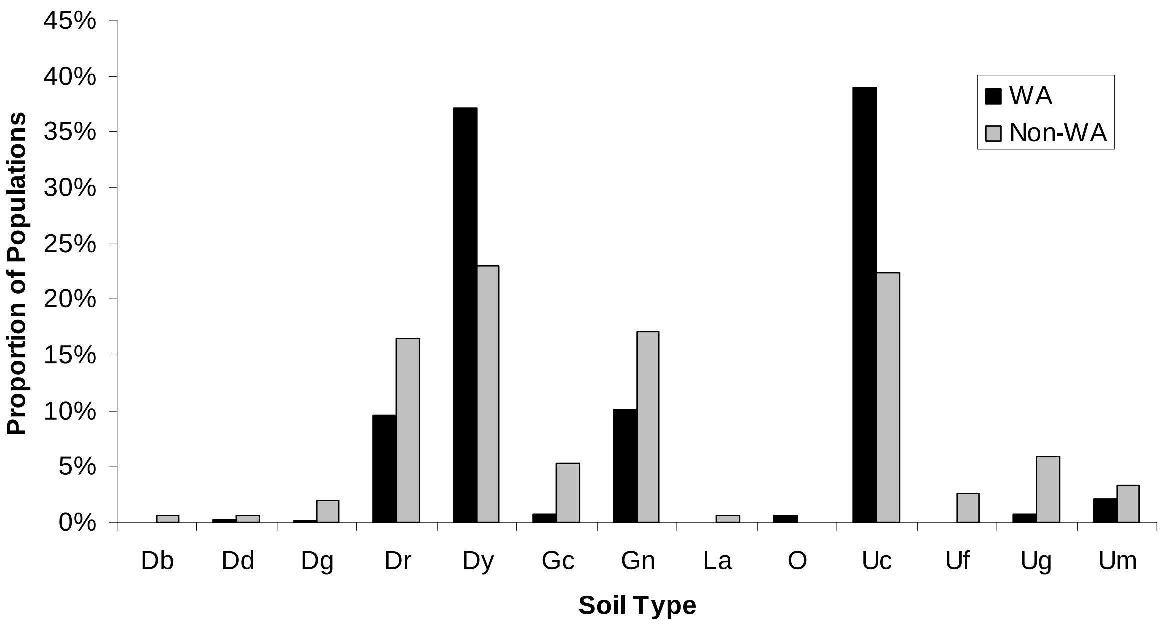


Fig. 20. The Northcote Key (Northcote 1979)

Primary profile form		**Subdivision**	
O	Organic		
U	Mineral and texturally uniform	**Uc**	Coarse particle size
		Um	Medium particle size
		Uf	Fine particle size
		Ug	Fine particle size with periodic cracking
G	Mineral and texturally gradational	**Gc**	Calcareous throughout
		Gn	Not calcareous throughout, but can be in B horizon
D	Mineral and texturally duplex	**Dr**	Upper B horizon red
		Db	Upper B horizon brown
		Dy	Upper B horizon yellow
		Dd	Upper B horizon dark
		Dg	Upper B horizon gley
La	Lakes		

Each of the subspecies grows on a range of soils, but whether they exhibit preferences for particular soil-types has not been determined. The following summaries are based on the study by McDonald and Maslin (in review), supplemented by field observations and additional data from the limited number of unambiguously identified populations available for GIS mapping. The soil and physiographic associations below should be considered preliminary observations only, prior to a more comprehensive assessment being made.

A. saligna ssp. *saligna* is most common on geologically recent coastal and sub coastal plains, most commonly associated with deep calcareous and siliceous 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. The most common substrate is limestone, however, in its eastern occurrences it is associated with granite outcrops.

A. saligna ssp. *lindleyi* occurs along seasonal watercourses, along 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. While most commonly associated with yellow and sometimes red duplex soils, it occurs on calcareous and siliceous sands between Perth and Geraldton, and on quartz sands associated with granite outcrops in the low rainfall eastern part of its distribution. It is recorded as growing over granite, limestone, sandstone, spongelite, quartzite, laterite and dolerite.

A. saligna ssp. *pruinescens* is 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. In the northern part of its distribution it also extends onto well drained ironstone gravels, a soil type that is uncommon for the species as a whole. It occurs over granite and laterite substrates.

A. saligna ssp. *stolonifera* is associated with laterite-derived alluvium or colluvium gradational soils in the eastern and southern part of its range. These loam and clay loam soils overly laterite and granite. Close to the coast in the western part of its range, it occurs on calcareous and siliceous sands and sandy loams, overlying limestone. It most commonly occurs low in the landscape, around creek lines, wetlands and estuaries.

The collection sites of *A. saligna* from eastern Australia are recorded as having similar soils to those described above for the endemic range of the species, suggesting it may have an adapted preference for these soil types. More work is required to establish the soils on which it is most productive. International reviews report *A. saligna* growing on a range of soils but performing best in deep sandy soils with adequate soil moisture and nutrients (El-Lakany 1987). This is consistent with observations made by the authors of planted stands in WA. The species does not tolerate prolonged water logging of soil (Fox 1995), but has been observed tolerating extended periods of seasonal inundation. There is very little information regarding pH preferences, although Marcar *et al.* (1991) reported the species to be growing in pH 7.5 to 9.5 in Pakistan.

The mapping work conducted for this review (sites collected post 1980) found the majority of collections of *A. saligna* are classified as occurring in cleared or disturbed plant communities. This is true both within its natural distribution (55%) and in eastern Australia (80%). This is consistent with *A. saligna* being an early succession species. The preference of the species for disturbed environments has consequent implications for its use as a crop. It suggests the species should be suited to an agricultural landscape, but may pose a weed risk. These issues are discussed in more detail the "Weediness and geneflow" (pg. 67).

Flora associations

A. saligna occurs in association with a variety of plant communities, typically in more open parts of dry sclerophyll forest, temperate woodlands, semi-arid woodlands and mallee (Doran and Turnbull 1997). It does not typically occur in dense and tall forest (Fox 1995).

The following summaries are based on information published in McDonald and Maslin (in review), supplemented by field observations and additional data from the limited number of unambiguously identified populations available for GIS mapping. The floristic associations below are general observations, which require further substantiation.

A. saligna ssp. *saligna* occurs in two widely separated regions. In its western range it occurs in open *Eucalyptus gomphocephala / Agonis flexuosa / Banksia* spp. woodland, frequently with *Allocasuarina fraseriana*. In riparian zones it commonly occurs with *Eucalyptus rudis*. In the eastern part of its range it is most commonly in open *Acacia* shrubland, occurring with a range of *Melaleuca* species in wetter parts of the landscape, and elsewhere with *Eucalyptus goniantha* and *Acacia conniana*.

A. saligna ssp. *lindleyi* has the widest distribution of the subspecies, and consequently the greatest range of environments and floral associates. Occurrences are commonly dominated by eucalypts, notably *E. camaldulensis, E. loxophleba, E. occidentalis, E. rudis, E. wandoo* and *Corymbia calophylla. Allocasuarina huegeliana* is a common associate, especially around granite rocks, and *Casuarina obesa* frequently co-occurs with ssp. *lindleyi* on low lying areas and drainage lines.

A. saligna ssp. *pruinescens* is associated with a range of eucalypt species, usually in open forest or woodland. These are dominated by *E. marginata, E. patens, E. rudis* and *Corymbia calophylla*. In seasonally wet areas it occurs with *Melaleuca preissiana* and less commonly, *M. raphiophylla*. Co-occurrence with ssp. *stolonifera* is recorded. The understorey shrub *Hakea prostrata* is a common associate.

A. saligna ssp. *stolonifera* occurs in association with *Eucalyptus marginata, Corymbia calophylla* woodlands through the greater part of its distribution in the southwest forest region. On the margins of rivers, creek lines and wetlands it is commonly associated with *Eucalyptus patens* and *E. rudis*. Co-occurrence with ssp. *pruinescens* in these areas is recorded. In the coastal western part of its range the vegetation is dominated by *Eucalyptus gomphocephala* and *Agonis flexuosa*.

Fauna Associations

In south-western Australia *A. saligna* supports a diverse range of insects, along with insects and arachnids that predate them. The majority are sap-sucking Hemiptera and leaf-feeding Coleoptera, (Van Den Berg 1980a, Van Den Berg 1980b, Van Den Berg 1980c, Majer 1979). Insects are recorded as feeding on all parts of the plant. *A. saligna* also supports a diverse ant community that are apparently attracted to extra-floral nectaries. This association may provide some protection from herbivorous insects, Majer (1979) study found that gland activity in *A. saligna* is greatest in young foliage and most active in spring and autumn, which is the time of maximum threat of herbivore damage.

In general, *Acacia* seed with large red arils is bird dispersed, and seed with smaller colourless arils is ant dispersed (New 1984), suggesting that the aril-type of *A. saligna* has evolved as an ant attractant. Ants from the genera *Rhytidoponera* and *Melophrous* are those most commonly associated with *A. saligna* and rapidly remove seed from under trees (J. Majer *pers. comm.*). The seed is taken into the nest where the arils are removed. The seed is undamaged and will create a buried seed store.

Biology

Reproductive biology

A. saligna can reproduce via seed or sucker growth. Suckering propensity varies between subspecies and may also be provenance dependent within subspecies (see "Taxonomy and species description" section of this report). 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 by the authors confirm that flowering phenology varies between subspecies. Flowering times generally overlap to some extent, although peak anthesis may not be coincident. It is therefore possible for pollen-mediated gene transfer or hybridisation between subspecies where they co-occur. The levels of interbreeding will depend on a range of factors: such as which subspecies (and possibly provenances) are involved, flowering intensity, and population size (Millar and Byrne 2007b). Selection of material for inclusion in any breeding program will be determined by target markets. As evidenced in the use of *A. saligna* overseas, multiple breeding programs may be required for different products, for example, a low growing palatable selection for fodder in Chile, a woody strain for firewood for Tunisia or woodchips for the WA wheatbelt, a non palatable, erect but dense canopy form for sandalwood hosts, etc. For use outside the natural range of the species there may be opportunity to produce selected lines by combining the subspecies into one program, subject to the flowering phenology of individuals with desirable traits, but within south-western WA genetic contamination from wild populations must be considered and regional selections may be preferred. Progeny trials established in 2006 draw on a wide range of the germplasm, to allow for maximum scope for selection of sources of different traits.

The reproductive phenology of *A. saligna* is reported to be similar in Queensland (Ryan and Bell 1989) and in South Africa (Milton and Moll 1982). In Chile, Perret *et al.* (2001) report the species flowering in early spring, between July and October, with fruit maturing between October and December, and able to be collected until February. Plants produce fruit by their third year. In Sicily, *A. saligna* flowers during early spring in April to May (Stringi *et al.* 1991).

Studies have revealed a range of mating systems in different species of *Phyllodineae Acacia*, from relatively high outcrossing rates over 0.9 to moderate rates of 0.6 and even inbreeding rates of 0.7 (Butcher *et al.* 1999, Coates *et al.* 2006, Moran *et al.* 1989). George *et al.* (2006a) used allozyme markers to investigate the mating system of three wild populations and one provenance planting of *A. saligna*. High outcrossing rates were observed in all four populations, with a mean multilocus outcrossing rate of approximately 0.9. A high multilocus outcrossing rate of 0.98 was also obtained for a planted stand of ssp. *saligna* in a study using microsatellite markers (Millar *et al.* 2008b). High outcrossing levels will require breeding methods that involve mass selection, to avoid inbreeding depression.

The reproductive output of *A. saligna* is relatively low. In an examination of seven *Acacia* species endemic to south-western Australia, the proportion of inflorescences to set pods for *A. saligna* ranged from 5.5 to 12.5% (Gaol and Fox 2002). Across all seven species the range was 0.7 to 63%. The study found evidence for differences in reproductive output between the subspecies of *A. saligna*. In another study of fourteen wild populations of *A. saligna* over two years, the mean proportion of inflorescences that produced at least one pod was 8% and the mean number of seed per pod was 4.1 (George 2006). Seed production of 120kg per hectare, equating to 81 grams per plant, has been reported from 3 year old plants in Sicily (Stringi *et al.* 1987). Seed banks can, however accumulate and become significant, especially when considering weed risk. 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 WA may be even higher than New South Wales.

Growth phenology

In south-western Australia, *A. 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, with much less growth occurring during the remainder of the year. In Israel, a flush of leaf and shoot development was observed between March to June (northern hemisphere spring), coinciding with maximum cambial activity, although the wood cambium was found to display some activity year-round (Fahn 1959).

Root growth characteristics measured in the study of Zegada-Lizarazu *et al.* (2007), showed overall root biomass production was positively correlated with soil moisture availability through time. Root distribution was affected by the irrigation frequency, with most roots found at increasing depths as irrigation frequency decreased. In the most well-watered treatment 85% of roots were found in the top meter of soil within tree rows and in the top 0.6m in the alleys between the trees. In contrast, in the least well-watered treatment 85% of roots were found in the top 1.2m in the tree rows and 0.9m in the alleys. In treatments irrigated at low frequency, root growth decreased in the upper 0.6m and increased at depth as the soil gradually dried from the surface and more water was extracted from depth. For treatments with ample soil moisture, root growth was initially rapid as the root system became established but then reduced. The reduction in root growth was correlated with an increase in above ground biomass production.

Longevity

In south-western Australia, *A. saligna* plants are reported to live for nearly 20 years under favourable conditions (Fox 1995). However, a 5 to 12 year lifespan is believed to be more typical. In trials established by the authors on farmland in WA, stand deaths have occurred commonly between 5 and 10 years of age. Observational experience suggests that tree longevity decreases with decreasing latitude; a correlation possibly reflecting the impact of higher temperatures and evaporative demand in lower latitudes. 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.). The lifespan of the species, even under the extreme conditions of climate and predation by co-evolved pests and diseases in SW WA is still within the target timeframe for the short rotation farm forestry crops being considered under the FloraSearch project. One of the key attributes that led to the priority selection of this species is its very rapid early growth, and this has again been demonstrated in the current progeny trials, where canopies are closing at age two. Development of longer time frame uses, such as hosting sandalwood crops will require selection for resistance to the key limiting factors of insect attack and *Uromycladium* infection.

Root architecture and water use

The recent revision of the taxonomy (McDonald and Maslin in review) highlights differences in root architecture between the subspecies. Most notable of these is ssp. *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 (see Fig. 23). Field observations by the authors suggest there may be variation in this characteristic at provenance level within the subspecies. As such observations are difficult to qualify across a wide range of environments, and it is anticipated that some observation of this trait will be possible in the recently established progeny trials. The structural differences are indicated in Fig. 24.

The species is able to produce an extensive root system, which is morphologically responsive to environmental conditions. El-Lakany and Mohamed (1993b) found that the species could produce a shallow but expansive root system when irrigated with sprinklers and a deep and less expansive root system when drip irrigation was applied. They determined that 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). In Tunisia *A. saligna* growing on deep loamy soils had roots penetrate to a maximum depth of 2 meters (Nasr *et al.* 2005). Studies have also found that the species produces high density of roots in the top 100 cm of soil (El-Lakany and Mohamed 1993a, El-Lakany and Mohamed 1993b) and that root distribution in the soil profile is influenced by soil water status (Zegada-Lizarazu *et al.* 2007).

A. saligna has been found to use relatively more water than annual plants. For example, in the Murray–Darling Basin the soil profile under tree belts incorporating *A. saligna* and two *Atriplex* species was drier, as measured using a neutron moisture probe, than adjacent annual crops. After 4 years the volumetric soil water content in one site under the belts was roughly 0.1 m^3/m^3 to a depth of six meters, whilst under the adjacent annual crop the soil water content was reduced by an equivalent amount to a depth of only one meter; after which it increased to 0.2 m^3/m^3 by six meters depth (Knight *et al.* 2002). A five month study using a neutron moisture meter in north-western Kenya found that the water use of an *A. saligna*-sorghum intercrop was the equivalent of 840 mm, whilst under sorghum alone it was 360 mm (Droppelmann *et al.* 2000b). A study in progress in WA has measured dewatering under 3 year old farm plantings to a maximum depth of 4 meters (W. Hibbit pers. comm.)

An understanding of the water use efficiency (WUE) of *A. saligna* will be important for predicting potential productivity in different rainfall zones of south-western Australia and elsewhere. Such data will also be useful for estimating the quantity of water required to give economically competitive yields on farmland (see “Productivity and yields” section of this report), for further discussion of yields). Zegada-Lizarazu *et al.* (2007) estimated WUE for a range of irrigation frequencies in a five year old *A. saligna* trial in the Negev desert. There was a positive correlation between irrigation frequency and WUE, which ranged from 9.42 kg (above ground dry biomass) $ha^{-1}mm^{-1}$ in low irrigation frequency treatments to 19.04 (above ground dry biomass) $ha^{-1}mm^{-1}$ in high irrigation frequency treatments. This equates to a range of 0.94 to 1.90 g DM (above ground) per litre. In a pot trial experiment using six month old *A. saligna* seedlings, Nativ *et al.* (1999) determined WUE to be 2.3 g DM L^{-1} when irrigation was supplied at 100% of evaporative demand and 2.8 g DM L^{-1} when irrigation was supplied at 50 % of evaporative demand. These studies demonstrate the dynamic relationship between WUE and environmental factors such as water availability.

Fig. 21. ***Acacia saligna*** **growing on deep sand at El Tangue Community, Tongoy, Chile.**

Planted in 1983, the plants were 22 years old when this photo was taken (Photo: W. O'Sullivan).

Fig. 22. Dead and dying *Acacia saligna* in a five year old mixed species trial on farmland near Dandaragan, WA. (Photo: D. Huxtable)

Fig. 23. A suckering colony of *Acacia saligna* ssp. *pruinescens* on the Muirs Highway, WA.

The suckering is being contained by grazing in the paddock at the rear of the photo, and by regular road maintenance in the foreground (Photo: W. O'Sullivan).

Fig. 24. Root architecture.

(A) Taproot of *Acacia saligna* ssp. *lindleyi,* excavated by road works, Nyabing. (B)Taproot of *A. saligna* ssp. *lindleyi*, exposed by flood waters, Murchison River. (C) Suckering A. *saligna* ssp. stolonifera, road verge, Grimwade. (D)Suckering *A. saligna* ssp. lindleyi, road verge Hill River (Photos: W. O'Sullivan).

Numerous plant studies have shown that a strong negative correlation exists between WUE and the ratio of stable isotopes of carbon; for a review see Ehleringer *et al.* (1993). In their study on *A. saligna,* Nativ *et al.* (1999) found that the carbon stable isotope ratio was a useful indicator of WUE. They concluded it could serve as a selection criterion for improving the WUE of the species via breeding. The notion of exploiting genetic variation in WUE in breeding programs, to improve biomass productivity, is supported by Donovan and Ehleringer (1994).

Seed and gum phytochemistry

An early report on the seed chemistry of *A. saligna* (Ramdan 1957) claimed it to be free of toxic compounds and to have nutritional qualities comparable to groundnut meal, containing 30.7 % protein 13 % crude fibre. More recent work however, reports that the seed contains protease inhibitors (Kortt 1985, Maslin *et al.* 1998), which can be deactivated by heating or cooking (Maslin and McDonald 2004). Stringi *et al.* (1987) reported that seed from a trial planting in Sicily contained 1.38% mimosine, a toxic alkaloid.

The gum of *A. saligna* is reported to contain glucuronic acid-galactose-arabinose-rhamnose in the ration 24:46:8:21; the glucuronic acid and rhamnose content of the gum are the highest recorded for the *Acacia* genus (Anderson *et al.* 1972). Earlier gum analyses were performed by Anderson and Bell (1976) and Charlson *et al.* (1955).

Utilisation

Historical use

Acacia saligna has a long history of human utilisation. The seed was exploited as a source of food by the Aboriginal people of south WA (Bindon 1996, Meagher 1973, Cherikoff and Isaacs 1989). *A. saligna* was also utilized by early European settlers in Australia as a source of gum, tannin and timber (Maiden 1889). Since then it has been recorded as being used at various times for gum, fuel, shelter, fibre and as an ornamental (Lazarides and Hince 1993, Wiersen and Leon 1999).

There has been renewed interest in the human food potential of *A. saligna* over the past decade. Maslin *et al.* (1998) rated it as one of the most promising species for trialling in southern Australia for edible seed production. The WorldWideWattle website (2007) reports that World Vision is currently exploring the human food potential of the species in Ethiopia. Flour made from *A. saligna* seed is mixed with flour of a native grain 'teff' (*Eragrostis* sp.) to make Injera, a traditional flat bread. Protease inhibitors contained in the seed are deactivated by heat treatment or cooking (Maslin *et al.* 1998). Scope for using the acid stable gum of the species as a food additive has been documented (Michaelides 1979), however the authors are not aware of any precedent for using the gum for this purpose.

A. saligna is commonly used in Australia for revegetation and ecological restoration works, due to its ease of establishment and rapid growth rates (Fig. 25). In WA it is frequently used in road-side amenity plantings (Fox 1995, Maslin 1997). Farmers often include the species in revegetation projects, primarily for erosion control and reduction of groundwater recharge. It has been occasionally grown as a fodder plant, to provide a contingency food source at the end of summer when other pasture options are limited. It has also been favourably assessed for use as a host species in sandalwood (*Santalum spicatum*) plantations (Brand *et al.* 2003), if used in combination with other longer lived host species (Fig. 25).

Outside Australia, *A. saligna* is considered an exceptionally useful species due to its tolerance of mild drought and poor soil, its high biomass productivity, ease of establishment and responsiveness to supplemental irrigation (El-Lakany 1987). In North Africa it has been utilized since the early 1900's (Leone 1924, cited by El-Lakany 1987), and is now exploited extensively for fodder and firewood

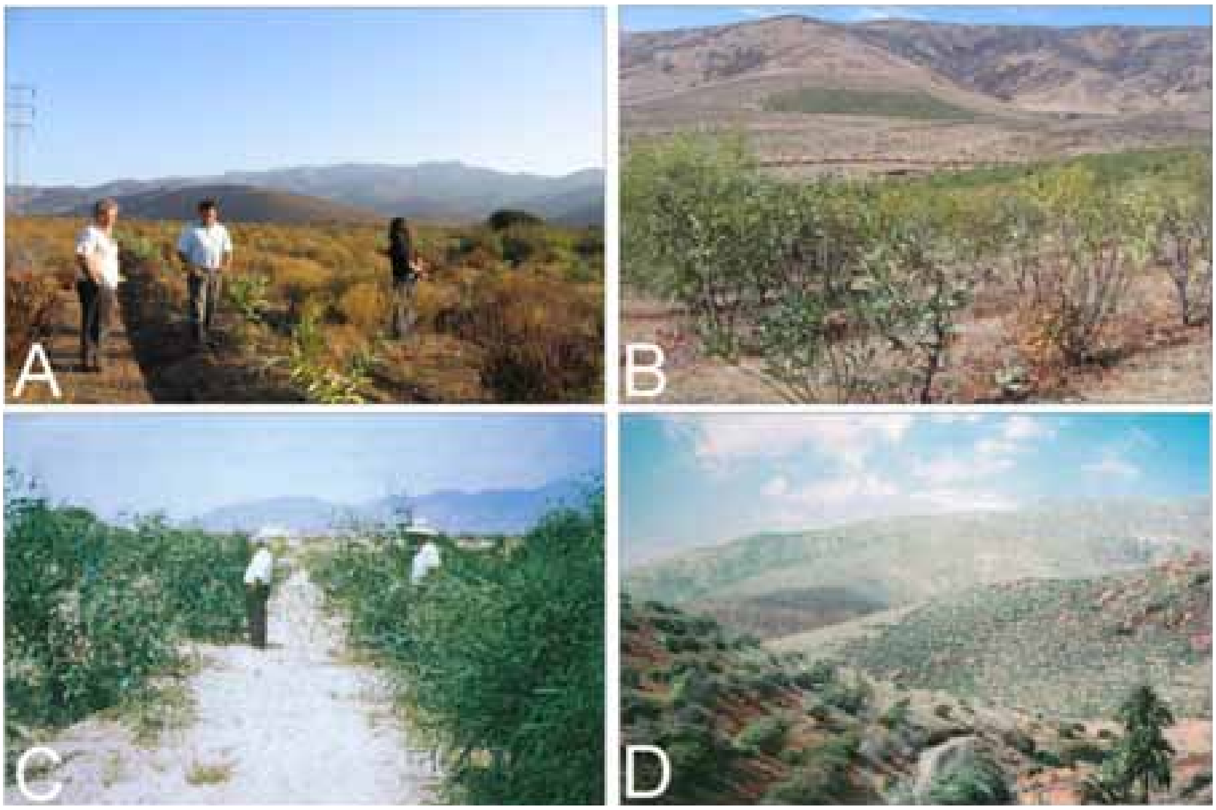
(Doran and Turnbull 1997, El-Lakany 1987, Le Houerou 2002, Le Houerou and Pontanier 1987, Stringi *et al.* 1987, Tiedeman and Johnson 1992). For similar reasons it is also exploited (although to a lesser extent) in southern Europe (Le Houerou 2002, Tilstone *et al.* 1998), eastern parts of Africa (Jama *et al.* 1989, Thulin 1983) and the Middle East (Lock and Simpson 1991, Sheikh 1981). It has also been introduced into South America and is being increasingly exploited for forage, soil stabilisation and fuel; particularly in Chile (Perret and Mora 1999). Examples of uses outside Australia are shown in Fig. 26.

Fig. 25. *Acacia saligna* utilisation in Western Australia.

(A), (B) As fast screening amenity plantings in Perth (C) As a host plant for native sandalwood (Santalum spicatum) in Bolgart (D) As fodder plantings near Boyup Brook (Photos: (C) D. Huxtable, others N. George).

Fig. 26. ***Acacia saligna* utilisation outside Australia.**

(A) Plants on deep ripped savannah mounded rangeland, in 120mm rainfall zone at Las Cardas Experiment Station, Chile (B) Fodder trials growing at Mincha Sur, Chile (C) Two year old planting at Cabo de Gata, Spain. Area experiences 150 mm annual rainfall, sandy soil over deep brackish watertable. (D) Planting on the island of Fuerte Ventura, Canary Islands. This area experiences <150 mm annual rainfall. (Photos: (A) & (B) Wayne O'Sullivan. (C) & (D) reproduced with permission from Le Houerou (2002)



Proposed utilisation in south-western Australia

Dryland salinity is the major driver for including perennial plants such as *A. saligna* in the farming systems of south-western Australia. To be effective in controlling salinity, perennial revegetation will need to displace substantial areas of annual crops and pastures. This will not be possible unless the new perennial systems provide a comparable economic return to the annual agriculture they displace (Bathgate and Pannell 2002, Pannell 2001, Lefroy *et al.* 2005). The scale of landscape change is such new woody plant industries must target bulk commodity markets to avoid the risk of oversupply (Cooper *et al.* 2005). Higher value, niche markets can only play a secondary role in salinity management (Bartle *et al.* 2007, Cooper *et al.* 2005). The challenge of making woody perennial plants competitive in bulk commodity markets should not be underestimated. To be economically competitive, it is likely that woody crops will need to generate economies of scale, utilise all biomass components and create multiple product, integrated processing industries (Bartle *et al.* 2002). Additional "product value" could be afforded by the valuation of environmental services, such as carbon sequestration and the protection of biodiversity.

A detailed review of potential products from large scale woody crops grown in the Australian context was made by Olsen *et al.* (2004). The most promising candidates were panel boards, bioenergy, fodder and chemicals; each of which is now briefly discussed.

Panel Boards: Panel boards are a type of reconstituted wood product, manufactured by bonding wood particles or fibres together with adhesive agents. Existing panel board markets are extremely large and growing (FAO 2005). Panel board manufacture is relatively adaptable to woody feed stocks, although some traits such as wood density and colour affect feed stock utility. Assuming quality criteria are met, the key market entry requirements are availability of large volumes of feed stock materials at a competitive price. A domestic market exists in WA, with potential for expansion.

Bioenergy: Potential energy markets for woody biomass include electricity, process heat and solid and liquid fuels. At present, a combination of technical and institutional factors prevents bioenergy from being cost competitive except in particular niche applications. The immaturity of technologies to separate, refine and transform biomass into chemicals and fuels is cited as the major impediment to using biomass industrially (Ragauskas *et al.* 2006). However, mounting concern over global warming is likely to favour bioenergy development. The price of oil, notoriously difficult to predict into the future, is another key factor of influence. Bioenergy from woody crops is likely to be augmented with other products; as more lucrative products can be made from high value fractions of the biomass whilst lower value residues can be used for energy conversion (Cooper *et al.* 2005).

Fodder: Livestock industries are well established in Australia. Fodder plants have several advantages that increase their likelihood and rate of adoption by farmers. Perennial grazing models share many similarities with annual pasture systems and can be built incrementally into these systems. There is also scope to exploit synergies with existing annual pasture species by broadening the feed base available to stock, providing nutritionally useful secondary compounds in animal diets and allowing for more productive use of marginal landscapes (Revell and Bennell 2006).

Biomaterials and Chemicals: Chemical products, derived from the primary components of biomass (cellulosic materials and lignin) or secondary plant compounds, could provide an additional revenue stream to complement the other products discussed. A range of technologies exist for manufacturing specialty or commodity chemicals from biomass. Ideally, chemical co-products would be cheaply and easily extracted from plant biomass without compromising other product streams. Extractive products like eucalyptus oil and tannins have a long history of production and both could re-emerge if large scale biomass production and new product development occurs. In WA, there appears to be good opportunity to produce low-cost biomass but opportunities for converting this to bulk chemical commodities need development.

The scope for growing *A. saligna* biomass as a feed stock for these products is now elaborated.

Characteristics of Acacia saligna biomass

When cultivated in favourable conditions *A. saligna* is relatively fast growing (Olsen et al, 2004, Doran and Turnbull 1997, Michaelides 1979) (for a discussion of factors affecting yields see "Productivity and yields" section of this report). Economic analysis has shown biomass yield to be a key determinant of the economic competitiveness of woody crops in low rainfall (<600mm annually) farming areas (Cooper *et al.* 2005). Consequently, the rapid growth rate of *A. saligna* has been a key factor in its selection as a domestication candidate. The large genetic diversity observed in the species provides potential for developing even more productive cultivars.

The utility of the biomass is dependent on its composition. There is reasonable consistency in studies of above ground biomass partitioning of *A. saligna*. Unpublished research conducted by the authors at a 4 year old trial site at Narrogin, WA, determined that dry above ground biomass consisted of 16 % foliage (phyllodes) and 84% wood and bark. Bark accounted for 20-25% of the wood/bark fraction. Above ground biomass partitioning in South Africa was found to be 12% foliage and 88% woody-matter (Milton and Siegfried 1981). An Egyptian study found 20% foliage and 79.3% woody-matter (El-Osta and Megahed 1992). These proportions could be expected to vary with growing conditions, subspecies and possibly provenance. They will also vary with age, consisting of an increasing percentage of wood relative to other fractions in older plants. Setting rotation lengths for woody shrub crops such as this will be determined by the mix of products and the economics of the rotation length. Such consideration has been evident in the analysis of products from the emerging mallee eucalypt industry in WA, where recent years have seen a shift from the production of oil rich foliage to a longer rotation giving a balance of leaf and woody biomass for different markets. Likewise, the moisture content of green biomass will vary between components. Results from destructive sampling by the authors from four year old farm plantings in WA are summarised as follows: moisture content for 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). A detailed examination of wood properties was made by Olsen *et al.* (2004). 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. Subsequent measurement of wood chips using the water displacement technique to determine volume gave a mean value of 585 kg/m^3. They conducted the conventional range of tests for paper and panel board making properties and found that the wood fibres from cores had mean length and width dimensions of 430±232 μm and 18.8±4 μm respectively, the wood cellulose content was 38-40% (dry basis), ash content 3.3% (dry basis), pH 5.4, wood buffering capacity 0.162 mmol/g and hot water soluble extractives 10.3%. The wood did not have any obvious characteristics that would prevent its use as a feedstock for a range of products. Studies conducted on pine and eucalypt species have found that factors which impact on the quality of wood, such as density, fibre length and fibre coarseness, are often variable and under moderate to strong genetic control (Cotterill and Brolin 1997, Pot *et al.* 2002, Whiteman *et al.* 1996). If this is the case for *A. saligna,* it should be possible to manipulate wood properties to improve feed stock quality. Olsen *et al.* (2004) contrast *A. saligna* wood properties data with *Pinus radiata*.

Panel boards and other wood products

Preliminary tests, including laboratory scale panel manufacture, have shown that *A. saligna* wood can be used to make medium density fibreboard (MDF) and particle board (Olsen *et al.* 2004, Table 4). The physical and mechanical properties of the wood, particularly strength, are comparable to the industry requirements for these products (CPA 2006). Wood basic density is slightly higher than desirable, especially for use in particle board. As an approximate guide, the preferred basic density for MDF feed stock is less than 750 kg/m^3 for particle board less than 500 kg/m^3. Panel densities above this are undesirable due to handling difficulties and high transport costs. As previously suggested, it is probable that low wood density cultivars can be developed through breeding selection. Further work will be necessary to determine what impact manipulating wood density might have on other physical and mechanical characteristics of panel board produced using *A. saligna* wood.

Table 4. Physical and mechanical properties of panel boards manufactured using the woody biomass of *Acacia saligna* (Olsen *et al.* 2004).

	Density (kg/m3)	Modulus of Rupture (MPa)	Modulus of Elasticity (MPa)	Internal Bond Strength (kPa)	Thickness of Swell (%)
MDF	830	30	3298	953	14
Particle Board	714	18	2825	619	5

The suitability of *A. saligna* biomass for Kraft paper production was also evaluated by Olsen *et al.* (2004). 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). Paper from dense wood can have low tensile strength and is better suited to printing, whilst lower density gives a stronger product better suited for packaging (Downes *et al.* 1997). Ideal fibre characteristics for paper production are increased length and decreased coarseness. Work in eucalypts has found increased fibre length and decreased coarseness promotes better bonding between fibres within the sheet, and that tensile, tear, bending, freeness, pulp yield and brightness properties are positively correlated to fibre length (Via *et al.* 2004, Whiteman *et al.* 1996). Fibre length and coarseness, which are important determinants for product strength, are both highly heritable in other pulp-wood species (Via *et al.* 2004).

Kraft 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. As for the panel boards, *A. saligna* wood density encompasses the ideal range for paper manufacturing. Any selection work to decrease the wood density to make it more suitable for panel board production may also confer benefits to its use as a feed stock for paper production. The length to width ratio of *A. saligna* wood fibres is lower than that of other species commonly used for pulp production (Cotterill and Brolin 1997, Pot *et al.* 2002).

Biomass energy

Combustion properties of *A. saligna* biomass for energy production were reported by Olsen *et al.* (2004), in their study of a selection of woody species endemic to WA. Factors affecting the quality of biomass for use in energy conversion processes include its moisture content and ash fraction, a measure of inorganic elements. Dry biomass has a greater calorific value than moist biomass, making it more efficient to handle and convert into energy. High levels of inorganic elements, in particular alkali metals such as sodium and potassium, can cause fouling and corrosion in energy conversion equipment. 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). Other studies report similar GCV values (for example El-Osta and Megahed 1992). 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. The suitability of using the woody biomass as a gasification or biomass-to-liquids feed stock was not assessed; however the low ash content is an indicator of its suitability. Low ash feed stocks are also desirable for pyrolysis processes (Chiaramonti *et al.* 2007).

Less is known about the prospect for using *A. saligna* 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 *A. saligna* biomass, such as bark and phyllodes, from being suitable pellet feed stocks. Ethanol production by fermentation prefers feed stocks with a high cellulose to lignin ratio (Dinus 2000, Wyman 1999). Lignin and inorganic plant components are problematic, in that they are unable to be converted into sugars and can disrupt enzymatic hydrolysis conversion processes (Dinus *et al.* 2001). Hardwood species typically contain about 43% cellulose and 35% non-cellulosic polysaccharides that can also be fermented (Downes *et al.* 1997). 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). The proportion of lignin in *A. saligna* wood has not been measured, however it is likely to be high relative to herbaceous and softwood plant species. The importance of biomass composition is likely to be counterbalanced by the cost of the biomass and the quantity available. Processors could be expected to adapt to a less optimal feed stock if the price is low enough and supply risks are low.

Prevailing settings for domestic energy markets means that it is unlikely that *A. saligna* will be competitive as a single product energy crop in WA. A more plausible scenario is for bioenergy to be one of a suite of products generated via integrated biorefinery models, as has been proposed by Ragauskas *et al.* (2006). Combustion of low value biomass components to produce heat and/or electricity could provide the energy to support higher value manufacturing processes. Any surplus energy produced could be sold to other users.

Livestock feed

Potential exists to use the foliage of *A. saligna* as food source for livestock. Large markets exist for processed animal feed and domestic prices on a $Au/tonne basis are higher than those for panelboard and bioenergy feedstocks (Bartle *et al.* 2002). As such, where biomass is harvested, it may be possible to increase the unit value of the whole plant biomass by separating and processing the foliage component. Alternatively, *A. saligna* could be grazed *in situ*. Grazing is a large pre-existing industry and the incorporation of perennial forages into existing agricultural industries requires minimal technological or production changes. *A. saligna* is already utilized for grazing to a limited extent in south-western Australia, as well as elsewhere in the world. The foliage has a high crude protein content, which can complement other foodstuffs in a mixed grazing system. 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. 1*992), and/or the presence of tannins decreasing palatability, digestion and absorption of nitrogen (Reed *et al. 1*989, Reed 1995, Woodward and Reed 1989). The value of *A. saligna* as a livestock feed has been examined extensively and all studies show that nutritional quality of the species is low (Abou El Nasr *et al.* 1996, Ben Salem *et al.* 2002b, Ben Salem *et al.* 1997, Ben Salem *et al.* 1999, Degen *et al. 1*995, Degen *et al.* 2000, Dumancic and Le Houerou 1981, George *et al.* (2007), Howard *et al.* 2002, Krebs *et al.* 2003, Le Houerou 1991, Meneses and Flores 1999, Reed *et al. 1*989, Stringi *et al.* 1987). 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). Simulations in GrazFeed (Donnelly *et al.* 1997) have demonstrated that the average digestibility and crude protein of *A. saligna* is insufficient to maintain the live weight of sheep and cattle due to a lack of energy (George *et al.* 2007). *In vivo* trials have shown that livestock fed solely or predominantly on *A. saligna* perform poorly in comparison to animals fed diets containing feeds such as oaten hay (see for example, Atti *et al.* 2003, Ben Salem *et al.* 1999, Ben Salem *et al.* 2005b, Degen *et al.* 1997, Krebs *et al.* 2003, Meneses and Flores 1999). A summary of the feed quality is shown in Table 5.

Table 5. Feed quality characters of *Acacia saligna*.

All values are presented in g/kg of dry matter. Tannin content is given in tannic acid equivalents.

Character	**Reported values (g/kg) for *A. saligna***
DMD	190-400[A], 570-600[E] , 445-562[F]
Crude protein	160[D], 130-140[B], 125[C], 100[A], 106-167[F]
NDF	446[C], 384[B], 334-401[F]
ADF	297[C], 265[B], 248-320[F]
Hemicellulose	149[C], 58-91[F]
Tannins	CT 80[C], 14-27[A] PPT 60-107[F]
Ash	220[B], 110[D], 77[A], 72[C] , 75[F]

[A] (Krebs *et al.* 2003), [B] (Degen *et al.* 2000), [C] (Degen *et al.* 1995), [D] (Stringi *et al.* 1987), [E] (Ben Salem *et al.* 1999) [F] (George *et al.* 2007).

The feed quality of forage plants can change with plant age, maturity of foliage and season (Minson 1990, Wilson 1969). Only one study known to the authors (Krebs *et al.* 2003) has examined changes in feed quality due to differences in season and plant maturity in *A. saligna*. This study 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. For *A. saligna* to be grazed *in situ* or used as a processed animal food, an improved understanding of the effects of plant and foliage age, season and frequency of harvest on feed quality is required.

A. 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). This reduced intake and low digestibility is significant, and can lead to poor or negative growth rates in animals (Degen *et al.* 1997, Krebs *et al.* 2003, Reed 1995, Woodward and Reed 1989). The tannins form compounds with proteins, carbohydrates, cellulose, hemicellulose and amino acids that are either indigestible or reduced in digestibility (Degen *et al.* 1995, McSweeney *et al.* 2001). An additional consequence of inhibited nutrient use is the potential increase in the cost of ingesting toxins in browse (Provenza *et al.* 2003).

Tannins can also interfere with the determination of fodder quality in plant samples. For example, in an assessment of methods used to determine forage values, Makkar *et al.* (1995) found that proanthocyanidins (condensed tannins) interfere with the determination of (overestimate) fibre fractions of foliage and faecal samples from stock grazing on the foliage. They also distort cellulose and hemicellulose values, and the nutritional value of feeds. They concluded that it was difficult to measure the total tannins in fibre fractions using current methods.

Low levels of tannin 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). Genetic improvement work is ongoing to select important forage legumes such as lucerne and clover with increased tannins, to increase protein utilisation, and help combat bloat (Reed 1995). Woodward and Reed (1989) report that in fodder tree trials in Ethiopia the phenolic content of *Sesbania sesban* was so low that fermentation in the rumen of trial animals was too rapid, causing excess nitrogen to be excreted as urea. By contrast, in the same trial the amount of nitrogen bound by *A. saligna* was described as 'extreme', and of a level that would cause the animals to starve. The limits for tannins are drawn by Larkin *et al.* (1999) (cited in Lefroy 2002), who consider tannins beneficial to animal nutrition when below 0.2% dry weight, to bind protein when above 1%, and to reduce palatability and digestibility when over 5%.

It may be possible to make *A. saligna* foliage more acceptable as a livestock feed using physical or chemical treatments. It has been reported that the tannins in *A. saligna* can be degraded or neutralized via physical methods, such as chopping (Ben Salem *et al.* 2005a). Other studies have found that there was no difference in growth between that animals fed *A. saligna* which had had the tannins reduced via field drying and those fed fresh material (Ben Salem *et al.* 1999). Polyethylene glycol (PEG) can be used to bind tannins and mitigate their deleterious effects on digestion. A number have studies have demonstrated that supplying PEG to livestock being feed *A. saligna* increases the digestibility of plant nutrients and stops microbial enzymes being deactivated, with corresponding improvements in animal production (Atti *et al.* 2003, Ben Salem *et al.* 2002a, Ben Salem *et al.* 1999, Krebs *et al.* 2003). It has been found that lambs given *A. saligna*, in combination with an energy and protein concentrate with PEG, had reduced carcass fat compared to those fed a common diet including oat hay and an energy and protein concentrate (Atti *et al.* 2003). The authors of the study suggested that finishing lambs on *A. saligna*, supplemented with either concentrate or feed blocks containing PEG, would make livestock production more economically efficient. Cost and practicality of use may constrain the use of PEG in operational grazing systems.

An alternative strategy for dealing with the tannins in *A. saligna* is to use the foliage as part of a mixed diet, which as a whole confers benefits for animal production. Ben Salem *et al.* (2005a) investigated whether feeding small amount of *A. saligna* increases the proportion of rumen undegradable protein, and consequently benefits growth performance in lambs. The trial involved feeding sheep a diet of oaten hay *ad libitum* along with 200 g of soya bean meal, then testing treatments which included either or both of 100 g of *A. saligna* and 20 g PEG. Importantly, the soya bean meal was feed to the animals only after *A. saligna* was consumed. It was found that lambs given the basic diet, the basic diet and PEG, or the basic diet with PEG and *A. saligna* had similar growth rates (38.8–48.3 g/day). Lambs given the basic diet with *A. saligna* but no PEG had highest daily weight gain (66.7 g/day). The authors concluded that *A. saligna* could be used to improve sheep performance, provided that an appropriate tannin to protein ratio is maintained and the sequential feeding strategy is adopted. *A. saligna* may also have selective anti-microbial properties that can be exploited, although it is unknown whether this is due to tannins or other plant constituents (P. Hutton pers. comm.). Further work is required to confirm the mode of action of any anti-microbial agents. A general screening of the tannins in the species is appropriate, as certain types of condensed tannins can confer other benefits to livestock, such as reducing parasite burden (Waghorn *et al.* 1998). The feasibility of inoculating livestock with tannin metabolizing microbes, allowing them to consume high tannin feeds, has been demonstrated in several studies (Ben Salem *et al.* 2005b, Norton 1999).

Even if an animal food source has adequate nutritional characteristics, it may not be readily accepted by livestock. The voluntary intake of *A. saligna* is reported to be low. Voluntary intake is determined by factors including the chemical and physical properties of feed as well as the dietary experience of the livestock (Baumont *et al.* 2000). The low intake of *A. saligna* has been attributed to low palatability due to high tannin levels, but the removal of condensed tannins via air drying or PEG was not found to increase the intake of *A. saligna* (Ben Salem *et al.* 1999). The literature on this subject was reviewed by Krebs *et al.* (2003). They concluded that the low voluntary intake exhibited by livestock being fed *A. saligna* is probably associated with the inhibitory effects of the high condensed tannins on digestion, rather than reduced palatability associated with condensed tannins.

Animal training strategies to improve the voluntary intake of *A. saligna* have been explored. Baumont *et al.* (2000) cite an example where dietary experience with high tannin feeds, particularly early in life, led to around a 40 % increase in feed intake. Ben Salem *et al.* (2005b) conducted a study using lambs given either high or low tannin-containing feed early in life. Lambs from both groups were then given either oaten hay or *A. saligna*. Those fed on oaten hay performed better regardless of their early experience with high tannin feed. However, animals exposed to tannins early in life exhibited significantly higher digestible crude protein intake and retained more nitrogen than the inexperienced lambs.

The consistent findings that *A. saligna* biomass is a relatively low quality food source for animals detracts from its use for this purpose. However, there is considerable variation in the feed quality of the species reported between studies, and it has been proposed that different accessions may have different fodder quality (Dynes and Schlink 2002). Sampling across the range of the species, George *et al.* (2007) found that the average digestibility, crude protein and tannin content of wild populations varied considerably. Some populations exhibited favourable feed qualities, especially in terms of digestibility. The extent to which this variation is under genetic control was not elucidated, although some correlation with subspecies was made. A combination of strategies aimed at developing improved cultivars, feed mixtures and feeding sequences which incorporate *A. saligna* as part of a mixed diet warrant further investigation.

Biomaterials and chemicals

Chemical products can be categorised based on their origin in the biomass utilisation process. The first category includes chemical compounds contained in the raw biomass feedstock, such as secondary plant compounds (Olsen et al, 2004). The existence of such compounds in amounts amenable to cost effective extraction, without detriment to other biomass processing steps, is dependent on the feed-stock species. Alternatively, component cellulosics and lignin in the feed stock biomass can be reconstituted into platform chemicals such as alcohols, organic acids and esters (Ragauskas *et al.* 2006, Werpy and Peterson 2004). Most woody plant species would have some propensity for this type of secondary processing; however commercial success would probably be linked to the development of purpose cultivars from species with inherently favourable traits.

A. saligna contains tannins that could theoretically be extracted for productive use. Plant tannins have historically been defined as water soluble polyphenols with the ability to precipitate proteins. After reviewing the literature definitions, Reed (1995) provided the following more comprehensive definition; "high molecular weight phenolic compounds with the ability to form strong complexes with proteins, other macromolecules, and minerals". These characteristics can be exploited commercially for a range of applications such as wood adhesives, anti-corrosion agents and leather tanning (Barbour 2000). Tannins can be broadly grouped into two classes, the proanthocyanidins (otherwise known as condensed tannins), and the hydrolysable tannins. Some applications, such as leather tanning are non-discriminating, and can use tannins from either group, while other uses, such as in adhesives require specific chemistry, in this case the proanthocyanidins (Lancefield Consultants 1998).

An exploration by Lancefield Consultants (1998) of potential products and markets for western Australian produced plant derived tannins identified applications in drilling mud, floatation, iron stabilisation, corrosion treatment, brewing and cosmetics, as well as the dominant leather treatment uses. Although the report was an investigation of the commercial potential of tannin from brown mallet (*Eucalyptus astringens*), most of the conclusions drawn in the report are equally applicable to *A. saligna*. Brown mallet has a history of use for tannin production, has a very high tannin content of the bark, and supported a modest industry in the early part of the twentieth century. Despite this, under modern settings the prospects for the development of a renewed industry in WA were not encouraging; taking into account infrastructure costs, operational scale and competition from substitute products. Leather tanning is now dominated by chromium salts and synthetic products, and the plant-sourced tannins share of this market declined some 55% between the 1950's and the 1990's. The market share remaining for this and other applications, including the significant emerging market for tannin based adhesives, is dominated by three other plants, quebracho (*Schinopsis lorentzii)*, mimosa (*Acacia mearnsii)* and to a lesser extent chestnut (*Castanea sp*). Additionally, the variation in tannins between plant species will prevent the easy substitution of *A. saligna* tannins into existing or new markets established to operate with other plant tannins. Although Australia is a modest importer of vegetable tannins for the adhesive market, this need is easily supplied by the world's mimosa plantations, many of which are in countries with lower costs of production than Australia. Barbour (2000) reports that there are some 500,000 ha of *A. mearnsii* in plantations around the world.

It may be possible to extract tannins for anthelmintic uses. Condensed tannins of *A. saligna* are among a range of products being investigated for their anthelmintic properties, as a possible alternative to existing control methods for gastrointestinal nematodes in grazing animals. Resistance is increasing to existing products, and tannins from *A. saligna* have been demonstrated to reduce migration of nematode larvae, and to reduce the development of nematode eggs (Kahn and Diaz-Hernandez 1999). The market potential for anthelmintic agents is unknown.

The potential for deriving commodity chemicals from *A. saligna* biomass is largely unexplored, but is important given the commercial imperative to maximise the value of the whole tree biomass. As is the case with existing petroleum refining, it is likely that chemicals will constitute a small high value fraction (~5%) of bio-refinery output; with fuels and energy being the dominant products (Ragauskas *et al.* 2006). In exploring market opportunities, emphasis should be placed on domestic and export markets with favourable settings with respect to market size, stability and cost effective delivery to buyers. WA presents unique challenges for market development, given its geographic isolation and small, specialised domestic economy.

Environmental benefits and services

Efforts to develop woody perennial crops in WA are underpinned by the principles of sustainable development: namely the attainment of economic, environmental and social sustainability. It will be difficult for woody crops to compete with other land uses purely on economic grounds. Therefore, it is important that environmental services provided by woody crops are recognised and valued. Key services include biodiversity protection through landscape recharge reduction, habitat augmentation, erosion prevention and carbon emissions abatement. The environmental benefit that offers best prospects for generating revenue for the landowner in the near future is carbon emissions abatement.

A. saligna is a short-lived perennial, at least in WA, and it is most likely to be developed as a phase crop. While a phase crop is not permanent at any one location, its use within a farm or production system is rotational and so the farm or system could have a 'permanent' average area under phase crops. It follows that the average standing biomass, for that average area of phase crop, could qualify as a permanent carbon sink. This would generate carbon offsets revenue for the farm or system during the period of carbon accumulation. Such systems would incur the obligation to maintain and account for that sink in perpetuity. To provide an indication of how attractive this might be, assume that for a 5000 ha farm 5% is under *A. saligna* phase crop at any time, the average crop biomass over time (accounting for the harvest cycle) is about 40 green tonnes/ha or about 40 tonnes of CO_2 equivalent/ha, and this has a market value as an offset of $20/tonne. Under these conditions the value of the sink is $200,000. Only the above ground biomass has been considered here and it may be possible to demonstrate an accumulation of root biomass and soil carbon as well.

The farmer would need to discount this revenue by the open ended obligation it incurs. If this does not prove attractive, the emissions control system will still be useful to *A. saligna* phase cropping through the competitive advantage that it would generate for bioenergy that does not incur the penalty of limits on emissions.

Agronomy

Agronomy refers to the application of scientific knowledge to the growing of crops. It encompasses crop plants, their interface with other organisms in the environment and the soils and landscapes in which they are grown. It could be argued that the analogous forestry term 'silviculture' should be preferred to agronomy. Agronomy is used here because the crop is managed within an agricultural system. In this section, agronomic information relevant to the development of *A. saligna* as a crop plant for dryland farming in Western Australia is reviewed.

Productivity and yields

The importance of fast growth rates for the economic success of woody crops has been identified in earlier sections. *A. saligna* has a demonstrated capacity for rapid growth rates under optimal conditions. In this subsection, factors affecting *A. saligna* productivity are reviewed. Note that the effect of planting time, the impact of different establishment methods, temperature (soil and atmospheric), soil pH and fire on yields are not discussed; the authors did not find any published information that dealt with these factors. Note also that pests and diseases are dealt with explicitly in a later section.

Observed yields

In WA, *A. saligna* produces high volumes of biomass compared with other species across a range of site types (Olsen *et al. 2*004). The authors have observed four year old stands with growth rates exceeding 20 dry tonnes of above ground biomass per hectare per year (Fig. 27). 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 (Fig. 28). 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. Earlier studies in the Negev region report yields of 5.5-9.8 tonnes/ha/year of lopped material under conditions of runoff irrigation (Droppelman and Berliner, 2000). Variable growth rates have also been reported from other parts of the world. For example, in the 500 mm rain fall zone of Sicily, on a site with fertilized but degraded clayey soils, *A.*

saligna produced only 13 green tonnes/ha in around 4 years (Stringi *et al.* 1987); in Tunisia and Libya, El-Lakany (1987) reports yields of 3.5 tonnes/ ha/year of dry wood on a deep sandy loam soil, receiving 150mm annual rainfall, with some additional runoff; in heavy clay loams in 350mm rainfall Tunisia, Tiedeman and Johnson (1992) conducted trials harvesting at different frequency, and report average yields of 1.6 tonnes/ha total dry biomass from 2.5 year old plants, and 5 tonnes/ha total dry biomass from 3.2 year old plants. They estimate that under these conditions, established *A. saligna* will be able to produce an average of 1.2 tonnes of forage dry matter/ha/year, with the ratio of wood to foliage determined by harvest frequency.

A. saligna is considered to be tolerant to drought and water limiting conditions. A minimum rainfall requirement of around 350 mm has been proposed by Fox (1995), although in the Mediterranean *A. saligna* is reportedly grown without irrigation in a rainfall of as low as 150 mm (Le Houerou 2002), and in Chile in areas with less than 100mm of rainfall (Perret *et al. 2*001). This may be due in part to lower evapotranspiration in these regions. The ability of *A. saligna* to tolerate drought is attributed to an extensive root system that allows it to harvest scarce water, and the capacity to osmo-regulate by increasing sugars and free amino acids, especially proline (Albouchi *et al.* 1997, Nativ *et al.* 1999). Despite these adaptations *A. saligna* shows a preference for habitats with additional water, such as stream lines and around the base of large rocks, and is highly responsive to supplemental irrigation (El-Lakany 1987, Zegada-Lizarazu *et al.* 2007). Work in South Africa found that one of the factors that strongly influence the distribution of *A. saligna* was water availability (Higgins *et al.* 1999). The authors have also observed dramatic response to increased water availability at sites in south-western Australia. Trees observed growing in drainage lines, soaks and irrigated gardens display better growth than nearby trees that would not have access to the same amount of additional water. In addition, the authors have also observed pronounced edge effects in block and belt plantings, with plants on the outside rows exhibiting significantly better growth than interior plants (Fig. 29). These differences are ostensibly due to the edge plants having access to water from a much greater soil profile volume.

Measuring biomass productivity

A number of studies have demonstrated that it is possible to accurately predict the biomass productivity of *A. saligna* using non-destructive measurements of stem cross sectional area. 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). Studies from Egypt and Chile have also accurately predicted biomass productivity using stem basal diameter and plant height (Bratti *et al.* 1998b), and plant height and crown diameter (Abou-Deya 1995). The same variables have been used to develop similar allometric relationships in WA in unpublished research by the authors. The ability to accurately predict biomass yields will be valuable since it will provide a rapid and non-destructive estimate of yields from *A. saligna* crops.

There is evidence that that measuring stem cross sectional area increments through time can also be used to estimate biomass regrowth from pruned or coppiced plants. In a study of the effect of pruning treatments on *A. saligna* biomass production dynamics, Droppelman and Berliner (2000) found that regression coefficients from non-pruned trees could also be used to estimate the regrowth of pruned trees. Their experiment supported the “pipe model” theory of plant water relations, which assumes a constant amount of sapwood area for each unit of leaf area and feeder roots in woody plants.

Fig. 27. ***Acacia saligna*** **51 months after establishment on a highly productive site north of Esperance, WA (Photo: D. Huxtable).**

Fig. 28. Marked variation in growth in a trial plot 41 months after establishment, in a planting at East Beverley, WA, reflecting topsoil depth and consequent available moisture (Photo: D. Huxtable).

Fig. 29. Edge effect in a 4 row belt planting 44 months after establishment at Narrogin, WA (Photo: D. Huxtable).

Reliable site productivity functions (equations to predict final mean annual dry weight based on site environmental conditions) would be valuable for allowing the potential of *A. saligna* in different parts of the wheat-sheep agricultural zone to be assessed (Downing and Tuskan 1995). These functions could be derived from empirical studies across a large number of sites, using well understood and relatively low sophistication allometric methods. Potentially more versatile are process models based on plant physiology, hydrology, climate and soil dynamics. These can be developed to predict growth and explore different management scenarios. Process models, such as 3PG and CABALA developed by Commonwealth Scientific and Industrial Research Organisation (CSIRO), have been valuable tools for short rotation eucalypt farming in southern Australia and elsewhere. The disadvantage for process models is the task of model parameterisation and validation; this is relatively expensive, time consuming and requires a greater level of expertise to implement.

Response to soil-type and nutrients

The authors know of no studies that have specifically examined the impact of different soil substrates on the biomass yields of *A. saligna*. However, reviews of the species suggest it will grow on most soil types, with yields maximised on deep sandy soils (Doran and Turnbull 1997, Fox 1995, Michaelides 1979). Observations made by the authors of several tens of planting sites throughout the WA wheat-sheep agricultural zone support this broad assertion.

Research in South Africa has found that available soil nutrients significantly influence the distribution of *A. saligna* (Higgins *et al.* 1999). No known studies have specifically addressed, or tried to quantify, the impact of nutrient additions on the productivity of *A. saligna* in field trials. Trials that have assessed the productivity of *A. saligna* in field-based situations have either not used fertilizers or have used fertilizer without unfertilized controls for comparison. However, 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 to *A. saligna* in pots, 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). Two studies testing the impact of root symbionts on the growth of *A. saligna* included fertilized and unfertilized treatments. These studies also found that the growth of *A. saligna* was responsive to the addition of nutrients. 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). The addition of 0.5 g/L potassium nitrate fertilizer increased the dry mass of plants at 3 months from 0.08 to 1.38 g/plant (Koreish *et al.* 1997). It is not possible to extrapolate these results to field plantings with any confidence, although it is reasonable to assume that providing seedlings with additional nutrient at planting will improve the growth of young plants. Studies to determine the cost effectiveness of fertiliser application in the field are therefore warranted.

The importance of micro-nutrients is also poorly understood. Nodulation in annual legumes is known to require additional iron, and a similar finding has been made for *Acacia mangium* (Lesueur and Diem 1997). Nodulation may have an impact on productivity in *A. saligna* (see “Agronomy - Root symbionts” section of this report for details). An examination of the impact of additional iron on the growth of *A. saligna* deserves consideration.

The relative importance of soil types and their interaction with other growth factors, such as water and nutrient availability remains to be elucidated. One study has shown that three way interactions between different genotypes of *A. saligna,* rhizobium strains and different soils types can cause significant differences in yields (Nasr *et al.* 1999). Understanding how to maximise performance on different soil types is an important and ongoing agronomic task.

Crop layout and density

There is very little published work investigating the impact of crop layout and density on the production of *A. saligna*. However, the pronounced edge effects seen in some trial plantings in WA demonstrate that trees in belt configurations will, at least under some conditions, 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 WA. 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 6).

Table 6. The effect of planting density on *Acacia saligna* growth, 24 months since establishment on farmland at Lake Bryde, WA.

Planting Density	Mean Plant Height (m)	Mean plant SBA[1] (cm^2)	Plot SBA (m^2/ha)	Estimated Plot Biomass[2] (green tonnes/ha)	Estimated Productivity[3] (dry tonnes/ha/yr)
1000	1.62	35.4	3.46	6.5	1.6
2000	1.41	22.7	4.27	7.4	1.8
4000	1.10	16.7	5.94	9.4	2.3
8000	1.24	11.6	8.74	12.7	3.2

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

[2] Above ground plot biomass estimated using allometric regression equations developed by the authors at other sites in WA.

[3] 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.

Work from the Negev desert region of Israel (Sauerhaft 1997) showed limits in planting density not reached in the WA trials. In irrigated trials of three densities (840, 1330 and 2520 stems per hectare), the highest productivity was obtained at the intermediate density There was little change in the yield of woody material between the different density plantings, with the increase in production being attributed to a greater weight of foliage. The trials were pollarded at 2m height two years after planting and again a year later, with the same ranking recorded both times.

Harvesting

With the exception of in-situ grazing systems, the lack of existing woody crop analogues for *A. saligna* means that new harvesting systems need to be developed. Conventional forestry harvest and supply chain systems are not suitable for shrub-like woody plants grown on short harvest cycles in dispersed layouts. The method of harvest, and the response of the plant to harvesting, will have a profound effect on the most appropriate production system models.

Harvest methods

Harvesting biomass is one of the most significant production costs facing short cycle woody crops and this cost must be reduced below a threshold before utilisation of the biomass can occur (McKendry 2002, Nordh and Dimitriou 2003). Whole tree harvesting and utilisation is considered mandatory for bioenergy and wood product industries using purpose grown crops, in order to provide sufficient returns to growers and achieve production scale. This is because much of the biomass resource is relatively small dimension (<50mm diameter) material.

Almost 80% of total energy inputs in the production of woody crops occur in biomass harvest and transport, arising mainly from the use of fossil fuels, so optimisation of these stages has the potential to improve the energy ratio for the crop (Wu *et al.* 2005). Chipping is anticipated to consume about half the energy required for harvesting and recent work on chipping technology has achieved considerable reductions in specific energy requirements for chipped woody biomass from short cycle crops (R. Giles pers. comm.). The key objective of chipping is to convert standing biomass into a flowable, easily transported form. However, optimised chipping methods may also reduce the cost of feed stock pre-treatment at processing facilities.

Existing technologies used in comparable overseas systems, such as European willow coppice systems, cannot meet the demanding economic conditions that are anticipated for short cycle tree crops in WA; nor can the harvesters cope with the size and form of species such as *A. saligna*, at least in their current 'wild' form. Most research work that discusses methods for increasing the efficiency of harvest deals only with harvest methodology, or the harvester design. However it is possible that the efficiency of harvest could be improved via changes in plant morphology, such as through a reduction in near-ground-level forking and attainment of upright plant form (Giles and Harris 2003). The morphology of *A. saligna* is known to be highly variable (Maslin and McDonald 2004, McDonald and Maslin in review) and some of this variation can be attributed to genetic variation within the species (George *et al.* 2006a). The potential therefore exists to improve harvesting characteristics by modifying *A. saligna* morphology via selection and breeding.

A conceptual biomass supply chain, somewhat analogous to systems used for sugar cane, is described in Giles and Harris (2003). A prototype continuous flow harvester for short cycle woody crops is currently under development by the Australian Future Farm Industries Cooperative Research Centre.

Response to harvesting

The productivity of *A. saligna*, in terms of biomass production and biomass composition, is affected by harvesting. Factors such as harvest frequency, cutting height, plant age and time of year are believed to be important. Work from North Africa suggests that *A. saligna* will coppice after cutting even if cut several years in succession (Tiedeman and Johnson 1992). However, the authors have observed wide variation in coppicing ability in WA, with some provenances failing to coppice if cut near ground level (Fig. 30). Coppicing ability affects the types of production systems *A. saligna* is suited to and their economic viability. As such, developing a thorough understanding of how *A. saligna* 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. Cutting is documented to result in different biomass partitioning compared to uncut trees, resulting in more foliage produced than wood (Doran and Turnbull 1997, Droppelmann and Berliner 2000). 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, producing on average 1.8 kg/plant, 0.6 kg/plant and 1.0 kg/plant respectively, after 8 months (Bratti *et al.* 1998a). The authors were unable to find any research on the relationship between age of harvest and productivity. Grazing of plants *in situ* can be considered to be an alternative form of harvesting. The effect of grazing on productivity is unknown.

Genetic variation

The considerable genetic diversity within *A. saligna* suggests that economically important characters, such as productivity and water use efficiency, are likely to exhibit genetically induced variation. Evidence supporting this has be found in trials conducted in Chile using fourteen named Australian provenances of *A. saligna*, where significant differences in biomass productivity between the different sources of germplasm have been detected (Poblete and Rojas 2004). Now that the species taxonomic review has been completed, it may be possible to describe the material used in these trials at the subspecies level. This could also be achieved using diagnostic microsatellite markers developed for *A. saligna* that can assign individuals at the subspecific level (Millar *et al.* 2008a).

The high level of genetic variation in the species is likely to complicate agronomic studies seeking to unravel the impact of different environmental factors on *A. saligna* productivity. As a precursor to conducting agronomic trials, it is therefore imperative to build an understanding of the relationship between genotype and productivity. Significant genotype by environment interaction was detected in a Chilean study (Poblete and Rojas 2004). Such interaction is a feature of widely distributed species, which are also likely to have locally specific adaptations (Hufford and Mazer 2003). While the selection of stable provenances and genotypes is often possible with plant breeding, the extreme range of critical environmental factors such as rainfall and evaporation covered by this species suggest that a cautious approach may be prudent. The best performing subspecies and provenances of *A. saligna* in one location can not be relied upon to be the best performing provenances under all environmental conditions. The development of clones for use in trials would be advantageous for determining the level of interaction between genetic and environmental factors.

Fig. 30. Response to harvest.

(A) *A. saligna* ssp. *saligna* has failed to coppice six months after cutting at 5cm above ground level at East Beverley, WA. The plants were 30 months old when harvested (Photo: D. Huxtable) (B) By contrast, these plants were shooting 20 days after harvest at the Canella demonstration plot, Mincha Sur, Chile. (C) Strong regrowth following removal of foliage from six year old plants at El Tangue, Chile (Photos W. O'Sullivan).

Major trials to evaluate a comprehensive sample of the natural genetic variation in *A. saligna* were established by the authors in south-western Australia in 2006, as part of the FloraSearch project. The trials included 2 site replications of ~400 families: consisting of 20 families each from 20 provenances representing all subspecies and spanning the geographic range of the species. The ongoing objective of these trials is to minimise the impact of environmental variation, to allow a quantitative assessment of the level of heritable genetic variation in biomass yield and other economically important traits. Early observations confirm the highly variable morphology within the species complex (under the same site conditions). These trials will provide valuable information on the potential for improving the productivity of *A. saligna* using selection and breeding methods. A full review of the breeding program being applied to *A. saligna* is presented in FloraSearch report 3 a (Chapters 4 and 5).

Root symbionts

As a leguminous plant, *A. saligna* can fix atmospheric nitrogen by forming symbiotic relationships with bacteria in root nodules. For a given site, the ability of *A. saligna* to form these types associations with bacteria occurring in the soil will influence its productivity. There is scope to improve growth rates by developing bacterial inoculants that surpass the efficacy of those occurring *in-situ*. Technology for this has been developed for other leguminous crop species to improve their productivity on different soil types.

Within its natural range in south western WA, 133 distinct strains of root nodule bacteria have been isolated from *A. saligna*; from a variety of sites and soils types (Marsudi *et al.* 1999). These isolates, comprising both fast and slow-growing rhizobium and bradyrhizobium, exhibit tolerances to different soil and climatic conditions. This diversity opens the prospect for developing targeted bacterial inoculants to suit a range of different environmental conditions. *A. saligna* is also reported to nodulate with strains of nitrogen-fixing bacteria from soils outside its natural distribution, including local bacterial species in Egypt (Koreish *et al.* 1997), Ethiopia (Wolde-Meskel *et al.* 2005), Morocco (Hatimi 1999), Sicily (Quatrini *et al.* 2003), South Africa (Hoffman and Mitchell 1986) and Tunisia (Nasr *et al.* 1999). It was found to form nodules with 30 strains of rhizobium and bradyrhizobium isolated from 18 native legume species growing in North Western Australia (Yates *et al.* 1999). In this study, the isolates were tested on four species of south-western legumes, of which *A. saligna* nodulated with the greatest range of species.

A number of studies have found that the presence or absence of root-nodule bacteria can impact substantially on *A. saligna* 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). Similarly, a pot trial conducted in Egypt found the average dry weight of inoculated plants was 1.56 g after 3 months growth, compared with 0.08g/plant for the uninoculated treatments (Koreish *et al.* 1997). This study used microbial strains isolated from *A. saligna* plantings, in addition to commercially available *Acacia*-specific strains, four cowpea strains and two peanut strains. Interestingly, the highest productivity was achieved using an isolate from cow pea. 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).

Mycorrhizal symbiosis, between plant roots and fungi, is another form of symbiosis, which can improve the ability of plants to extract mineral elements from the soil. *A. saligna* has been shown to form symbiotic relationships with mycorrhizal fungi native to the soils of south-western Australia (Jasper *et al.* 1989). Plants growing in Morocco (Hatimi 1999), Sicily (Quatrini *et al.* 2003) and South Africa (Hoffman and Mitchell 1986) have also formed associations with native soil fungi in those regions

Several studies have shown that inoculation with mycorrhizal fungi increases the biomass productivity of *A. saligna*. In pot trials using soil containing 0.5 mg P/kg, plants inoculated with mycorrhizal fungi produced twice the biomass of un-inoculated plants after 3 months of growth (Jasper *et al.* 1989). The study concluded that the fungi were increasing the ability of the plants to utilize available phosphorous. At higher rates of phosphorous application the study found the difference between the inoculated and un-inoculated plants diminished, suggesting that the fungi are only conferring a nutrient uptake benefit when soil phosphorous is scarce. A trial in Morocco, using plants inoculated with a complex of mycorrhizal fungi obtained from coastal dune soils in the same region, found inoculation increased dry weight by 72% in comparison with un-inoculated plants after 8 weeks (Hatimi 1999). A second trial from Morocco showed that the weight of seedlings of *A. saligna* inoculated with one of three strains of mycorrhizal fungi had 2 to 4 times the mass of the un-inoculated control, depending on the strain used (Hatimi *et al.* 1997). On a landfill site in Sicily, plants inoculated with both a mixture of mycorrhizal fungi and rhizobium had a higher survival rate and produced greater biomass than un-inoculated plants (Quatrini *et al.* 2003). In a four month greenhouse study preceding this field trial, biomass production as measured by shoot dry weight was over ten times greater in the inoculated plants compared to un-inoculated controls.

It is not known whether the early growth benefits described above would be maintained through a crop rotation of several years. However, there is clearly potential for the activity of root nodule bacteria and mycorrhizal fungi to influence the performance of the species in crop plantings. The behaviour of root symbionts can be biologically complex and reactive to environmental factors. Indeed, significant interactions between *A. saligna* genotype, root nodule symbionts strain, and soil conditions have been reported (Nasr *et al.* 1999). Despite these difficulties, it will be important to consider these interactions in the design and assessment of future agronomic trials.

Other environmental factors

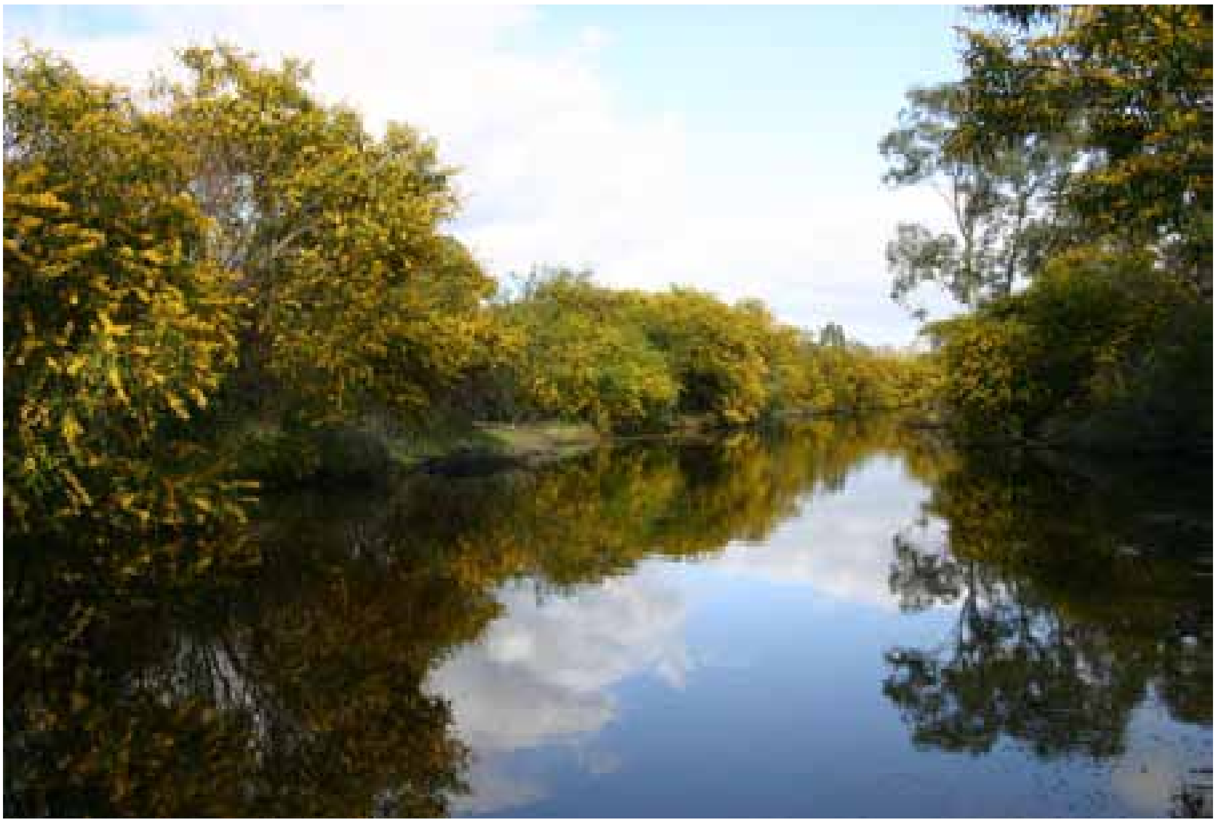
In the south west of WA, the performance of crop plants can be affected by soil salinity, seasonal waterlogging and frost. Each of these factors imposes constraints on the area of land available for *A. saligna* to be grown productively.

A. saligna can survive in conditions of relatively high soil salinity (Michaelides 1979, Simmons 1988). Studies have shown that plants can grow in soil with salinity levels of 10 to 20 dS/m (Draz *et al.* 1996, El-Bagoury *et al.* 1993, El-Baha *et al.* 2003). However, the productivity of *A. saligna* is depressed by comparatively low salinity levels. Pot trials conducted in Egypt using six month old *A. saligna* plants found that yields were depressed by 10% after irrigation with just 6 dS/m water (El-Bagoury *et al.* 1993). Whilst *A. saligna* can tolerate higher soil salinity than many annual crops, this depression in growth was greater than the depression in growth seen in *Atriplex* and *Panicum* species in the same trial. El-Bagoury *et al.* (1993) and El-Baha *et al.* (2003) report that salinity levels of over 20 dS/m will depress growth by approximately 50 to 80%, but other work has found growth to be reduced by 50% at salinity levels of only 10 dS/m (Draz *et al.* 1996). The reason for the variability between these studies is unclear, however factors such as nutrient availability, soil type and the presence of root symbionts all appear to interact to affect the response of *A. saligna* to soil salinity (El-Baha *et al.* 2003, Hatimi 1999, Koreish *et al.* 1997). Genetic variation between provenances may also have contributed to the discrepancies between these studies.

A. saligna responds favourably to additional water, as discussed in earlier sections, but there is little information on the effect of prolonged water logging on survival and productivity. Fox (1995) claims that the species does not tolerate constant water logging of soil. The species does commonly occur in riparian habitats and the authors have observed that plants can survive inundation by annual flooding for periods of several weeks (Fig. 31). The phenology of such events has not been examined.

Fig. 31. *Acacia saligna* ssp. *lindleyi* on the Arrowsmith River, WA, September 2005.

Many of the trees here were inundated for several weeks. Spectacular flowering was followed by heavy seed set (Photo: W. O'Sullivan).



A. saligna does not readily tolerate frost. The distribution of the species around the Mediterranean is apparently limited by frosts (G. Gintzberger pers. comm.). The authors have observed a series of mild frosts injure and kill phyllodes of *A. saligna* seedlings in a nursery, whilst seedlings of other species from *Atriplex*, *Melaleuca* and *Eucalyptus* genera were undamaged. A study of *A. saligna* conducted in New Zealand by Pollock *et al.* (1986) found that a single frost of -6°C caused damage to plants by killing phyllodes and stems and that less severe but repeated frosts of -4°C were also fatal. The study found that the plants could re-sprout after frosts.

Pests and diseases

Artificially increasing the abundance of a plant species can often intensify pests and diseases that afflict it. This phenomenon has been observed in the *Acacia* genus in Australia. Increased plant abundance has resulted in increased insect pest abundance and previously innocuous species have become pests (New 1984). Predicting pest and disease problems that could arise for plant domestication candidates is difficult. Often there is little information regarding the biology of known or suspected pest species. This precludes a meaningful assessment of the economic implications of pests and measures to control them. However, understanding the potential impact of pest species is a critical component of new crop development. Historically, there are numerous examples where inadequate attention to pests resulted in the regional failure of a new crop: for example rubber cultivation in Brazil (Cocks 2003) and cotton growing at the Ord River in north WA (Yeates *et al.* 2006). Conversely, pests may also be important as a means of controlling weediness if the species is used outside its natural range.

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.). *A. 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). All of these are discussed in more detail below.

Gall rust

Gall Rust (*Uromycladium tepperianum* (Sacc.) McAlp.) has been found on over 100 species of *Acacia*, as well as on the related species *Paraserianthes lophantha* (Morris 1987). 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). Cross-inoculation experiments indicate there is specificity between strains of Gall Rust and particular *Acacia* species (Morris 1987). The propagules of Gall Rust are wind-dispersed (Morris 1999). Young leaflets, phyllodes, stems and reproductive structures of *A. saligna* are susceptible to Gall Rust infection (Morris 1991, Fig. 32). The fungal teliospores germinate on plant-parts, penetrate the epidermal cell walls, develop hyphae which penetrate inner epidermal wall and grow intercellularly though the mesophyll tissue to vascular bundles (Gathe 1971). Infection leads to the formation of “witches-brooms” and conspicuous, perennial, globose galls 0.5 to 7 cm across (Gathe 1971). *A. saligna* trees that are heavily infested by Gall Rust seem to be more susceptible to other stresses (Morris 1991), and heavy infestation can lead to tree death (Fox 1995, Gathe 1971). The incidence of gall rust can be episodic; the authors have observed affected stands in south WA recover from quite severe infestations. The factors underpinning stand recovery have not been elucidated.

Fig. 32. Gall rust (*Uromycladium tepperianum*).

Top row of pictures shows galls of gall rust afflicting *A. saligna*. Bottom row of pictures shows whole trees impacted by gall rust. (Photos: N George).

Morris (1999) reviews the use of Gall Rust as a bio-control against weedy *A. saligna* in South Africa. After the release of Gall Rust in multiple locations the fungus spread rapidly, dispersing by wind, up to 10 km from original infection sites within 3 years. After the introduction of the fungus, stand density was observed to decline by 90-95%. While some seedling regrowth was killed directly by the fungus, much of the mortality is reasoned to be secondary, with significant canopy reduction predisposing the plants to other stress factors, such as drought.

Longer term monitoring of research plots in South Africa, extending to 15 years after the introduction of *U. tepperianum*, confirms that the fungus significantly reduces the lifespan of individual *A. saligna* plants, and impacts on the density and vigour of populations (Wood and Morris 2007). By comparing data collected pre and post introduction of the fungus as a biological control agent, the authors determine that the life span of the trees (reported in early literature as 30-40 years) had declined to less than 10 years.

Insects were found to parasitize the fungal galls but this did not appear to affect sporulation. The native fungi *Trichothecium roseum* (Pers.) Link: Gray, along with species of *Tuberculina* Tode: Sacc. and *Verticillium* Nees were found to infect and damage the galls, preventing them from sporulating normally (Morris 1999).

It seems likely that Gall Rust fungus could be detrimental to *A. saligna* crops in several ways: by killing trees, or reducing their vigour, or reducing their life-span, or making plantings susceptible to other stresses. At present, there is insufficient knowledge to adequately assess the level of threat posed by the fungus. Factors such as geographic location, proximity to other vegetation and climate are speculated to be important. Methods for controlling the fungus, including the development of resistant cultivars, also need to be considered. Old *et al.* (2000) state that for other genera of trees infected by other gall rusts, significant differences in resistance exist at provenance and family level. Screening for resistance to this fungus would be a primary objective in any breeding program.

Invertebrates

A survey of *A. saligna*, conducted predominantly in coastal and sub-coastal regions between Geraldton and Israelite Bay of WA, was undertaken to document insect species that might serve as biological control agents (Van Den Berg 1980a, 1980b, 1980c). A summary of the phytophagous species found to be plentiful on *A. saligna* are listed in Table 7. The species that exhibited potential to be particularly damaging to *A. saligna* were *Pyrogoides sutuealis* (Coleoptera: Chrysomelidae), *Melanterius* sp. (Coleoptera: Curculionidae), *Adrisa* sp. (Hemiptera: Cydnidae) and *Cryptophasa melanostigma* (Lepidoptera: Xyloryctidae). Of these, *Cryptophasa melanostigma* (syn *Maroga melanostigma*) was found to be the most damaging, occasionally killing whole *A. saligna* trees by feeding on bark and ring-barking branches. It is known to feed on the bark of many native and exotic tree species, although the main hosts are *Acacia* (Nielsen and Common 1991). Only limited information was found on the general biology of the other species identified in the study, or the potential damage they could cause (Carver *et al.* 1991, Lawrence and Britton 1991).

Melanterius compactus, a seed eating weevil, was introduced into South Africa in 2001, to complement the biological control being affected by the fungus *Uromycladium tepperianum*. The fungus significantly reduces the amount of seed being produced, and the introduction of the weevil is anticipated to further reduce the amount of seed available for new generations of the weed (Wood and Morris 2007). The introduction of *M. compactus* builds on the success of other *Melanterius* species on *Acacia cyclops, A. melanoxylon* and *A. longifolia* (Wood and Morris 2007). Work in Africa on predation by *Melanterius servulus* on *Acacia cyclops* has found it to impact on seed banks, but not heavily enough to have a major impact on the weed potential of the species (Impson *et al.* 2004). While this type of insect damage is unlikely to affect biomass production of *A. saligna,* it may be deleterious to seed orchards.

Table 7. The common insect pests of *Acacia saligna*.

The following table is summarized data from the studies by Van Den Berg (1980a, 1980b, 1980c). Highlighted species are those identified in the study as showing potential to cause serious damage to *A. saligna.*

Order	Family	Genus species	Behaviour
Coleoptera	Belidae	*Belus* sp.	Adults feed on phyllodes and flowers
Coleoptera	Cantharidae	*Heteromastix* sp.	Adults feed on flowers.
Coleoptera	Cerambycidae	*Ancita* sp.	Larvae bore in woody stems
Coleoptera	Chrysomelidae	*Ditropidus carbonarius*	Adults feed on phyllodes and flowers
Coleoptera	Chrysomelidae	*Ditropidus* sp.	Adults feed on flower buds and flowers
Coleoptera	Chrysomelidae	*Ditropidus* sp.	Adults feed on flowers
Coleoptera	Chrysomelidae	*Pyrgo pandora*	Larvae and adults feed on flowers
Coleoptera	Chrysomelidae	*Pyrgo* spp.	Adults feed on flower buds and seed pods
Coleoptera	Chrysomelidae	*Pyrgoides* sp.	Larvae and adults feed on phyllodes and flower buds
Coleoptera	**Chrysomelidae**	***Pyrgoides sutuealis***	**Larvae and adults feed on phyllodes and flower buds**
Coleoptera	Corylophidae	*Sericoderus* spp.	Adults of at least two species seen feeding on flowers.
Coleoptera	Curculionidae	*Catasarcus* sp.	Adults feed on phyllodes
Coleoptera	Curculionidae	*Catasarcus spinipennis*	Adults feed on phyllodes
Coleoptera	Curculionidae	*Diethusa* sp.	Adults feed on flowers and developing seeds
Coleoptera	Curculionidae	*Leptopies* spp.	Adults of two species feed on phyllodes
Coleoptera	**Curculionidae**	***Melanterius* sp.**	**Larvae develop in young seeds, adults feed on flowers**
Coleoptera	Curculionidae	*Myrmacicelus exsertus*	Larvae develop in rusts and other galls, adults feed on flower buds and bark
Coleoptera	Scarabaeidae	*Diphucephala affinis*	Adults feed on flowers
Coleoptera	Scarabaeidae	*Sphaeroscelis pectoralis*	Adults feed on flowers
Hemiptera	Alydidae	*Riptorus* sp.	Adults feed on developing seed
Hemiptera	Coccidae	*Cryptes baccatus*	Nymphs and adults feed on twigs and branches
Hemiptera	Coreidae	*Mictis profana*	Nymphs and adults feed on twigs and branches
Hemiptera	**Cydnidae**	***Adrisa* sp.**	**Nymphs and adults feed on seeds underneath trees**
Hemiptera	Cydnidae	*Blaena setosa*	Nymphs and adults feed on seeds underneath trees
Hemiptera	Diaspididae	*Aspidiotus* sp.	Nymphs and adults feed on seed pods, twigs and branches
Hemiptera	Diaspididae	*Lindingaspis rossi*	Nymphs and adults feed on twigs and branches
Hemiptera	Diaspididae	Undetermined sp.	Nymphs and adults feed on twigs and branches
Hemiptera	Lecanodiaspidae	*Lecanodiaspidae anomala*	Nymphs and adults feed on twigs and branches
Hemiptera	Lecanodiaspidae	*Lecanodiaspidae* sp.	Nymphs and adults feed on twigs and branches
Hemiptera	Membracidae	*Sextius depressus*	Nymphs and adults feed on twigs
Hemiptera	Miridae	*Campylomma livida*	Adults feed on flowes
Hemiptera	Pentatomidae	*Dictyotus caenosus*	Adults feed on developing seeds
Hemiptera	Pentatomidae	*Dictyotus conspicuus*	Adults feed on developing seeds
Hemiptera	Pseudococcidae	*Dysmicoccus* sp.	Nymphs and adults feed on twigs and branches
Hemiptera	Pseudococcidae	Undetermined spp.	Nymphs and adults of two species feed on twigs and branches
Hemiptera	Psyllidae	*Psylla* sp.	Nymphs and adults feed on flower buds
Hemiptera	Psyllidae	*Psylla* spp.	Nymphs and adults of 3 species feed on twigss
Hemiptera	Scutelleridae	*Coleotichus cotatus*	Nymphs and adults feed on developing and mature seeds in pods
Lepidoptera	Cosmopterigidae	*Labdia* sp.	Feeds on flower buds and flowers
Lepidoptera	Cossidae	*Xyleutes liturata*	Bores into woody stems
Lepidoptera	Gelechiidae	*Anarsia molybdota*	Feeds on phyllodes, flower buds, flowers and seed pods
Lepidoptera	Glyphipterigidae	*Homadaula myriospila*	Feeds on phyllodes
Lepidoptera	Gracillariidae	*Acrocercops alysidota*	Mines in phyllodes and seed pods
Lepidoptera	Lasiocampidae	*Crexa* sp.	Feeds on phyllodes
Lepidoptera	Lycaenidae	*Nacaduba biocellata*	Feeds on phyllodes and flower buds
Lepidoptera	Lymantriidae	*Orgyia atheropla*	Feeds on phyllodes and flowers
Lepidoptera	Oecophoridae	*Macrobathra bigerella*	Feeds on phyllodes, flower buds, flowers and developing seeds
Lepidoptera	Tortricidae	*Eucosma triangulana*	Feeds on phyllodes, flowers and seed pods and bore in peduncles and branch tips
Lepidoptera	Xyloryctidae	*Cryptophasa melanostigma*	Feeds on bark and ring-barks trees

Other research has observed that large infestations of the sap-sucking Rutherglen bug (*Nysius vinitor* Bergroth) can attack the young growth of *A. saligna* leading to wilting (Angell and Glencross 1993). Sap-sucking Psyllidae are also known to attack flush and terminal growth in other *Acacia*, potentially causing die-back (New 1984). *A. saligna* is also reported to be affected by the mite *Aceria acaciflorus* and Phyllode Spotting Bug (*Rayieria* sp.) (Old *et al.* 2002). *Aceria acaciflorus* causes “Witches’ broom” and gall-like growths, and can act as a vector for other diseases, whilst *Rayieria* sp. can lead to defoliation (Old *et al.* 2002). Latania Scale (*Hemiberlesia lataniae*) infests *A. saligna* in Israel (Izraylevich and Gerson 1993). Low seedling emergence in direct seeded *A. saligna* in WA has been attributed to Red-legged Earth Mite (*Halotydeus destructor)* (G. Woodall *pers. comm.*). Any program aiming to establish plants by direct seeding methods in the south west of WA should anticipate the need to control this pest.

Other pests

Vertebrate pests of importance in south west Australia include kangaroos, rabbits and parrots. Mammalian species are known to have preferentially grazed and killed recently planted *A. saligna* where it has been a component of mixed species plantings. Mature *A. saligna* are reported to tolerate regular grazing by re-sprouting from the roots and trunk (Morris 1999, Witkowski 1991). Several species of parrot can cause damage to plantation eucalypts and other species used in farmland revegetation, by ringbarking young trees and destroying the growing tips of older plants. In *A. saligna* they have been observed ringbarking stems, causing branch death, which may compromise form but is rarely fatal to the plant the significance of such damage will be determined by the target product.

Propagation and establishment in Western Australia

Propagation

Propagation from seed

A. saligna can be readily propagated using seed (Angell and Glencross 1993, Doran and Turnbull 1997). In good growing conditions, the species produces large quantities of seed that is relatively easy to collect and clean. The seeds are oblong to slightly elliptic in shape, 0.4-0.7cm wide, 0.2 -0.4 cm thick, dark brown to black in colour and have smooth, shiny surface texture (McDonald and Maslin, in review). They typically weigh between 14 and 20 mg each. In wild populations the seed is readily predated whilst on the plants (Doran and Turnbull 1997, Fox 1995). Cleaned 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). The ideal germination temperature for *A. saligna* seed is reported to be 15ºC; at this temperature the seeds also exhibited the most rapid germination (Shaybany and Rouhani 1976). It is not known whether seed characteristics vary between subspecies and provenances.

To facilitate germination, the seed of *A. saligna* must be scarified to breach the hard seed coat. Without treatment, seed germination rates are reported to be as low as 3% (Milton and Hall 1981). Exposure to boiling water is a simple way to effect scarification and immersion in boiling water for 1 minute is effective (Doran and Turnbull 1997). Testing different scarification methods for *A. saligna* found that immersion in concentrated sulphuric acid at 50ºC for two hours produced an 80% germination rate, which was higher than seeds treated with cool acid or boiling water (Shaybany and Rouhani 1976). Mechanical breeching of the seed coat may also be suitable, since equipment is available that can rapidly and cheaply scarify large volumes of seed mechanically. It is unknown whether mechanical scarification provides any advantages in comparison with exposure to boiling water. In an unpublished experiment by the authors on another *Acacia* species, *Acacia bartleana*, mechanically scarified seed exhibited a higher and more rapid germination rate in the field than seed treated with boiling water. Twelve months after direct sowing in the field, the conversion rate of seed into living seedlings was 17.5% and 8.9% for the two treatments respectively.

In the south west of WA, the most common field establishment method is transplantation of nursery grown seedlings (see “Establishment and site preparation” section of this report below). For nursery seedling production, the seed must be sown in early summer (ideally during December) to achieve good growth in time for planting in the following winter (June-August). When sown early the seedlings are capable of rapid growth, but nursery managers report that seedlings sown later than the end of January struggle to achieve a plantable height by winter (A. Waters, pers. comm.). In Northern Africa the optimum seeding date in the nursery is considered to be early June (early summer) and the optimum transplantation period is October to November (late Autumn) (Tiedeman and Johnson 1992). In Chile seed sowing is recommended between October and December (late spring), with transplanting to the field in late June (early winter) (Perret *et al. 2*000).

Vegetative propagation

A. saligna can be propagated vegetatively via root-sucker growth (Angell and Glencross 1993) and tissue culture (Barakat and El-Lakany 1992). Work by Glock and Sedgley (1996) showed that vegetative propagation success varied across six ornamental *Acacia* species, with success of cuttings ranging from 0-90%. No significant advantage was conferred to the cuttings through the use of etiolation or girdling techniques as pre-treatments. Ten to twelve month old sucker growth is reported to achieve better establishment rates than direct seeding (Angell and Glencross 1993). Barakat and Lakany's (1992) describe techniques used to successfully produce multiple shoot buds from shoot tips. When transferred to soil, plantlet survival rate was greater than 90%. Jones *et al.* (1990) also discusses micropropagation technique and nursery practice for transferring rooted plantlets to *in vivo* conditions of a range of *Acacia* species, including *A. saligna*.

Using seed for propagation of plants is cheaper and requires less labour than vegetative propagation, but use of vegetative propagation may be appropriate under some circumstances; for example as part of a genetic improvement program. Vegetative propagation could enable gains from selection to be tested, by comparing parents and progeny in the same trials, or allow genotypes to be tested in multiple locations.

One nursery in the south west of WA produces root cutting stock of selected *A. saligna* lines. The material was selected because its propensity to sucker was considered to offer the advantage of faster and more reliable recovery in grazing systems. It was also partially in response to an observed low rate of seed production in the parent plants (A. Thamo pers. comm. 2006). The material preferentially selected by Thamo for this nursery line is now recognised as being *A. saligna* ssp. *stolonifera* (McDonald and Maslin, in review).

Establishment and site preparation

A. saligna can be established in the field by direct sowing of seed or transplantation of nursery grown seedlings. In south-western Australia the use of containerised seedlings is the most common means of establishing *A. saligna*, 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 40-90 cm^3. When planted in the field they range from 150-300 mm in height with a basal stem diameter of 2-3 mm. Containerised seedlings are also the favoured method of establishment in North Africa, where *A. saligna* is actively utilized as a crop (Tiedeman and Johnson 1992), and also in Chile (Perret and Mora 2006). For a comprehensive discussion of recommended nursery practices for seedling production, the reader is referred to Mullan and White (2002b).

Direct seeding has also been used successfully to establish *A. saligna* in WA. It is routinely used to establish *A. saligna* in combination with other species in roadside revegetation projects. Direct seeding is potentially less costly than the nursery seedling alternative, however reliable and repeatable methods have not yet been demonstrated in low rainfall (<600 mm annual) areas. Research has shown that direct-sown seed of *A. saligna* can emerge from a range of sowing depths. Seed sown at a depth of 5 mm emerged most rapidly, although plants were still able to emerge from a depth of 60 mm (G. Woodall pers. comm.).

Currently, only minimal areas are planted with vegetatively propagated material. Production of this material is more labour intensive and consequently more expensive. It also tends to be bulkier and more difficult to transport and handle in the field. However, it may appropriate for the establishment of breeding populations, or if elite lines of clones are developed to suit particular applications.

Fig. 33. Propagation of *Acacia saligna*.

(A) In-ground propagation of *A. saligna* at the Cavilolen nursery in Chile, where plants are grown in flood irrigated plastic bags. (B) Containerised seedlings at Los Condes Research Station, Chile. (C), (D) Container-grown *A. saligna* in Kalannie, WA. (Photos: W. O'Sullivan).

Site preparation tasks prior to planting or sowing include soil cultivation and weed control. In WA, soil cultivation methods have been developed to facilitate ease of planting, enhance survival and growth, and overcome site constraints (Fig. 34 & Fig. 35). For example, soil compaction resulting from machinery or stock movement should be relieved by ripping to a suitable depth (Mullan and White 2001). 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. Weeds are normally controlled using a combination of pre-emergent and knockdown herbicides, or by mechanical methods. (Angell and Glencross 1993, Tiedeman and Johnson 1992, Mullan and White 2002a). Although the fast growth and broad canopy of *A. saligna* is reported to suppress weed growth (Abebe 1994), good weed control in the first two years of field establishment is likely to improve survival and growth. In other parts of the world similar establishment methods are used. In north Africa, planting rows are first established with a tractor and plough to prepare furrows (Tiedeman and Johnson 1992), and in Chile planting sites are routinely ripped and mounded.

A. saligna responds favourably to additional nutrients (this is discussed in "Measuring biomass productivity" section, pg. 47). Angell and Glencross (1993) report that the nutritional requirements of *A. saligna* are similar to that of pastures on equivalent soils, and that NPK fertilizer and micronutrients should therefore be provided to improve productivity. In North Africa phosphate fertilizer is applied at the rate of 200 kg per hectare, or 100 grams per plant, to improve establishment success and growth (Tiedeman and Johnson 1992).

It has been reported that inoculation using root-nodule bacteria leads to an average 118% increase in establishment of *Acacia* seedlings in direct seeding work, particularly at sites experiencing harsher climatic conditions, with subsequent survival of inoculated seedlings significantly greater than for uninoculated controls (Thrall *et al.* 2005). This finding suggests the possibility of improving establishment and subsequent growth by developing bacterial inoculants. The authors are not aware of any specific inoculants for *A. saligna* being used operationally for site establishment. Although *A. saligna* is observed to nodulate readily, it should not be assumed that suitable bacteria will be present in the field (see “Root symbionts” section of this report) for a more detailed discussion of root symbionts).

Integration with adjacent land uses

To provide an effective solution to dryland salinity in south western Australia, *A. saligna* will need to be integrated with existing land uses based primarily on annual crops and pastures. System design has the parallel objectives of maximising the capture of the water surplus from annual agriculture and maximising the productivity of *A. saligna* on the land it occupies. This will require careful integration with other farming operations such as stock management, surface water management and cropping.

Protection from stock

A. saligna is vulnerable to grazing damage from stock when newly established. Stock exclusion until the plants are well above browsing height is recommended. This requirement can be problematic for the establishment of alley farming configurations, as fencing large planted areas is prohibitively expensive.

Modern grazing systems are exhibiting a trend away from set stocking paddocks in favour of rotational grazing. Establishing *A. saligna* during cropping phases, combined with careful management of stubble grazing, may allow the risk of grazing damage to be avoided to a large extent.

Competition and complementarity with other crops

There are anecdotal reports that in WA *A. saligna* can have favourable impacts on surrounding pastures. However, in environments where water or nutrients are limiting, such as the wheat-sheep agricultural zone, there is likely to be competition between agroforestry species and crops (Sanchez 1995, Eastham and Rose 1990). Root system studies have shown that *A. saligna* has extensive lateral roots (El-Lakany and Mohamed 1993a, El-Lakany and Mohamed 1993b), and produces large amounts of fine roots in the upper soil layers (Lehmann *et al.* 1998, Abdelkdair and Schultz 2005, Zegada-Lizarazu *et al.* 2007) (Fig. 36). *A. saligna* is therefore likely to compete strongly for water and possibly nutrients with adjacent crops, especially shallow rooted annual plants, if this resource is limited. Work in northern Kenya by Lehmann *et al.* (1998) on alley farming of *A. saligna* and *Sorghum bicolour* showed that although there was competition for water between the two plants, there was some partitioning of the soil profile, and a consequent greater utilisation of resources than would be achieved by a monoculture of either species. The tree roots responded to external stimuli such as pruning of the plant (a reduction in root system), and drought conditions (development of deeper root activity), observations that can help in system design.

Fig. 34. Low rainfall zone non-wetting sands being scalped, ripped and furrowed in preparation for planting *Acacia saligna* at Kendenup, WA (Photo: W. O'Sullivan).

Fig. 35. Low rainfall zone duplex soil being ripped and mounded in preparation for planting *Acacia saligna* at Bolgart, WA (Photo: D. Huxtable).

Studies have shown that crops adjacent to *A. saligna* belts show depressed yields. For example, a study in the Murray-Darling basin found that yields of barley, wheat and canola growing within 6 meters of a mature tree belt of *A. saligna* and *Atriplex nummularia* were depressed in most cases by 30-60% compared with the yield away from the belts (Knight *et al.* 2002, Unkovich *et al.* 2003). A study in Africa found that the yield of sorghum as sole crop was 6.6 tonnes/ha, where as the yield when sorghum was grown as an intercrop between rows of *A. saligna* spaced at 4 meter intervals was 0.7-1.4 tonnes/ha. If the *A. saligna* were pruned the yield was 5.3-5.7 tonnes/ha (Droppelmann *et al.* 2000a). The authors concluded poor yields were most likely due to a lack of available water to the intercrop as a result of the presence of trees.

After water, nitrogen is the key limiting factor in cultivated plant growth (Ramirez 1987), and there is ample evidence of the beneficial effect of crop rotations with N-fixing plants. Although the use of woody plants in this role is less common than that of herbaceous annuals, the effects on subsequent or companion crop growth are equally marked, and may afford additional advantages. Little data is available in the literature specifically dealing with *A. saligna* in this regard, but reports from other woody legumes, including other *Acacia* species, show that the value to subsequent crops in a rotation should be a consideration of any system evaluation. The tree crops functions of utilizing excess soil moisture, nutrient recycling, and erosion prevention are discussed elsewhere in this document. They may also contribute to weed suppression (Kwesiga and Coe 1994).

The work of Kwesiga and Coe (1994) shows significant increases in maize yields in plots fallowed with *Sesbania sesban*, against controls. Importantly, they also record that yields continue to increase for 2-3 years after the fallow crop, hypothesising that this is a result of delayed mineralisation of the below ground residues from the woody crop making nitrogen available over an extended time. These may be critical considerations for farming systems seeing rapidly increasing costs for external nitrogen fertiliser purchase and application. Such an effect is also acknowledged in forestry, where nitrogen is often a key limiter of productivity (Bormann and Gordon 1989). The role of *Acacia mearnsii* in this capacity is well established in southern Africa. Evans (1999) for example, in considering the sustainability of plantation forestry cites cases of tree crops benefiting from a previous rotation this species, and du Toit *et al.* (1999) discuss beneficial crop rotations of this *Acacia* with *Eucalyptus grandis* plantations.

Determining the impact of nitrogen-fixing woody plants on other species is especially complicated in systems where the plants are intercropped, rather than planted in rotation. In agricultural research, alley farming systems show high productivity gains from integrated belts of nitrogen fixing trees (Kang *et al.* 1984, Kass 1985), but generally such systems are intensely managed (for example; harvesting tree foliage to use as mulch), and are more common in high rainfall areas where water will be less limiting. In extensive forestry trials with a range of species across three different rainfall zones, Forrester *et al.* (2007) conclude that any positive benefit from the additional N supplied by the intercropping with N fixing species is overshadowed by limitations in other resources. This is supported by Hunt *et al.* (1998) who looked at the impact of naturally regenerating *Acacia dealbata* on planted *Eucalyptus nitens* productivity. In this case, there was a positive correlation between the amount of soil nitrogen and the density of the *Acacia*, but this did not increase growth in the *E. nitens*, due to competition for other resources. Somewhat contrary to these results is a report of research by Forrester *et al.* (2005), from a single high rainfall site which showed productivity in *Eucalyptus globulus* increased significantly over a 10 year period when interplanted with *Acacia mearnsii*, a result attributed to increased recycling of nutrients, especially N and P.

Evans (1999) makes the point that rainfall (and possibly stored moisture) on marginal sites is the key determinate of forestry productivity, and that generally foresters do not rely on soil moisture reserves or irrigation but seek to match crops with climatic conditions. This is not likely to be the case in the wheat-sheep agricultural zone of WA where rainfall alone is too low in most of the landscape to profitably grow woody crops in the current economic settings. Designing systems that profitably target the excess water in a low rainfall farming environment is a major challenge.

Fig. 36. Excavation showing a surface lateral root extending more than five meters from parent plant in a trial site near Lake Bryde, WA (Photo: D. Huxtable).

Surface water management

There is scope to design runoff irrigation systems that can supplement rainfall and increase *A. saligna* growth rates in WA. Such systems are used routinely throughout arid regions of Africa and the Middle East to improve the productivity of *A. saligna* (Abdelkdair and Schultz 2005, Droppelmann and Berliner 2003, Le Houerou 2002). Zegada-Lizarazu *et al.* (2007) measured biomass production in *A. saligna* plots under different levels of water application in the Negev desert. Plants with abundant soil moisture available maintained a steady growth rates through the summer months, whilst plants that depleted stored soil water through the summer had progressively reduced growth over this time. Where soil water was available, peak growth coincided with the hottest months. This finding, coupled with growth observations, supports the notion that in south western Australia *A. saligna* efficiently depletes finite soil water resources, which have accumulated over the winter months, in spring and early summer. Growth is likely to continue until the soil water reserves are depleted. Hence, the amount of soil water recharge and the soil water holding capacity of the root accessible soil profile are likely to be important determinants of above ground biomass production in runoff irrigated production systems.

A number of other studies in Africa and the Middle East investigating the growth of *A. saligna* have used water harvesting structures, however no un-irrigated controls have been used for comparison. A study in Ethiopia comparing the growth of *A. saligna* in two micro-catchments 25 and 100 m^2 in area found the above ground dry matter after 12 months to be 2.7 and 4.1 kg/tree respectively (Abdelkdair and Schultz 2005). A pot trial using 6 month-old *A. saligna* irrigated at 100, 75, 50 and 25% of transpirational demand found plant dry weight after four months growth to be 258.5, 212.5, 159.9 and 79.9 g/plant respectively (Nativ *et al.* 1999). Researchers in the Negev desert (nominally <100mm rainfall) planted *A. saligna* at three different densities (2520, 1330 and 830 stems per ha) in contained 0.1 ha catchments which were flood irrigated with the equivalent of 700mm of rainfall in a single annual event. The plots yielded between 2525 kg and 3104 kg dry wood from coppice above two meters high, averaged over two years (Sauerhaft 1997). Together these results provide further confirmation that whilst *A. saligna* can tolerate extremely low water availability, growth is substantially improved if transpiration demand is continually met. Hence, the species appears to be well equipped to use redistributed water in the landscape as part of an integrated recharge control strategy for salinity management. (The water use efficiency of *A. saligna* was earlier discussed in the "Root architecture and water use" section, pg. 32).

Many farmers in WA are familiar with surface water management structures such as grade and contour banks. However, there is little precedent for integrating surface water control structures with water delivery to woody crops. The potential for this concept is worth exploring further.

Weediness and geneflow

A. 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 which experience a Mediterranean-like 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 stabilisation 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), but despite considerable control efforts it is still common in the Northern, Eastern and Western Cape provinces of the country (Nkonki *et al.* 2003).

In a well constructed case study, Christodoulou (2003) shows that invasion by *A. saligna* into the Akrotiri salt marshes of southern Cyprus 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. Interpretation of aerial photographs shows the rate of incursion into the wetlands to be significant, with its spread aided by fire and human induced mechanical disturbance. Further work on biodiversity assessment in Cyprus shows that *A. saligna* has also been spreading in the semi arid zone (Kyriacou 2006). The report shows the species alters the nitrogen balance in the soil, and 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 it to dominate native vegetation after fire. Regeneration from suckers has also been recorded in Cyprus.

Where *A. saligna* has established as a weed it is difficult to control. 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. Old plantings of *A. saligna* could be difficult to remove and the species may become a volunteer in subsequent crops. The report recommended that any attempt to produce cultivars for South Australia should focus on reduced reproductive ability (i.e. low seed production, delayed time to seeding, reduced seed hardness, reduced suckering). Livestock grazing on young plants or regrowth may also provide an effective control. It is possible that the weediness of *A. saligna* could be reduced via the production of sterile triploids. This has been proposed for *Acacia dealbata* and *Acacia mangium* (Blakesley *et al.* 2002). Triploid strains could be developed by first producing tetraploids and then backcrossing these with diploids. It has been found that colchicine, a spindle inhibitor used to disrupt mitosis, can produce tetraploids in *A. dealbata* and *A. mangium* (Blakesley *et al.* 2002).

The totality of experience with translocating *A. saligna* suggests that extreme caution is advisable before introducing it into new locations. Future research directed at understanding and mitigating the major causes of weediness would be beneficial where the species is planted outside WA.

Within its natural range there is little risk of *A. saligna* becoming weedy, especially if utilisation is based on subspecies boundaries. A depth of observational experience by the authors and others has found little evidence of weediness in planted stands. However, because domestication activities will select for traits such as increased growth rates, greater tolerance of harsh environmental conditions and improved pest and disease resistance, consideration must be given to an increased weed risk developing concurrently with improved crop potential.

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. Co-adapted gene complexes could also be disrupted, affecting genetic diversity and potentially resulting in the spatial replacement of one plant group by another through hybridisation (Hufford and Mazer 2003, Mooney and Cleland 2001, Potts *et al.* 2003).

Studies of pollen-mediated gene flow using paternity analysis have confirmed the occurrence of inter-specific hybridisation between subspecies of *A. saligna* (Millar *et al.* 2007, Millar and Byrne 2007b). In these studies the majority of gene flow detected between *A. saligna* ssp. *saligna* and ssp. *lindleyi* occurred at short distances, up to 100 meters, although infrequent gene flow events were detected over distances up to 1500 meters.

The same work found differential levels of gene flow between the subspecies of *A. saligna*. Gene flow from populations of ssp. *lindleyi* to ssp. *saligna* was low, even though the subspecies were in close proximity at the study site. Gene flow in the reverse direction was more significant. Differences in the floral fecundity of these subspecies are believed to have contributed to this result. Gene flow between genetically divergent planted and wild populations may pose a problem for the maintenance of genetic diversity in small remnant natural populations and will need to be examined further. In assessing the impact of pollen-mediated gene flow between the subspecies it will be important to investigate the long term fitness of resulting hybrids. It should also be noted that a range of management options that aim to limit pollen-mediated gene flow from introduced populations into natural populations do exist (Potts *et al.* 2003), and these should be evaluated for *A. saligna*.

Conclusions and Recommendations

Acacia saligna has many desirable attributes that make it a candidate for domestication as a woody crop for the wheatbelt region in the south west of Western Australia.

Successful domestication will require a coordinated whole of industry approach. This will include biomass production, a harvest and supply chain delivering to processors, through to product science and marketing. Although the focus of this report is on primary production and biomass supply, it is imperative that priority setting and investment in research and development also take account of the industry required to process and market products from *A. saligna*.

Hence the domestication process will require:

1. Taxonomy: a sound understanding of the taxonomy of the species to provide the foundation for selection of germplasm

2. Genetic improvement: germplasm selection and initiation of breeding and seed production capability.

3. Agronomy: crop agronomy knowledge base (establishment and management) and the role of the crop in whole farm production systems

4. Supply chain: harvest and supply chain capability

5. Processing and product development: all the demand side including processing, product and market sectors

Domestication requires a coordinated strategy to determine investment priority. A wide range of potential priorities have been identified and discussed in this review. This concluding section of the review specifies only the major priorities for the domestication of *A. saligna*, and distils key recommendations for further investment in Research and Development.

1. Taxonomy

This has been completed and there is no immediate need for further work.

2. Genetic improvement

A. saligna has considerable diversity and its range extends over several botanical regions. There is potential to select and develop general cultivars, or site or purpose specific ones. Progeny experiments are now established in two very comprehensive collections. They provide a sound base for efficient definition of genetic variation, but they will age rapidly and their value will decline steeply over the next five years. They represent a significant investment, and assessment of important specific traits like productivity, form, coppice potential, phyllode digestibility and gall rust tolerance is a high priority. This will guide germplasm selection for the establishment of breeding populations.

Recommendation: Strongly support the work on assessment of performance in the existing progeny experiments.

3. Agronomy

A. saligna has many attractive agronomic attributes. The seed is relatively large, easy to collect, clean, store and techniques for establishment by direct seeding are well developed. It has good yield potential, grows rapidly and could be harvested in 4 to 5 year cycle. It is well suited to integration into dryland farming systems. As a legume it offers the potential for good biomass production with reduced nitrogen input even on poor soils. *A. saligna* performs strongly on sites where extra water is available. This suggests that it may grow best in belt systems or as a small block on selected moist sites.

A. saligna can be relatively cheaply established by direct seeding, but would be more cost effective if it was able to regenerate after harvest by root sprouting or coppice. The species does not reliably coppice, and the factors controlling this are poorly understood.

A. saligna is very susceptible to the native gall rust disease caused by the fungus *Uromycladium tepperianum* which reduces the productivity and longevity of the plants There may be cultural practices that could help manage the disease (e.g. narrow belt planting rather than solid block planting), but it is desirable to select for genetic resistance if possible.

Recommendation: Building on information from the existing progeny experiments, establish new experiments to develop knowledge about sprouting/coppicing ability, and about genetic resistance, or cultural practices, to control gall rust.

4. Supply chain

Development of a versatile woody crop harvester is underway in the domestication work on mallee eucalypts. This harvester will be designed to be suitable for harvest of a wide range of woody crops including *A. saligna*. Likewise the handling and transport components of the mallee supply chain will also be readily adaptable to other species. It is desirable to select for plant form that improves the ease of harvest in *A. saligna*.

5. Processing

The Search Project showed in laboratory scale tests that *A. saligna* wood had suitable properties for the manufacture of panel products. As the potential for development firms up it will be important to expand the intensity and range of laboratory testing to develop a better knowledge of wood properties. The progeny experiments can be used to determine the extent of variation that occurs. It would be desirable to then conduct operational scale manufacturing tests of panel products.

A. saligna phyllodes have potential for use as fodder and this could provide a revenue source competitive with the alternative use for bioenergy.

Recommendation: include tests of wood properties and phyllode nutritive value in progeny experiments, undertake operational tests of panel manufacture and fodder value.

Research priorities

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

1. Strongly support the work on assessment of performance in the existing progeny experiments.

2. Building on information from the existing progeny experiments, establish new experiments to develop knowledge about sprouting/coppicing ability, and about genetic resistance to, or cultural practices to control gall rust.

3. Include tests of wood properties and phyllode nutritive value in progeny experiments, undertake operational tests of panel manufacture and fodder value.

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3. Review of *Atriplex nummularia* (Old Man Saltbush) and its Potential for Domestication as a Fodder Plant in Australian Dryland Farming Systems

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Introduction

Atriplex nummularia (Lindl.) or more commonly Old Man Saltbush, is a native chenopod shrub species with a wide distribution through the arid lands of Australia. It is a productive and adaptable shrub widely utilised for forage on saline and non-saline land systems for over 150 years. Recent interest in Old Man Saltbush has increased as new landuse practices are sought for the marginal areas of the southern Australian agricultural zone that have been severely affected by drought and salinity. Internationally, it is now one of the most important perennial species for revegetation of low rainfall degraded areas (Alonso 1990, Le Houérou 2000 a,b) and to date, the use of halophytic plants such as *Atriplex nummularia* have promise for rehabilitation of saline land through their productive potential and ability to draw-down water tables (Barrett-Lennard and Malcolm, 1999, Barrett-Lennard *et al.* 2005).

Despite this increased interest, there are few commercially viable perennial-based farming systems for the lower rainfall wheat-sheep zone of southern Australia. The CRC Salinity FloraSearch project has identified Old Man Saltbush as having significant potential for broader application in a range of saline and non-saline agricultural areas. There is also strong community interest in emerging perennial based grazing systems in these regions with saltbush likely to be a key species. There is little history of domestication and significant gains in value are expected through a scientific approach to plant improvement. A current extensive germplasm collection has the potential to underpin exciting advances that can overcome the current limitations of Old Man Saltbush and enable its more widespead application to farming systems of the wheat-sheep zone of southern Australia.

In this review, we examine the existing literature on Old Man Saltbush and discuss the future potential of *Atriplex nummularia* for inclusion in a plant improvement program aimed at developing perennial-based fodder solutions to current and predicted degradation in the landscape. We define the desirable goals for such an improvement process and consider how these can be achieved in light of the currently understood challenges imposed by lack of knowledge and recognised limitations of the species. Our focus will be on the advancement of Old Man Saltbush as a fodder crop rather than a viable producer of woody biomass. We believe that as well as having adaptability to saline affected areas there is also promising potential for improved cultivars of Old Man Saltbush in non-saline low-medium rainfall areas.

Background

Dryland fodder production in southern Australia

Pressure for changes in land use management in the dryland agricultural and pastoral regions of Australia and other countries with similar climate conditions is arising from a range of environmental problems and changing market requirements for livestock products. Current climate change predictions suggest that increasing temperatures and changing rainfall patterns are likely to result in a combination of more intense rainfall events and harsher dry spells across many arid and semi-arid areas of the world (Hughes 2003, IPCC 2001, Lavorel *et al.* 1998, McKenzie *et al.* 2004, Mouillot *et al.* 2002). This has the potential to alter growing seasons, leading to productivity losses, increased sensitivity to disturbance, and altered vegetation composition (IPCC 2001). Dryland salinity is already a significant problem in many countries following excessive vegetation clearance for the introduction of annual cropping regimes (Clarke *et al.* 2002). Livestock production may also be affected as a result of increased grain prices and the reduced rangeland and pasture productivity (IPCC 2001). Pressure for change is also arising from a need to address growing resistance of stock to chemical anthelmintic drugs (Hordegen *et al.* 2003), as well as desire to reduce the use of antimicrobial drugs in livestock production. There is concern that antibiotics used in stock feed will lead to development of resistant organisms that could harm human health. The European Union has applied a total ban on antibiotics in stock feed and producers in other countries will be under pressure to follow suit to gain entry into European markets. These factors are stimulating research to develop new innovative farming systems that incorporate a much higher proportion of perennial species.

If we are to effectively limit these emerging impacts and embrace the associated challenges, we will need to adapt to these changing conditions through the development and application of new technologies and land management strategies. The uptake of new management strategies and technologies, however, has traditionally been slow (IPCC 2001) as landowners must be convinced that the benefits of adoption outweigh the costs of establishment and the risks of potential failure and lost opportunity. New advances would need to display the potential for positive financial returns and there must be a need that drives change (O'Connell *et al.* 2006).

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* (perennial halophyte shrubs in the family Chenopodiaceae) based on their ability to lower water tables, favourable habit, nutritive value, palatability, and ease of establishment. *Atriplex nummularia* Lindl. (Old Man Saltbush), is one particular species that has previously seen widespread usage. It is endemic to Australia in the 150 – 600mm rainfall zone and is well known for being tolerant of drought conditions and saline soils. It 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 exportation to many arid and semi-arid parts of the world, including extensive use for land reclamation and as fodder (Le Houérou 2000b).

Environmental benefits and services

Perennial fodder species have the potential to offer a range of environmental benefits, particularly when planted in those low rainfall areas that are marginal for cropping and/or are affected by dryland salinity. Benefits include the potential for lowering of water tables and stabilisation of strongly saline areas so that other pasture species can be planted (Barrett-Lennard 2002, Rogers *et al.* 2005), reduction of leakage and subsequent recharge of the water table (Barrett-Lennard 2002), stabilisation of degraded soil and prevention of erosion (Geddes and Dunkerley 1999), shelter for stock (Milthorpe *et al.* 2001), and enhancement of invertebrate diversity relative to cereal cropping areas (Lyons and Majer 1999). There can also be an increased productivity of marginal lands unsuitable for annual cropping through provision of a more reliable feed base in increasingly variable climates (i.e. as drought reserves and by filling the summer-autumn feed gap in annuals). These perceived benefits will help to provide the economic drivers considered necessary for widespread adoption by landholders (O'Connell *et al.* 2006). The challenge now lies in selecting the most appropriate fodder species for integration into these arid and semi-arid systems**.**

Atriplex nummularia as a domestication candidate

The past and existing usage of Old Man Saltbush highlights the already important role that this species plays in livestock production. However, whilst it has a long history of use in these areas, there has been limited data gathered on the genetic variation in natural stands of Old Man Saltbush and how this variation is expressed in the parameters that are important for acceptance and utilisation 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. A long history of grazing in the riverine plains in western New South Wales (NSW), for example, has resulted in the loss of much of the dominant *Atriplex nummularia* 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). While the extent of the genetic variability within and between populations is currently unknown there has been some international work done on the genetic composition of *Atriplex* suggesting significant levels of variability occur within and between populations. Bouda *et al.* (2006) used DNA molecular techniques to examine variability in a group of 8 Atriplex species from Morocco (including Old Man Saltbush) and found considerable diversity among species and also among some individuals from each species. Ortiz-Dorda *et al.* (2005) found similar variability within 51 populations of *Atriplex halimus* from the Mediterranean Basin using DNA molecular techniques. They differentiated two main groups which corresponded well with geographic distribution, but also found that 301 of the 306 individuals tested constituted an individual haplotype, signifying strong genetic diversity within and between populations. Twenty-five natural populations of *Atriplex titarica* displayed moderate levels of genetic diversity and low levels of inbreeding but significant differentiation amongst the populations. Genetic diversity was equivalent at the edges of the distribution and the centre (Mandak *et al.* 2005). If such genotypic variability is present in populations of Old Man Saltbush it will prove important for selecting those genotypes best adapted for the environments and fodder traits of interest and would suggests that examination of traits at the family level is warranted.

Taxonomy and Ecology

Species description

Taxonomy and 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). Common names include Old Man Saltbush, Giant saltbush and Cabbage saltbush. 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 (Fig. 37) (Cunningham *et al.* 1981). It is distributed through the more arid parts of eastern and central Australia. 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, also found in eastern and central Australia. 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. Its distribution is confined to Western Australia. The leaf petiole is indistinct in this subspecies with the leaves elliptic to obovate in shape and up to 2 cm across (Fig. 38) (Parr-Smith 1984).

Fig. 37. A 4-year old stand of *Atriplex nummularia* ssp. *nummularia* at Murray Bridge, SA.

Fig. 38. A mature *Atriplex nummularia* ssp. *spathulata* from Western Australia.

Distribution, ecology and biology

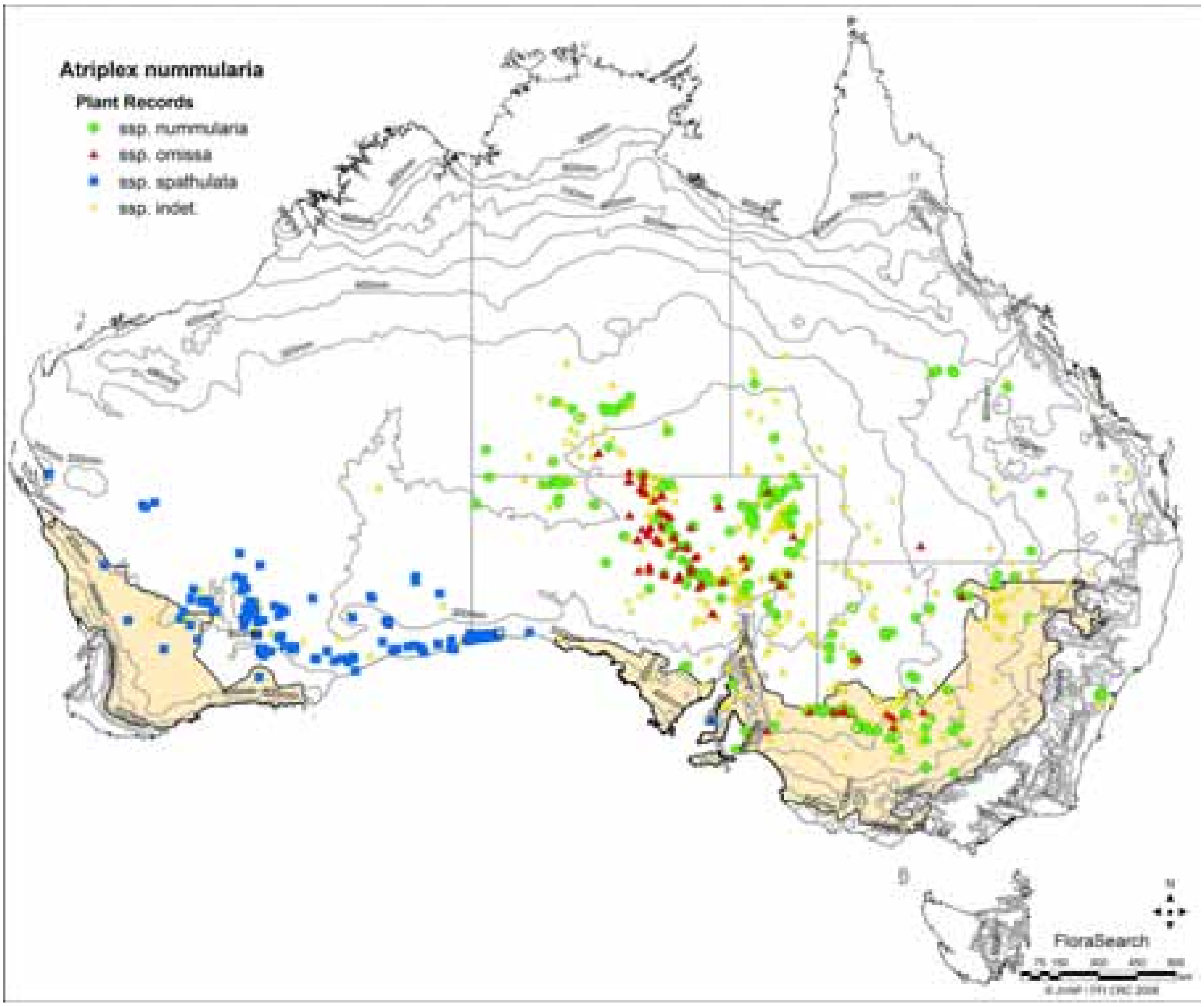
Species distribution

Australia

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 (Fig. 39).

In contrast, *A. nummularia* ssp. *spathulata* has a disjunct distribution from the other two subspecies, occurring primarily in the arid parts of Western Australia from the Nullarbor Plain in the east to the region around Shark Bay on the west coast (Fig. 39).

Fig. 39. Known distribution of the different subspecies of Old Man Saltbush compiled from herbaria records. Shaded region indicates the FloraSearch study zone.

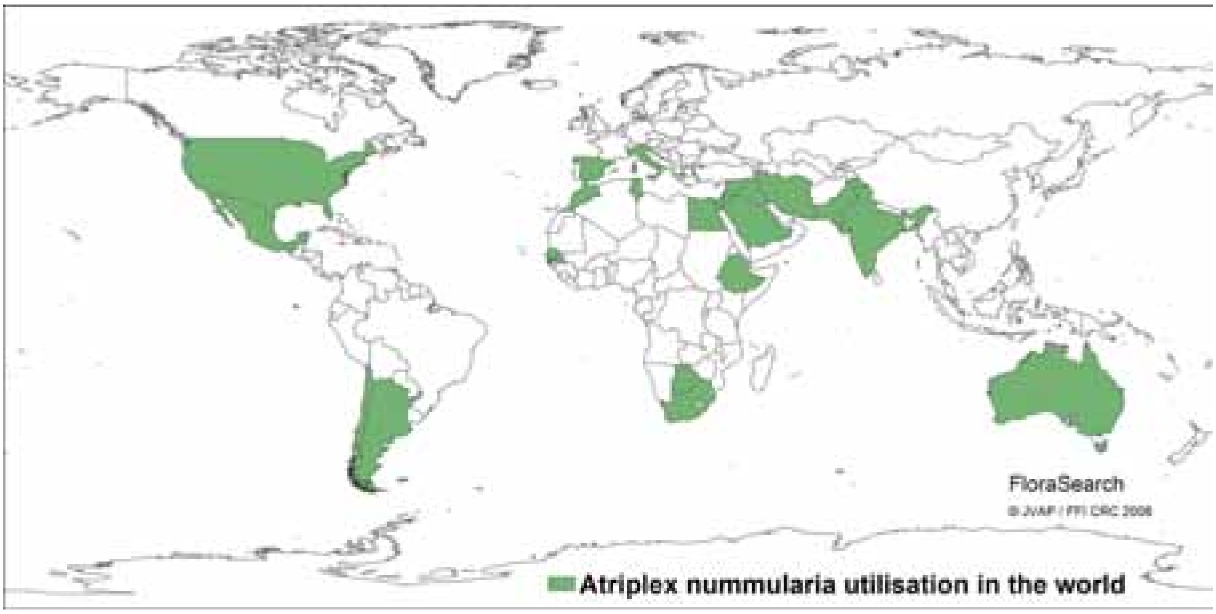


Overseas

Atriplex nummularia has also been planted extensively in other arid and semi-arid regions of the world (Fig. 40) with examples including those reported in Botswana (Aganga *et al.* 2003), Israel (Arieli *et al.* 1989, Benjamin *et al.* 1995), Syria (Jones and Arous 2000), Egypt (Abou El Nasr *et al.* 1996), Tunisia (Ben Salem *et al.* 2005, Ben Salem *et al.* 2002, 2004), Pakistan (Asad 2002, Khan *et al.* 2000), India (Lal 2001), Unites States (Watson 1990, Watson and O'Leary 1993), Chile (Alonso 1990, Ormazabal

1991), South Africa (van der Baan *et al.* 2004, van Niekerk *et al.* 2004c), Cape Verde Islands (Sandys-Winsch and Harris 1992), Argentina (Guevara *et al.* 2005, Guevara *et al.* 2003), Saudi Arabia (Hyder 1981, Khalil *et al.* 1986), Italy (Alicata *et al.* 2002), Ethiopia (Kaitho *et al.* 1996), Iran (Sameni and Soleimani 2007a,b), Iraq (Abdul-Halim *et al.* 1990), Morocco (Bouda *et al.* 2006, Chriyaa *et al.* 1997b), Senegal (Plenchette and Duponnois 2005), and Spain (Ortiz-Dorda *et al.* 2005, Ramos *et al.* 2004).

Fig. 40. World map indicating countries in which Old Man Saltbush is currently utilised.



Ecology

Climate and soils

Old Man Saltbush experiences a large range of temperature variation in its natural and naturalised ranges. It appears to have the ability to withstand moderate low temperature periods and frosts but sustained low temperature periods can be detrimental. Murad (2000) reported that Old Man Saltbush did not tolerate – 4^0C or below in Syrian steppe but others have reported greater tolerance of lower temperatures. Maiden (1894) noted that Old Man Saltbush was able to withstand minimum temperatures of –10^0C 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. Cold spells of greater intensity and duration can be detrimental to Old Man Saltbush survival. Davis (1981) found that Old Man Saltbush lacked the winter hardiness needed for Washington in Western United States, where winter temperatures were below freezing for up to 83 days in the November to March period with lows down to –20^0 C. All Old Man Saltbush plants in the study perished before the final samples could be taken. Old Man Saltbush was also found to be unsuitable for winter conditions in Spain (Enrique Correal, pers. comm.).

As well as a reasonable tolerance of cold temperatures, Old Man Saltbush is well known for its tolerance of drought conditions and high temperatures which can be 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 also has a high tolerance of saline conditions. In fact, low – moderate levels of sodium have been shown to enhance growth. Old Man Saltbush has the ability to actively synthesise compounds such as oxalates, betaines and prolines which assist in osmoregulation by increasing salt concentration in the cell sap (Leigh 1972).

A. nummularia ssp. *nummularia* and *A. nummularia* ssp. *omissa* can be found on a variety of soil types but primarily on the heavier clay and clay loam soils on alluvial plains (Fig. 41a) and on drainage depressions and sand dune swales (Fig. 41b) (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). Natural stands in western NSW have now been reduced to more relict areas as a result of intense grazing by cattle (Cunningham *et al.* 1981). Barson *et al.* (1994) tested predictions about the growth of Old Man Saltbush on cracking clays in Murray-Darling basin by comparison to field trials conducted in Western Australia and their models suggested severe limitations on cracking clays. They could not validate many of the predictions however because of a lack of trial data. Common vegetation associations are with black box (*Eucalyptus largiflorens*) and mulga woodlands (*Acacia aneura*) (Costermans 1981), and with *Acacia pendula* or *Atriplex vesicaria* (Leigh 1972).

A. nummularia ssp. *spathulata* grows on limestone plains and lake margins in alkaline loams and clay soils (Fig. 42a) (Mitchell and Wilcox 1994). Common vegetation associations include silver saltbush, bladder saltbush, pearl bluebush and it is common in the eucalypts of the goldfields gum belt (Fig. 42b) (Mitchell and Wilcox 1994).

There is very little published information on the population dynamics and community ecology of natural stands of Old Man Saltbush. Also this was also not one of the primary goals of this review, with focus instead being on the application of Old Man Saltbush to managed agricultural fodder systems rather than rangeland-type revegetation applications. The biodiversity benefits of Old Man Saltbush plantations in agricultural systems are soon to be addressed in a new FFI CRC project.

Biology

Reproductive 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 the winter and sets fruits in September and October that can be harvested easily (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 (Fig. 43a). The female flowers occur in dense clusters or singularly in leaf axils at the end of branchlets (Fig. 43b). Monoecious plants, as a rule, have a terminal inflorescence of male flowers and a variable number of female flowers in leaf axils lower down the stem (Fig. 44). Neither male nor female flowers have petals. The fruit consists of two paper-like bracteoles that can vary from smooth to prominently toothed along the edge with a hemispherical to rhomboidal outline (Fig. 45a). These bracteoles are pressed close together and house the seed at the base when present (Leigh 1972). It appears that fertilisation of the flower is not necessary for formation of the bracteoles, with up to 50% being seedless (Beadle 1952). Fruit production can be so prolific that branches may be bent to the ground or break under the weight (Fig. 45b).

It is not known whether the three sub-species of Old Man Saltbush hybridise naturally in areas where distributions overlap although hybridisation within the genus is common.

Fig. 41. Habitat examples for *Atriplex nummularia* ssp. *nummularia*.

A) Floodplain habitat and B) desert dune habitat

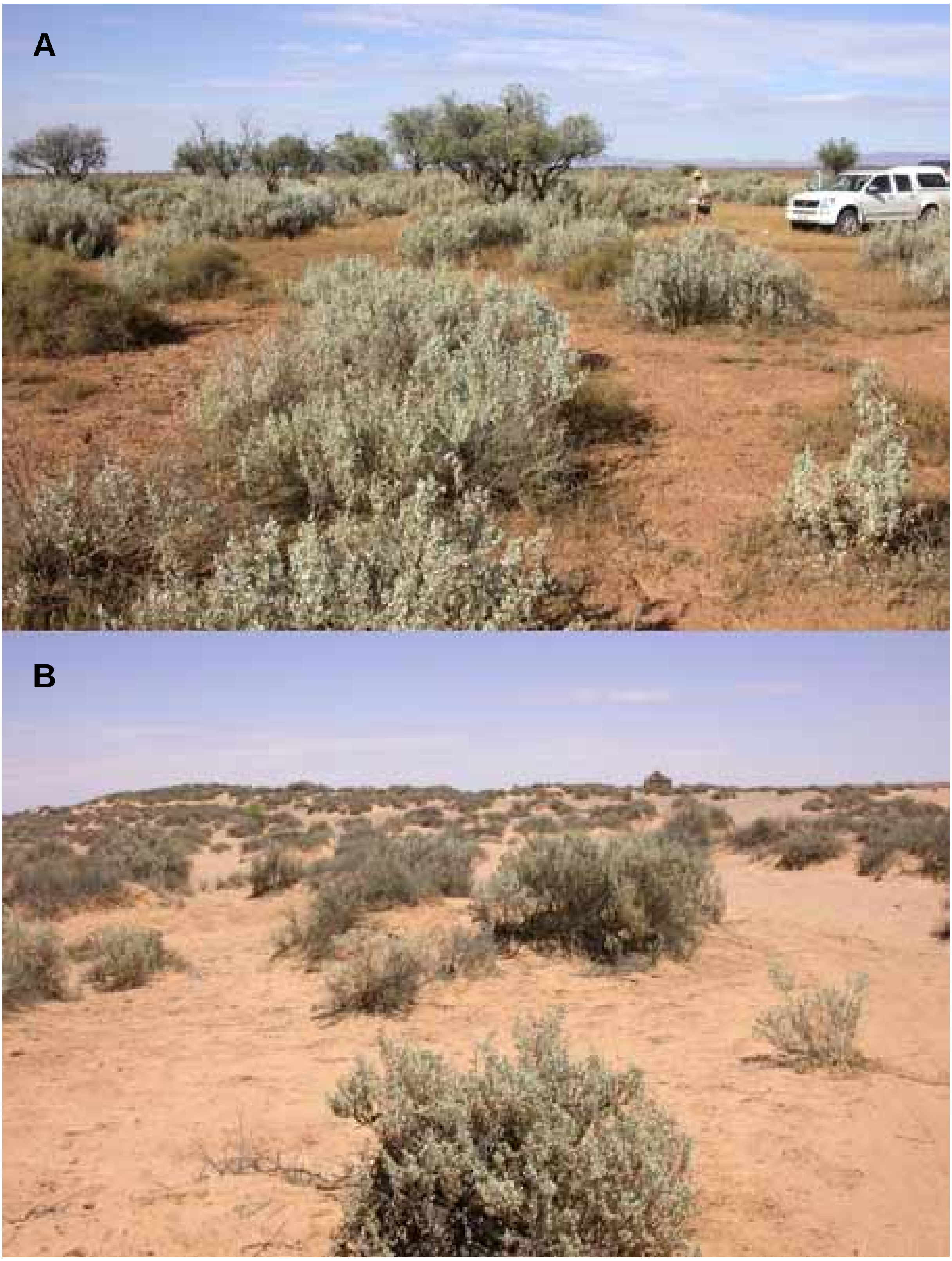

A
B

Fig. 42. Habitat examples for *Atriplex nummularia* ssp. *spathulata*.

A) Rangeland habitat and B) Woodland habitat

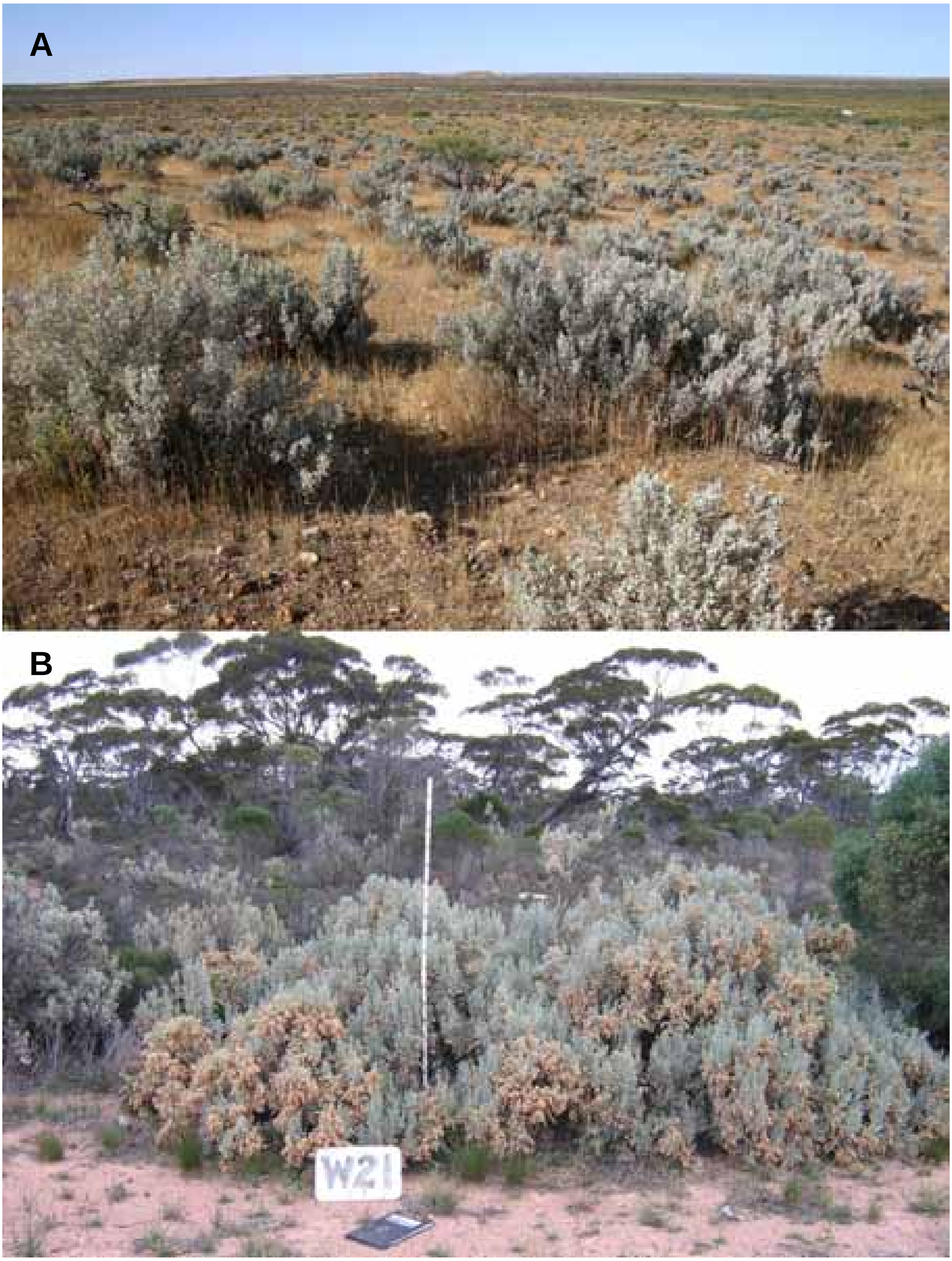


Fig. 43. Flower and fruit characteristics of Old Man Saltbush.

A) Male flower spikes, B) Female bractate flowers.

Fig. 44. Monoecious plant showing mature fruits in the leaf axils below the flower spike.

Fig. 45. ***Atriplex nummularia* fruits.**

A) Developing fruit with green bracts surrounding single seed. Note the sometimes prominently toothed margin, B) Mature fruit can form in dense clusters

Determination of the sex of individuals may not be as straight forward as was previously assumed if studies on other species in the genus are a guide. In *Atriplex cinerea* it was estimated that there is a 20 – 33% occurrence of monoecious plants in natural populations (Heyligers 2001). His analysis of herbaria specimens suggests that previously there may have been many monoecious plants where only branches with male flowers were collected due to the low numbers of female flowers present, subsequently leading to a misrepresentation of the rate of monoecy. Recent examination of a number of stands of Old Man Saltbush in South Australia suggest the percentage of monoecy is at least as high, if not higher, than seen in *A. cinerea* (D. McKenna Pers. obs.). Furthermore, Talamali *et al.* (2003) looked at flower morphology and sex determination in *Atriplex halimus* and found six different floral phenotypes including two forms of hermaphroditic flowers. McArthur *et al.* (1992) have alternatively considered floral phenotypes in *Atriplex canescens* as trioecious (having three sexual genders) and/or dioecious and having a "leaky genetical switch." Clones transplanted from three populations and grown in common gardens reveal the existence of two distinctly different genetic controls regulating gender expression. In some clones gender is fixed as male (staminate) or female (Pistillate), while in other clones gender varies, ranging from a mixture of male and female ramets to simultaneous hermaphrodites with various proportions of male and female flowers. For clones that vary their sex expression (sexual lability), variation occurs with irrigation treatments, between treatments and over time, as a consequence of the combined effects of genotype plus environment. The magnitude of sex change is also a product of the interaction of genetics and environment. Some clones have been repeatedly examined for 20 years. Sexual lability has also been observed in clones of *Atriplex amnicola* in WA, where the authors concluded it was age related phenomena rather than driven by environmental cues. The authors caution that lability needs to be considered when planting for seed production (Strawbridge *et al.* 1997). The presence of sexual lability and the level of monoecy in Old Man Saltbush has not been established but may have important implications for selections within a breeding program.

Growth phenology

Atriplex nummularia is a summer active C4 photosynthesis plant with the primary growth period in the spring and summer months. During winter there is a marked reduction in the allocation of biomass (Jones *et al.* 1970).

Root symbionts

Chenopods in general are considered to be infrequent hosts to arbuscular mycorrhizal (AM) fungi (Asghari *et al.* 2005). However, within the genus *Atriplex*, AM fungi have 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. They found that across the 9 species the percentage of AM infection was negatively correlated with soil salinity and nitrogen levels but positively correlated with soil phosphorous. There was an average infection rate of 32% and 45 AM spores/100g of soil across the nine species examined. The two Old Man Saltbush populations had 33% and 31% infection and 64 and 29 AM spores/100g of soil respectively. There was no investigation of the positive or negative effects of AM fungi inoculation on the growth of the saltbush species examined.

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. Subsequent experimental pot trials, where they inoculated seedlings grown in the glasshouse at two salinities (2.2 and 12 dS/m), 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. Inoculated seedlings were also significantly higher in phosphorous but the nitrogen levels did not change. The authors suggest that this is the first study to document significant growth benefits in *Atriplex* through inoculation with AM fungi.

Drew and Ballard (2007) conducted a pot trial where they germinated *A. nummularia* ssp. *spathulata* seeds in soil collected from under 3 natural stands of ssp. *nummularia*. They didn't use ssp. *nummularia* seed in combination with the soil from under ssp. *nummularia* and grew saltbush in the pots with sub clover *Trifolium subterraneum* rather than in isolation to see how the AM affected growth. They found that root disease was significant in the unsterilised soil resulting in significantly smaller root and shoot biomass compared to the controls. They also found that the 3-year old plantations had between 5 and 13% colonisation by AM fungi.

These examples suggest further investigation into the use of AM fungi for enhancing establishment and growth is warranted.

Longevity

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). The long-lived nature of well-managed stands means that the economic returns over time will more than compensate for the initial outlay of cost for establishment.

Water use

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. They found that the transpiration rate was small and at most times 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, which 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. Their study did not include an ungrazed control to compare the impact of grazing on water use but does suggest that the goals of grazing and site remediation are at odds. Ashby and Beadle (1957) looked at water use at a range of salinities in the glasshouse and found that the osmotic potential of Old Man Saltbush plants can be much higher than the solution they were grown in, especially for the low salinity control (30 times for control to 2x for highest salt). 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. Blott (2000) investigated the effects of mixed shrub belts (Old Man Saltbush, *Acacia saligna*, river saltbush) on water use and crop yield in belt systems at Walpeup Vic. She found drying of the soil profile at 250 – 550 cm under the shrub belts and out to 7m from the centre of the belts 3yrs after establishment. There was little change in moisture conditions under the crops away from the shrub belts but there was an associated reduction in the crop yield adjacent to these belts. The water use of Old Man Saltbush belts integrated with annual crops has also been investigated at a number of other sites in south eastern 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). Unkovich *et al.* (2003) planted mixed rows of *Acacia saligna* and Old Man Saltbush and looked at water use and competition with inter row crops. At the dryer sites, once the water under the belts had been used there was increased competition with the crops leading to a reduction in the crop yield of 45% in the 9m adjacent to the belt. Water use under the belts in the 0 – 5.5m zone varied from 209mm to 636mm depending on the site and year.

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).

Work on the water use of a number of other *Atriplex* species revealed that over a 2-year period there was a substantial increase in soil chloride concentration beneath the plants (Barrett-Lennard and Malcolm 1999). Increase in soil and groundwater conductivity was proportional to the leaf density and indicated about 60 – 100 mm of groundwater was used over the two-year period.

Glenn *et al.* (1998) found that the evapotranspiration (ET) of Old Man Saltbush irrigated with saline cooling tower blowdown water was not significantly different to that when irrigated with non-saline pond water. *Atriplex nummularia* had higher productivity, water use efficiency and consumptive water use than many conventional forage crops in Arizona irrigation districts. In contrast, Miyamoto *et al.* (1996) also looked at ET when irrigated with water of increasing salinity up that of sea water, and found that ET decreased significantly with increasing salinity of the irrigation water.

Utilisation

Historical use

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). The extent to which this reduction in saltbush numbers and rangeland condition resulted in loss of favourable genotypes is unknown. In particular, the prolonged drought of the 1890's saw grazing pressure increase significantly on the natural stands of saltbush (Peacock 1901, Peacock 1904). 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).

Following these drastic reductions in numbers it was recognised by some that there was a need to manage stands of *A. nummularia* (Peacock 1901) and it was questioned why its value was not more fully appreciated by stockowners (Anonymous 1895, Holdsworth 1903). After the failure of the grasses and herbage in the drought it was proposed that saltbush had the potential to future-proof properties if existing plants could be conserved and enclosed, and that cultivated saltbush could provide the most profitable form of fodder relief in drought times (Anon 1895, Kelly 1902, Peacock 1901, 1904). It was also recognised that stands of Old Man Saltbush provide shelter for animals and have 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). Kelly (1902) noted that Old Man Saltbush was recognised as the best variety as it produces more fodder, is deep rooting and very drought resistant, although stock prefer grasses and herbage when present. His suggestion was that a few hundred acres would be invaluable in the drought times.

Early reports suggest that distribution of germplasm and propagules was generally of those sampled from a limited number of genotypes. Maiden (1894) recounts a report from the *Agricultural Journal* of May 1893 in which a small amount of Old Man Saltbush seed from Baron Von Mueller was used to grow the source plants for the whole of the Orange Free State and Transvaal in South Africa. As further testament to the way that early propagation and dispersal was conducted Maiden also recounts that one plant of *A. halimoides* was the mother plant for all of the other *A. halimoides* plants in the country. Similar methods of distribution from limited source stocks were conducted for Old Man Saltbush in the early 1890's in India (Maiden 1894). In Australia, the manager of the Wagga Wagga experimental farm in NSW reported that he was only able to get a few plants that were delivered from the far west of NSW to grow. From these he propagated a large number of cuttings, stating that 25 – 30 plants provided sufficient cuttings to plant out an acre. Attempts at broadcast seeding were not successful (Valder 1896).

Overseas use

As discussed previously, 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. Many of these introductions have occurred on a large-scale basis. 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 these regions 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). Other uses have included the disposal of saline waste water through the irrigation of plantations of old Man Saltbush (Glenn *et al.* 1998, Watson *et al.* 1994). The widespread up take in these areas and the continuing need to supply fodder suggest significant benefits could be achieved in these areas with the introduction of improved germplasm.

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). If selections of Old Man Saltbush are to be made then it will be important to have a better understanding of these different components and what constitutes the fodder value of a crop.

Digestibility

An important determinant of the intake of forage by livestock is the level of dry matter digestibility (DMD). 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). Fodders with levels of DMD 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. A number of *in vitro* (laboratory) techniques have been developed to predict *in vivo* (in the animal) digestibility and ultimately the energy value of a feed. These include digestion in rumen fluid, production of digestive gases during fermentation and disappearance of material from an enzyme mixture (van der Baan *et al.* 2004). The documented measures of the *in vitro* digestibility of Old Man Saltbush provided by these techniques range from 52.9 –77.8% (Table 1), with leaf material having about twice the digestibility of the stems (Warren and Casson 1996). The NDF and lignin content of Old Man Saltbush, at 30 – 55%, is similar to that of most hays and other green forage (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. Despite recent advances in animal nutrition and plant physiology, however, there is not always a direct relationship between measured attributes and their value to stock (Islam and Adams 2000). In reality, none of these prediction methods are perfect and all need to be calibrated to *in vivo* data (usually using standard calibration samples). For most traditional types of feed (for example oaten hays) these calibrations are widely available and fairly accurate. 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.

Measuring the energy value of saltbush is therefore problematic. One of the main reasons that caution is needed when calculating the metabolisable energy is the high concentrations of ash it contains (up to 35%), which has no apparent energy value (Masters *et al.* 2005). Therefore, values for dry matter digestibility need to be corrected for this ash content, something that has not always been done in the literature (Masters *et al.* 2001). Masters *et al.* (2001) suggested that organic matter digestibility (OMD) or digestible matter in the dry matter (DOMD) are more indicative measures of the available energy content of a feed. However, Wilson (1977) examined the relationship between digestibility and organic matter intake and found that there was no correlation between the two, suggesting digestibility alone is a poor indicator of fodder value. He noted that the sheep do not rely on a single plant species in the field when other fodders are available and it may be that consumption of other species in the diet avoids realisation of the full impact of the anti-nutritive components of the feed. So, as well as the need to improve digestibility, there is a need to consider the other components of the feed.

Nutrient composition

One of the major indicators of the nutritive value of a fodder is its protein concentration (Islam and Adams 2000) which is conventionally calculated by multiplying the total nitrogen concentration by a factor of 6.25. The quoted values for protein concentration in Old Man Saltbush range from 8.3% to 27.0% with an average of 15.4% (Table 1), which sits 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. 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.

Aside from protein there are a number of important elements required for animal health. An in depth discussion of the role of these different dietary elements is beyond the scope of this review but is discussed thoroughly in Freer *et al.* (2007). In general though, 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 (Table 2). Van Niekerk *et al.* (2004b) examined mineral composition of Old Man saltbush in South Africa and found Ca, Mg, Zn and Mn were in sufficient concentrations to meet nutritional requirements. Levels of P and Se were variable depending on the site where the plants were grown. The way that animals combine a range of beneficial minerals through selection of complementary feed sources is also not currently understood. Potential exists for the use of Old Man Saltbush as a feed source that supplements a range of minerals that are lacking when annual feed is deficient.

A more recent discovery is that Old Man Saltbush is high in Vitamin E that may help to protect browsing animals from nutritional myopathy and also may improve the colour and shelf life of the meat (Pearce and Jacob 2004). As with most of the other nutritional aspects there needs to be further investigation into the variation in vitamin E contents before its potential for improvement can be assessed. An effectively improved cultivar could reduce the need for vitamin supplementation.

Islam and Adams (2000) found seasonal variation in nitrogen, phosphorous and cations in Old Man Saltbush in WA and El-Shatenawi and Abdullah (2003) examined the seasonal variation in nutritive and mineral content in a winter dominant rainfall area of Jordan. They 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. Na was not significantly different through the season but did show a trend of increasing during the dry summer months. Ca and Mg values did not differ significantly throughout the year.

Table 8. Nutritive components and digestibilities for Old Man Saltbush fodder samples recorded from Australian and international studies.

DM = dry matter, OM = organic matter, CP = crude protein, NDF = neutral detergent fibre, ADF = acid detergent fibre, DMD = dry matter digestibility, and OMD = organic matter digestibility.

Table 8. Nutritive components **Author(s)**	**Country**	**DM (g/kg)**	**OM (%DM)**	**Ash (%DM)**	**CP (%DM)**	**NDF (%DM)**	**ADF (%DM)**	***in vivo* DMD**	***in vivo* OMD**	***in vitro* DMD**	***in vitro* OMD**	**Comments**
Guevara *et al.* 2005	Argentina		74.7	25.3	13.6						47.0	70% leaves & 30 % twigs
Dixon 1880	Australia			31.3	16.4							
Franklin McEvoy *et al.* 2007	Australia				10.7	29.9				72.0		pepsin cellulase
Norman *et al.* 2004a	Australia			28.0		22.0	8.1					
Norman *et al.* 2004b	Australia			28.0	15.4	30.5	17.1				59.1	mean of 4 most preferrred
				26.3	12.7	31.2	17.9				60.6	mean of 4 least preferred
Tiong *et al.* 2000	Australia			29.1	15.6	25.2	13.4		62.0		41.9	mean of 5 sites
Warren & Casson 1993	Australia							67.0				WA2
								54.0				WA3
								83.0				Vic
								70.2				leaf
								40.4				stem
								72.1				leaf
								40.2				Stem
								48.3				stem
				22.4	11.3	43.5		80.0				
Wilson 1966a	Australia				27.0					52.9		
					17.0					68.0	65.0	
					20.8					74.0	67.0	
					18.8							
Wilson 1966b	Australia	190.0										Combined leaf and stem
		260.0										Combined leaf and stem
		230.0										Combined leaf and stem
Wilson 1977	Australia		70.5	29.5	20.6	32.4	14.1		86.3		68.8	Faecal analysis & Terry/Tilly methods

Table 8. Nutritive components Author(s)	Country	DM (g/kg)	OM (%DM)	Ash (%DM)	CP (%DM)	NDF (%DM)	ADF (%DM)	*in vivo* DMD	*in vivo* OMD	*in vitro* DMD	*in vitro* OMD	Comments
Abou El Nasr *et al.* 1996	Egypt	386.0		24.9	12.7	59.4						
El-Hyatemy *et al.* 1993	Egypt			22.8	17.5							
Hassan & Abdul-Aziz 1979	Egypt			25.0	18.9				72.1			Fresh leaf
Kaitho *et al.* 1996	Ethiopia	212.0										
Konig *et al.* 1990	Ethiopia			25.2	10.5							
Howeizeh & Salehi 1999	Iran			11.4	11.6	51.0	37.0					
Koocheki 2000	Iran			28.5	23.5					77.8	68.8	Method digestibility unknown
Al-Charchafchi 2001	Iraq			25.5	14.5							Spring
				21.3	12.7							Autumn
Benjamin *et al.* 1995	Israel			28.3	18.7			53.8	51.0	73.0	59.0	
								53.8	51.0	66.0	63.0	
Abu-Zanat & Tabbaa 2006	Jordan			25.2	12.8	40.7	27.5					Leaf & Twig cuttings
Abu-Zanat 2005	Jordan		76.2	23.8	13.8	34.7	22.3	36.4	40.1			
El-Shatnawi & Abdullah 2003	Jordan				17.7							Winter
Chriyaa *et al.* 1997a	Morocco			30.8	13.7	34.8	15.2					
Chriyaa *et al.* 1997b	Morocco		68.7		13.4	34.2	14.4	63.1				
Hyder 1981	Saudi Arabia			27.2	16.3							
khalil *et al.* 1986	Saudi Arabia			24.3	25.2		15.5			76.0		
Mirreh 1996	Saudi Arabia		71.7	28.3	18.1							Leaves
			87.2	12.8	8.3							Twigs
van der Baan *et al.* 2004	South Africa								34.2		39.5	
											38.2	
											30.8	
											34.0	
											36.9	
S-Colomer & Passera 1990	Spain		76.4	23.6	17.0	44.7	28.5					Spring
			70.9	29.1	13.8	32.4	19.2					Summer
			68.0	32.0	17.5	34.8	21.1					Fall
			70.4	29.6	18.7	21.4	11.5					Winter

Table 8. Nutritive components Author(s)	Country	DM (g/kg)	OM (%DM)	Ash (%DM)	CP (%DM)	NDF (%DM)	ADF (%DM)	*in vivo* DMD	*in vivo* OMD	*in vitro* DMD	*in vitro* OMD	Comments
			74.5	25.5	13.2	31.2	16.2					
			72.7	27.3	15.9	36.1	15.1					
			78.6	21.4	20.3	40.7	21.4					
Gonzalez-Lopez *et al.* 1990	Spain	343.0	76.4		17.0	44.6						
Ben Salem *et al.* 2002a	Tunisia	270.0	91.3		16.9	44.2						Ave of 9 samples
Ben Salem *et al.* 2002b	Tunisia	301.0	77.3		19.0	43.9						
Ben Salem *et al.* 2004	Tunisia	286.0	74.5		17.8	44.5	22.5					Ave of 8 samples
Ben Salem *et al.* 2005	Tunisia	289.0	77.2		17.1	52.1			70.3			Ave of 8 samples
Davis 1981	USA				11.6							Plant1 Aug
					12.8							Plant2 Aug
					12.4							Plant3 Aug
					9.4							Plant1 Dec
					9.5							Plant2 Dec
					10.5							Plant3 Dec
Watson & Oleary 1993	USA			18.1	9.2	49.7	33.7					Cut 1 4.5 months
				24.7	13.1	40.5	24.3					Cut 2 13 months
				22.0	9.1	48.9	31.7					Cut 3 16.7 months
				22.3	8.5	47.2	30.6					Cut 4 27 months
Watson 1990	USA			29.4	18.6	40.9	22.4					
Watson *et al.* 1987	USA			27.6	16.7	40.6	27.5					12 weeks after transplant
				19.8	12.3	53.2	38.0					22 weeks after transplant
				15.4	10.1	53.9	36.7					30 weeks after transplant
				26.6	20.8	33.5	20.8					12 weeks after fist clip
				21.9	12.9	43.4	27.2					22 weeks after fist clip
				18.9	10.1	46.9	30.2					30 weeks after fist clip
				22.4	13.6	46.0	30.1					22 weeks after second cut
				22.6	13.3	41.5	16.4					26 weeks after second cut
Kessler 1990	Yemen	330.0	72.0		16.0							
Average		281.5	75.2	24.7	15.2	39.7	22.4	58.6	58.4	70.0	52.0	
Minimum		190.0	68.0	11.4	8.3	20.7	8.1	36.4	34.2	52.9	30.8	

Table 8. Nutritive components **Author(s)**	**Country**	**DM (g/kg)**	**OM (%DM)**	**Ash (%DM)**	**CP (%DM)**	**NDF (%DM)**	**ADF (%DM)**	***in vivo* DMD**	***in vivo* OMD**	***in vitro* DMD**	***in vitro* OMD**	**Comments**
Maximum		386.0	91.3	32.0	27.0	59.4	38.0	83.0	86.3	77.8	68.8	

Table 9. Mineral composition of Old Man Saltbush fodder samples recorded from Australian and international studies. Values are expressed on a dry matter basis

Table 9. Mineral composition **Author(s)**	**Country**	**Ca (%)**	**P (%)**	**Na (%)**	**K (%)**	**Cl (%)**	**Mg (%)**	**Fe (mg/kg)**	**Cu (mg/kg)**	**Zn (mg/kg)**	**Mn (mg/kg)**	**Oxalate (%)**	**Comments**
Guevara *et al.* 2005	Argentina			5.60		7.70							70/30% leaves & twigs
Franklin McEvoy *et al.* 2007	Australia	6.30		7.90									
Norman *et al.* 2004b	Australia	0.77		7.25	3.63	11.76	0.77	189.50		18.84	146.86	3.29	mean of 4 most preferrred
		0.73		6.89	3.83	11.64	0.78	178.40		19.61	170.17	2.97	mean of 4 least prefered
Warren & Casson 1996	Australia			5.70	1.90	7.90							
Wilson 1966b	Australia			5.50	2.10							5.80	Combined leaf and stem
				8.20	2.70								Combined leaf and stem
				6.20	2.80								Leaf
				2.60	1.70								Stem
				6.40	2.60								Leaf
				2.40	1.50								Young stem
				0.80	0.70								Old stem
El-Hyatemy *et al.* 1993	Egypt	1.26	0.02	6.13	1.27								
Hassan & Abdul-Aziz 1979	Egypt			7.80									
Al-Charchafchi 2001	Iraq	1.20		5.91	2.80	7.24	4.64						Spring
		0.64		3.89	2.28	7.06	4.28						Autumn
Abu-Zanat 2005	Jordan	1.21	0.11	5.94									
Alazzeh & Abu-Zanat 2004	Jordan	0.12	0.04						10.10	53.80	34.30		Leaf & Twig cuttings
El-Shatnawi & Abdullah 2003	Jordan	0.58	0.20										winter
Chriyaa *et al.* 1997a	Morocco	0.69	0.05		1.11		0.21	602.10	4.80	27.80	65.20		
khalil *et al.* 1986	Saudi Arabia	1.44	0.24	4.85	2.49		0.76	420.00	24.00	54.00	74.00		

Table 9. Mineral composition Author(s)	**Country**	**Ca (%)**	**P (%)**	**Na (%)**	**K (%)**	**Cl (%)**	**Mg (%)**	**Fe (mg/kg)**	**Cu (mg/kg)**	**Zn (mg/kg)**	**Mn (mg/kg)**	**Oxalate (%)**	**Comments**
Mirreh 1996	Saudi Arabia	1.40	0.31	5.66	4.86								Leaves
		1.08	0.18	1.60	2.74								Twigs
Colomer & Passera 1990	Spain		0.19										Spring
			0.14										Summer
			0.12										Fall
			0.37										Winter
			0.11										
			0.18										
			0.39										
Ben Salem *et al.* 2002a	Tunisia	5.49	0.09	4.00			0.50						
Ben Salem *et al.* 2002b	Tunisia	3.10	0.10	4.20			0.50					3.70	Ave of 9 samples
Ben Salem *et al.* 2004	Tunisia	1.36	0.18	4.70	2.89		0.84	285.10	13.00	47.00	56.50		Ave of 8 samples
Ben Salem *et al.* 2005	Tunisia	0.35	0.27	8.03	1.98		0.56	5.94	27.84	12.31	147.91		Ave of 8 samples
Davis 1981	USA											8.80	Plant1 May (6weeks)
												8.20	Plant2 May (6weeks)
												4.70	Plant3 May (6weeks)
												2.90	Plant1 Aug
												2.50	Plant2 Aug
												3.70	Plant3 Aug
Watson *et al.* 1987	USA	1.13	0.11									9.07	12 wks after transplant
		0.92	0.11									4.21	22 wks after transplant
		0.63	0.09									2.81	30 wks after transplant
		1.26	0.13									4.55	12 wks after fist clip
		0.94	0.13									4.67	22 wks after fist clip
		0.81	0.10									3.78	30 wks after fist clip
		0.93	0.12									3.11	22 wks after 2nd cut
		0.90	0.13									1.92	26 wks after 2nd cut
Watson *et al.* 1993	USA							553.00	6.00	35.00	59.00		Cut 2 13 months
								313.00	4.00	25.00	32.00		Cut 3 16.7 months
								308.00	4.00	31.00	41.00		Cut 4 27 months
								391.00	5.00	30.00	44.00		Ave of regrowth
Average		**1.41**	**0.16**	**5.28**	**2.41**	**8.88**	**1.38**	**324.60**	**10.97**	**32.21**	**79.18**	**4.48**	

Table 9. Mineral composition

Author(s)	Country	Ca (%)	P (%)	Na (%)	K (%)	Cl (%)	Mg (%)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Mn (mg/kg)	Oxalate (%)	Comments
Minimum		0.12	0.02	0.80	0.70	7.06	0.21	5.94	4.00	12.31	32.00	1.92	
Maximum		6.30	0.39	8.20	4.86	11.76	4.64	602.10	27.84	54.00	170.17	9.07	

Secondary compounds

Salt

As previously discussed, the ash content of Old Man Saltbush can be up to 30% and is predominantly composed of sodium, potassium and chloride (Masters *et al.* 2005). 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 (1966a) 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). MacFarlane *et al.* (1967) examined the water metabolism of Border Leicesters and Merinos feeding on a pure stand of *Atriplex nummularia.* Water consumption increased markedly, with both breeds consuming about twice that of sheep on the control diet. These effects proved to be breed specific with the Leicesters having higher water consumption than Merinos.

The inclusion of 150g day^{-1} of salt in the diet, and the associated 2 litre increase in water consumption reduced residence time of the feed in the rumen of sheep by up to 40% (Hemsley *et al.* 1975). This can have beneficial effects for wool growth because the reduced residence time in the rumen means less protein degradation and a greater proportion of amino acids going though for absorption in the small intestine, which is an important factor in wool growth (Hemsley 1975). Unfortunately, Hemsley (1975) suggests that such benefits may only be realised in diets that are very high in protein because depressed food intake as a result of the salt may lead to insufficient energy intake by the sheep. Hemsley *et al.* (1975) found that 150g/day salt load resulted in 24% decrease in organic matter digestion but protein digestion decreased by only 10%. A more 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.* 2005). 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. Arieli *et al.* (1989) suggested that the low energy realisation on saltbush was related to low digestibility and increased energy expenditure to metabolise minerals in the rumen. They suggested that efforts should be made to lower the mineral content of the shrub.

Betaines

Saltbushes have the ability to accumulate inorganic ions 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. Glycinebetaine is a tri-methyl nitrogen compound that is synthesized in the cytoplasm and plays a major role in osmoregulation (Masters *et al.* 2001). Tiefert (1989) found that glycinebetaine made up about 45% of the non-protein nitrogen, or around 20% of the total N in Old Man Saltbush plants. As salinity increases, levels of glycinebetaine increase progressively (Khan *et al.* 2000). There is some evidence that inclusion of betaines in the diets of ruminants will lower fat deposits in the tissues (Fernandez *et al.* 1998).

Oxalates

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% in a study by Davis (1981). Watson *et al.* (1987) also found that young plant material had oxalic acid concentrations of 9.07%, which decreased to 2.8% in older plants. Measurements from 5-year old plants from two sites in South Africa revealed oxalic acid levels of 3.26%and 3.51% (van Niekerk *et al.* 2004a). Abu-Zanat *et al.* (2003) examined seasonal and age related oxalate levels and found that mean levels for the spring were 7.62% and for the fall were 4.78%. Once again the levels were highest in young seedlings compared to 5 – 10 year old plants. New regrowth following clipping of older plants had similar levels to the pre clipping measurement for these individuals. Wilson (1966b) measured oxalic acid concentrations of 5.8%. 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.

Palatability, voluntary intake and learned behaviour

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). Grazing trials in other saltbush species such as *Atriplex vesicaria* have shown that Merinos preferentially graze female plants over male and bisexual plants in South Australia (Walsh *et al.* 2005). Male plants with fewer flowers were also eaten in preference to those with dense flower spikes. Interestingly, manual removal of flowers by the researchers did not change the selection process of the sheep, which also preferred female plants with very low or very high fruit densities over those with intermediate fruit densities. The authors found that morphological aspects of the plants such as growth habit and foliage density did not have a consistent influence on grazing, and suggested chemical differences between sex phenotypes as a possible causal factor for grazing preference (Walsh *et al.* 2005).

Prior grazing history of a population has also been found to provide significant differences in palatability. Plants from *A. vesicaria* populations that had an extensive history of grazing proved to be less palatable than plants from a population with a limited grazing history. Variation in palatability was also higher in the populations with an existing history of grazing (Pearson *et al.* 1990).

Palatability trials for Old Man Saltbush are limited in number but it was placed in the highly acceptable category in a palatability trial of multipurpose tree species in Ethiopia (Kaitho *et al.* 1996). 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. At this stage it is still necessary to conduct feeding trials and make observations of preference.

If available, sheep will select low salt rations to compensate for salty water or saltbush diets (Wilson 1968). This was supported by research using carbon isotopes that measured diet selection and revealed sheep choose a combination of high and low salt components in the diet to balance the need for nutrients versus managing salt intake (Filmer and Thomas 2006). If Old Man Saltbush is to be used as a component in a forage system then it may not be appropriate to select the most highly palatable individuals for improvement, particularly if the other fodder within the system is important for ensuring maximal energy intake (see next section of this report), but is of only moderate palatability.

Energy supplementation

Even from the early days of saltbush grazing there were qualitative reports that sheep fed exclusively on Old Man Saltbush did not fare as well as those on a mixture of saltbush and other fodders combined (Peacock 1901). This has led to suggestions that it is 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. The supplementation strategy is aimed at increasing the use of available nutrients in the rumen. 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. While the initial feeding trials suggested that a saltbush diet was sufficient to maintain weight or even produce some weight gain (Wilson 1966b), it was later shown that this can be attributed to increased consumption and retention of 10 – 15% more water in the carcass than in control sheep (Warren and Casson 1996, Warren and Casson 1994, Warren *et al.* 1995). Pearce *et al.* (2004) also found that lambs grazing saltbush prior to transport and slaughter were more hydrated, with reduced carcass shrinkage and better returns to processors than those finished off on stubble.

There is now a growing body of literature on the use of saltbushes with supplementation from other energy sources. Hassan and Abdel-Aziz (1979) fed rams straight saltbush diets or saltbush with the addition of 50, 100, or 150 g barley grain per day. Those on saltbush lost 80g/day. The addition of 100g barley per day resulted in significantly less weight loss, and 150g/day resulted in weight gain of 62.5g/day over the trial. The addition of the barley significantly increased the organic matter derived from saltbush in a linear fashion and increased digestible crude protein intake. The level of faecal and urinary nitrogen significantly decreased with the addition of 150g/day of barley, indicating increased nitrogen retention and utilisation from the feed. 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 western Australia. Sheep in this trial performed significantly better on Old Man Saltbush than on *Atriplex amnicola.* In Tunisia, Ben Salem *et al.* (2005) monitored the behaviour of grazing Barbarine lambs on Old Man Saltbush only and Old Man Saltbush + 400g barley grain or Old Man Saltbush + *ad libitum* cactus pads. Without supplementation they spent 55% of time foraging on saltbush and 27.3% foraging on other vegetation. Supplemented sheep spent more time foraging on other vegetation than Old Man Saltbush. The Old Man Saltbush only sheep lost weight at 35g/day whereas the barley and cactus supplemented sheep increased in weight by 67 and 20g/day respectively. The N balance was negative for the Old Man Saltbush diet and positive for the other 2 diets with barley 3 fold that of cactus. 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. Similar results to these have also been found in feeding trials using other species of *Atriplex* (Warren and Casson 1996, Warren *et al.* 1990, Warren and Casson 1994, Warren *et al.* 1995).

The majority of the feeding trials have used barley grain as a supplement for Old Man Saltbush diet. du Toit *et al.* (2004) found there is an optimum level of barley supplementation above which the benefits are reduced. Addition of 15% of barley and maize gave the highest incremental increase in DM and NDF digestibility. Negative effects were seen when they went above 30% supplementation in the diet.

Rather than using Old Man Saltbush as a primary fodder that is supplemented with alternative energy sources, its use as a N supplement for lower quality feed has been investigated internationally (Abu-Zanat and Tabbaa 2006, Abu-Zanat 2005, Ben Salem *et al.* 2002, Ben Salem *et al.* 2000, Chriyaa *et al.* 1997a, 1997b, Glenn and Brown 1999) It has been found to be a cost effective supplement to spineless cactus diets resulting in growth in sheep similar to traditional diets when used in this way. Old Man Saltbush also proved better in combination with unimproved pasture than just unimproved pasture alone – resulting in maintenance or increase in live weight (Kessler 1990).

Agronomy

Productivity and yields

Edible dry matter production

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^{-1} which is beyond what is desirable for a standing fodder crop. Watson and O'Leary (1993) examined initial production and subsequent regrowth under irrigation in California. Using a conventional hay bailer they collected an estimated 8 t/ha after the first 4.5 months, then a further 2.3, 3.2 and 2.1 t/ha of regrowth after a further 8.5, 12.2, and 22.5 months respectively. Clipping of 9-month old plants by Watson (1990) resulted in an average of 307.8g of dry matter per plant in an irrigated stand at densities up to 14,350 plants/ha. Plants irrigated with saline water by Glenn *et al.* (1998) produced a yield of between 22 and 29 t/DM/ha/yr edible fodder at a density of almost 28,000 plants per hectare.

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 Western Australia 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 & Casson 1993). Warren *et al.* (1995) found that four other saltbush species on saline land produced less than 0.5 tDM/ha/yr. Warren & Casson (1993) suggest that the implications for animal production are likely to be significant if DM production can be increased beyond these figures. 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 the harvesting of an extra 39mm of rainfall resulted in an increase in survival from 67% to 95% compared to the natural rainfall treatment. 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.

Leaf/stem ratio and wood density

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.* 2005). Estimation of the standing edible biomass in a plantation would be enhanced by the development of generic productivity models that allow easy estimation of the different fractions of the biomass. In Israel, Ben Salem *et al.* (2005) destructively sampled a 12 year old Old Man Saltbush plantation at a density of 2500 plants/ha and regressed the measured biomass against height, circumference, crown, and ellipsoid volume. The plants had been grazed annually between 4 and 12 years of age. They estimated the best equations for foliage biomass (FB = 0.69 x Volume, r^2 =0.90) and woody biomass (WB = 1.56 x Volume, r^2 = 0.91). An average plant produced 1.4 kg of edible DM (3.5 t/DM/ha) and 3.3 kg of woody biomass (8 t/DM/ha) meaning a leaf/stem ratio of 0.42:1.

An added complication is that there is seasonal variation in the proportion of edible biomass. Gates and Muirhead (1967) found the leaf to stem ratio was highest in spring (2.88) and lowest in autumn (1.49). Leaf to stem ratio was always higher in Old Man Saltbush than in other saltbush species tested. Significant variation in leaf and stem dry matter on a seasonal basis with highest CP values recorded at the end of the growing season (twigs higher than leaves 17.7% vs 21.3%) (El-Shatnawi and Abdullah 2003).

Plants also become woodier as they age. 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). Recent destructive sampling work in on two different provenances in South Australia (D. McKenna unpublished data) also suggests substantial seasonal variation in available edible biomass of Old Man Saltbush. 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). Benjamin *et al.* (1995) found that planting density had an effect on the stem to leaf re-growth ratio following grazing. Plants at lower density had a greater amount of leaf re-growth relative to woody regrowth compared to those plants at high densities.

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).

Little is known of the proportion of biomass that accumulates in the root system of Old Man Saltbush. Jones *et al.* (1970) harvested plants of increasing age and found a linear relationship between leaf area index and dry biomass accumulation. In 500 days from germination bushes produced 2330g dry weight. Proportion of biomass in the roots declined from 27% to 14% over the three harvests of the study.

Growth architecture

The growth architecture and growth form of Old Man Saltbush can vary considerably depending on the prevailing rainfall and soil type and also on the subspecies in question. As mentioned previously, subspecies *nummularia* is the largest of the three subspecies and can have a tendency to outgrow the reach of sheep and also become quite woody if not managed properly. A recently established trial that included 28 provenances collected across 2 subspecies has revealed a large amount of variation in growth architecture (Fig. 46).

Fig. 46. Variation in structure and form in 19-month old plants of *Atriplex nummularia* ssp. *nummularia* and ssp. *spathulata* at a provenance by family trial site at Monarto, SA.

Response to grazing

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 5th 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. Ungrazed plants quickly become woody and may grow too large for sheep to be able to effectively access the new growth, although a small amount of untouched foliage may enable a quicker recovery (Fig. 47). 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.

The ability of Old Man Saltbush to respond to extreme defoliation has recently been shown in a coppicing experiment carried out by the FloraSearch team at Murray Bridge in South Australia. A 2.75 year old plantation was measured for biomass accumulation by cutting individuals back to the base stems and weighing the cut leaf and stem. Despite below average rainfall there has been impressive regrowth from these plants (Fig. 48).

Fig. 47. Old Man Saltbush plantation following a crash grazing at Tammin, WA.

Note the component of the foliage that is out of reach of the livestock, which may aid in recovery after such intense grazing.

Fig. 48. Regrowth after an intense coppice in the Autumn, 9-months earlier.

The two plants recently coppiced in the foreground indicate the size of the stems from which regrowth has occurred

Genotype by environment interaction

The desired goal of a selection process would be to derive a clone or clones that perform consistently well for the traits of interest across different sites, irrespective of site differences. Currently, there is limited information available on the effects of environment on the expression of traits. It will be important to have an understanding of the extent of G x E as this may dictate the number of clones that need to be developed. Recent work by the FloraSearch group in a large replicated provenance by family trial at two sites has shown that GxE was significant for biomass accumulation, plant volume, branching angle, node length and leaf size. At this preliminary stage of the trial it may suggest that a number of clones will be needed. These results will be further bolstered by the inclusion of grazing preference trials and nutritional analysis in the near future**.**

Propagation and establishment

Propagation from seed

The fruit of Old Man Saltbush is comprised of a seed encased in two woody bracts. Up to 30 – 50% of the fruits lack seed or contain deformed seeds because the bracts can form whether fertilisation has occurred or not. 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). Campbell and Mathewson (1992) also found both hard and soft seed present in the De Kock cultivar from South Africa. Under lab conditions, the germination of seed enclosed in the bracteole was inhibited but water-cleaned and debracted seed had 75.3% germination. The soft seeds were 1.3 times more likely to germinate than the hard seed when fresh and the application of a gibberellic acid treatment resulted in 90% germination which was independent of photoperiod.

Other manual scarification approaches have been tried in the effort to enhance germination percentages. Abu-Zanat and Samarah (2005) applied both physical (scarification, water soaking and gamma radiation) and chemical (potassium nitrate and sulphuric and gibberellic acids) treatments to naked seeds and to seeds still encased in the bracts. There was a highly significant increase in germination as a result of excising the seed from the surrounding bracts for all treatments (77.7% and 4.0% respectively for the control treatment). At the treatment level for naked seeds there were significant increases in germination resulting from the 2% potassium nitrate (88.0%) and 150ppm gibberellic acid treatments (88.1%), with sulphuric acid and radiation treatments reducing germination. Water immersion and scarification produced no significant increase in germination. Sulfuric acid and manual scarification also resulted in poor germination in a lab trial by Peluc and Perera (2000).

There is some suggestion that there is an innate dormancy period after which germination percentage increases. Edwards (1974) looked at seed age and germination and found results similar to those of Beadle (1952), with low levels of germination for seeds over 7 years of age. Edwards (1974) also showed from two trials that maximum germination was in 4 year old seed rather than new seed. Turk (1998) also recorded significantly higher germination in1-year old seed than in fresh seed.

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 white 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. Donaldson (1990) also found that imbibed fruits germinated better in pots than naked seed, yet the result was the opposite for seeds and fruits germinated in petri dishes. In both cases maximum germination was just under 50%. Seeds of *A. nummularia* were more likely to germinate at lower water potentials than *A. amnicola* and *A. undulata* (Stevens *et al.* 2006). For direct seeding, seeds collected from individuals that produce volunteer seedlings are better than seed from individuals that don’t recruit as they can withstand saltier and cooler establishment conditions (Malcolm 1993).

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*. The inhibited seeds were still able to be germinated if washed and planted under control conditions. Bajji *et al.* (2002) and Sharma (1976a) suggest that summer will not be the most effective period for planting because of higher salinity as a result of the increased evaporation and elevated temperatures outside the optimum range. Autumn or winter after rains may be better option. As well as a significant decrease in germination percentage, Mahala and Karan (2006) found that increasing salinity to 4.5% resulted in a 60.8% reduction in shoot length of seedlings. 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 favourable germination niche) before planting. Germination was significantly enhanced using this method, however this option would not be cost effective. 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 when water is readily available (particularly in heavier soils). Using this technique, sandy soils produced increased above ground mass but reduced root mass. In heavier clay soil the result was reversed.

Once seedlings have been transplanted in the field they can rapidly establish a root system. Noble and Whalley (1978) conducted root growth observations in root boxes for Old Man Saltbush. The roots of transplanted seedlings grew to a depth of 1.60 m in 4 weeks, reaching the bottom of the boxes. Transects at 118cm of depth revealed a root density of 86.8 strikes per 26cm. 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).

Vegetative propagation

Atriplex nummularia is known to be relatively easy to propagate vegetatively using cuttings, although little is known about family variation for this trait. Indeed, much of the early distribution of Old Man Saltbush was conducted using this approach. Malan (2001) found that the highest rooting percentage was achieved with terminal cuttings of juvenile material, established in spring using 3 g kg-1 exogenously applied indole-3-butyric acid (IBA). Cuttings exposed to high humidity and heat during summer were susceptible to disease. Strike rate using stem cuttings was considered poor and this technique was to be avoided.

Establishment and site preparation

Old man Saltbush is a poor competitor in the seedling stage so it is important that correct weed management is adhered to in the establishment phase. As previously mentioned, stands can be established either by direct seeding or by the planting of nursery grown seedlings or cuttings. 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). Recent work by researchers at the University of Adelaide suggests that ripping may not be as necessary as previously thought. They conducted a trial examining the effect of ripping versus non-ripping on the establishment of root system and established that those plants placed in non-ripped ground had greater root penetration and development than those in ripped ground. Plantations should be ready for an initial graze at 12 – 24 months of age depending on the prevailing conditions (Milthorpe *et al.* 2001).

Weed risk and geneflow

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. Overseas *A. nummularia* is planted for cultivation however in South Africa it is considered to have weed potential (Nel *et al.* 2004) and restrictions are applied to where it can be established. The global compendium of weeds website (Randall 2002) lists *A. nummularia* as a weed or noxious weed and notes that it is an escapee from cultivation. The references cited refer to *A. nummularia* experiences in South Africa, Chile and the United States of America. *A. nummularia* ssp. *nummularia* has already been introduced and planted widely in Western Australia. 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.

Production systems

Integration with adjacent land uses

Old Man Saltbush offers good opportunities for integration with existing land uses. Their ability to utilise marginal area will value-add to the farming returns for a property. Having a green feed source such as Old Man Saltbush allows the spelling of particular paddocks at times when flowering and seeding times are critical. Spelling of paddocks by putting sheep on the Old Man Saltbush also allows a greater range of perennials in the pasture (Milthorpe *et al.* 2001). Forage shrubs can also complement the existing pasture species at times when there is low productivity in other annuals and perennials (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 green and dry biomass from the high density plantation (15 and 6 t ha^{-1} respectively) 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).

Livestock 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 that is grazed every 3 – 6 years is now not openly advocated as the plants become too large and woody to be effectively utilised. Therefore, 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. Stock newly exposed to Old Man Saltbush will need an adaptation period to become familiar with the new feed. As mentioned previously, for most effective utilisation of the Old Man Saltbush it will need to be incorporated into a mixed grazing system or an additional energy supplement will be needed to ensure animal well being. Adequate water supplies are also necessary because of the high salt content in the feed (Milthorpe *et al.* 2001).

Saline landscapes

The genus *Atriplex* is well known for its tolerance of saline conditions but there are a number of salt related effects that have been recorded in both laboratory and field trials. It has previously been shown that halophytes have increased growth at low salinity levels but that at higher levels of salinity growth can be retarded (Greenway and Osmond 1970, Barrett-Lennard 2002). Greenway (1968) investigated the growth of Old Man Saltbush under increasing chloride concentrations in solution cultures. He found above ground biomass was increased at mid concentrations of 100-200 m-equiv/l NaCl compared to low concentrations. Similarly, Ramos *et al.* (2004) found that Old Man Saltbush grew well in low to medium sodium levels but increasing salt levels induced a progressive decline in length and weight of plants grown in the glasshouse. KCl had a more inhibitory effect than NaCl. Irrigation with water of increasing salinity also resulted in significant reductions in size and biomass production in pot trials conducted by (Miyamoto *et al.* 1996). Tests of the growth of Old Man Saltbush at four salinity levels for a number of salts showed that the addition of salt increased growth over the controls, with growth being best at the lower end of the salt scale at 0.05M and death occurring at 0.6M solutions. Low salt levels resulted in greater shoot/root ratios and larger leaves that were thinner (Ashby and Beadle 1957). In a field setting, an increasing salinity gradient across the study plantation was shown to coincide with lower growth in the areas of higher salinity (Slavich *et al.* 1999). Le Houerou (2000) found only half maximum yields were expressed when grown in a saturated soil extract of EC $30dSm^{-1}$.

As well as reductions in yield, Glenn *et al.* (1998) found leaf material had significantly more moisture and ash in the saline irrigation treatment compared to the standard pond water treatment and (Miyamoto *et al.* 1996) also found ash levels increased with increasing salinity. The salinity trials conducted by Ashby and Beadle (1957) showed ash in the control was still high at 20.8% but this value increased at higher salinity values to between 29 and 54% depending on the salt medium the plants were grown in. With the accumulation of ash, which is predominantly sodium, potassium and chloride, there is also an accumulation of glycinebetaine, which is used is used in osmoregulation as the salt concentrations increase in the cytoplasm (Khan *et al.* 1998, Khan *et al.* 2000). Consequently, Ashby and Beadle (1957) found the osmotic potential of the plants was much higher than that of the solution they were grown in, even for the control (30 times for control to 2x for highest salt). Daily water use was appreciably less in the saline treatments, although these had the higher biomass dry weight. Ramos *et al.* (2004) suggest that *Atriplex* has the ability to use Na ions to fulfil osmotic functions without affecting its performance under salt stress.

There is also a seasonal component to the accumulated salt levels in Old Man Saltbush. Wilson (1966a) found the highest leaf sodium content in the summer (8.2%) and lowest in winter (3.2%), a trend that was also found by Sharma *et al.* (1972) and was opposite to the trend seen in the soil water content. There is strong natural variation in leaf shape, number and area, irrespective of salinity in Old Man Saltbush (Gates 1972). Lamina area at harvest varied from 3.9 – 7.5sq cm and leaf number from 100 – 230. However, salinity related effects included a larger leaf area, increased leaf moisture and thickness with increasing salinity and a significant reduction in transpiration per unit area. Wilted plants recovered better at high salinity than the control (Gates 1972). Al-Naber *et al.* (1998) simulated increasing salinity stress in tissue culture medium using NaCl and Manitol to induce water stress. They found seedlings had the same number and length of shoots with increasing salinity, but a reduction in number of leaves. Fresh weight of plants increased with increasing salinity.

Harvesting technologies

To date there has been little effort put into developing harvesting methodologies for Old Man Saltbush in Australia. The more standard and cost effective approach is to allow livestock to consume the green feed off the plant. There has been some work done in the USA in relation to harvesting for dry feed by Watson and O'Leary (1993) who used alfalfa hay harvesting and bailing equipment.

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 Western Australian 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.

Conclusions and Future Directions

Our review of the literature on Old Man Saltbush (*Atriplex nummularia*) 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.

1. Evaluations of fodder properties

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. Currently, only the *in vivo* analyses are able to provide accurate measures of energy values but this is an expensive and time consuming method not suited to a broad-scale screening of large numbers of individuals. 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 infrared scanning (NIR) that will allow assessment of nutritional and energy components of native fodder shrubs such as Old Man Saltbush. If more rapid ways of assessing nutritional status were derived it would make the process of selection more practical.

Old Man Saltbush does have limitations that need to be considered if effectively utilised including high cost of establishment and our understanding of the nutritional aspects. 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 they may provide. Current research under the Enrich program is screening a range of other native shrub species that could be used in conjunction with Old Man Saltbush as a forage system. The goal is to select species that provide a complimentary suite of nutrients and beneficial compounds that improve animal well being and reduce the associated costs of livestock management.

2. Potential for bioenergy

Despite potential for good woody biomass accumulation, bioenergy applications have not been considered in this review, which is focused on a development program for Old Man Saltbush as a fodder shrub. Indeed, the selection criteria and correct management for maintaining a high proportion of leaf biomass may be at odds with the goal of increasing the woody biomass fraction for bioenergy. If bioenergy were to be a goal of development then the selection criteria would need to change from that required for fodder.

3. FloraSearch trials

If the level of genetic variation among populations is to be determined then a there is a need to collect germplasm and establish growth trials, ideally across a number of different sites in order to examine the genotype by environment interactions. In order to address this lack of knowledge on genotype variation, the FloraSearch team conducted an extensive germplasm collection from across the range of Old Man Saltbush in 2005 and 2006. 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 in FloraSearch 3a 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 genetic versus environmental variation and associated genetic parameters in the new family/provenance trials for a number of traits relating to nutrition and productivity

- Defining breeding objectives and selection criteria through the following research;

  1. Gaining a better understanding of nutritional components and how they relate to animal well being

  2. Gaining a better understanding of livestock preference in single and mixed species systems

  3. Developing more reliable rapid assessment techniques for nutritional assessment of native shrub species

  4. Examination of the complementary benefits of mixed species grazing systems in which Old Man Saltbush is an integral part

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

- Development of more effective direct seeding techniques in order to reduce the cost of establishment

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.

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4. Review of *Eucalyptus rudis* (Flodded Gum) and its Potential for Domestication for Western Australian Dryland Farming Systems

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Introduction

Eucalyptus rudis is a medium sized tree that has been selected for domestication for use as a multiple-purpose woody crop in the wheatbelt agricultural region (also called the wheat-sheep zone) of the south-west of Western Australia (WA). It is easy to propagate and establish, is capable of rapid growth, coppices readily can be used in environments subject to seasonal waterlogging and moderate salinity, and has considerable genetic variability and potential for improved crop cultivars. It has low wood density for a eucalypt and is potentially an attractive feedstock for panel board products.

The purpose of this report is to review and synthesise all available knowledge on *E. rudis* relevant to its development as a woody crop. It will focus on its potential for use in the farming systems of the wetter western parts of the wheatbelt of WA. The principal source of information is the scientific literature supplemented where appropriate with knowledge gained by the authors and other practitioners who have worked on the species. This report briefly outlines the WA land-use context for domesticating *E. rudis* addressing its taxonomy, ecology, historical and prospective uses and development of its agronomic potential. The review concludes with a summary of major findings and directions for future research.

Background

The motivation for public investment in the development of new woody crops for the wheatbelt has been mainly environmental. A combination of climate and geology has predisposed south west WA to major salinity and erosion problems following the removal of native vegetation for farming. More recently the prospect of climate change presents an additional reason for extensive revegetation.

Dryland farming in Western Australia

The WA wheatbelt (or wheat-sheep zone) region comprises some 15 million ha of farm land between the latitudes 29 and 34 degrees south (Fig. 4). It has a Mediterranean type climate with an annual rainfall range of 300 to 600 mm. It consists of an ancient deeply weathered (~25 m) granite plateau of low relief and elevation of ~300 m above sea level. The native woodland and shrublands display exceptional biodiversity. Development for agriculture occurred during the twentieth century and farms have typically retained ~10% of the native vegetation. The agricultural plant species are all introduced winter growing annuals, including cereals, pulses, oilseeds grain crops and legume/grass species for pastures.

The problem of dryland salinity

The conversion of native woodlands and shrublands to annual plant agriculture reduces evapotranspiration by a small amount. The low relief and generally deep, permeable weathered profile means that most of this water infiltrates into the profile and slowly accumulates as stored soil water and groundwater. As groundwater systems fill they mobilise previously stable salt storages (built up over many millennia from trace inputs via rain and dry fallout) and form saline discharge areas in low landscape positions. This process not only damages land and water supply on farms (see Fig. 1 & Fig. 2), but on a regional scale, it changes the hydrological characteristics of whole river systems, causing loss of water resources, biodiversity and amenity, increased flood risk and damage to infrastructure. Agricultural salinity has recently been comprehensively reviewed in a series of reports from the National Dryland Salinity Program (Powell 2004, Robbins 2004, van Bueren and Price 2004).

In theory, revegetation with perennials, especially deep rooted woody species, could reverse or control salinity. However, the considerable human and physical infrastructure invested in wheat-sheep agriculture, its current profitability and the scale of the salinity problem will dictate that the bulk of revegetation be profitable and implemented in harmony with the current agriculture. These constraints mean that revegetation options for salinity control will need to be complemented by other methods e.g. perennial herbaceous pastures, productive salt tolerant pastures on salt affected areas and various engineering options to collect and safely dispose of saline discharge water. At present, large scale, commercially viable, perennial woody crop options for the wheatbelt do not exist (Lefroy *et al.* 2005).

Eucalyptus rudis as a domestication candidate

The standing of *Eucalyptus* as a prospective genus for investigation is based on its prominence in the Australian flora and its history of utilisation. It is a large genus comprising over 800 species (Brooker *et al.* 2002) which, with the exception of a few species on islands to the north, is largely confined to Australia. South-western Australia is an area of extraordinary eucalypt diversity (Brooker and Kleinig 2001).

Eucalypts are the most widely planted tree in the world (Eldridge *et al.* 1994), and significant commercial plantings in tropical and temperate areas of many countries are based on the genus (Leakey 2004). They are grown for fuel, fibre, timber, pulp, oils, shade and land rehabilitation in Africa (particularly South Africa), South America (notably Brazil and Chile), China, India and Mediterranean Europe (Brooker *et al.* 2002).

Historically there has been considerable development of eucalypt species as crop plants for temperate climatic zones in Australia and around the world, but this breeding work has focussed on a limited range of species from medium to high rainfall areas. Eldridge *et al.* (1994) rate the ten most important eucalypts, in terms of global productivity as; *Eucalyptus globulus*, *E. grandis*, *E. saligna*, *E. viminalis*, *E. deglupta*, *E. exserta*, *E. paniculata*, *E. urophylla*, *E. camaldulensis* and *E. tereticornis*. The latter two species here are in the Exsertaria section of the Symphyomyrtus subgenus, otherwise known as the 'redgum' group. These two species are frequently used where reduced rainfall threatens to compromise the performance of the other higher rainfall species (Darrow 1995, Kulkarni and Lal 1995, Gulbaba *et al.* 1995). *Eucalyptus rudis*, the species under discussion in this document does not have a history of use, but is in this same taxonomic group.

Serious endeavour to develop woody perennial crop species for dryland farming systems in Western Australia (WA) began in the 1980s, with the exploration of mallee eucalypts for short cycle coppice crops (Bartle and Shea 2002). Mallee development commenced in earnest in 1993, culminating in the establishment of some 12,000 ha of mallee crops by some 20% of wheatbelt farmers, and the operational testing of a processing option (Enecon 2001). Work towards making mallee a commercially competitive crop option is ongoing. Mallee established a new woody crop paradigm of short harvest cycles (3 to 6 years), low cost continuous harvest systems and regionally based industries producing industrial products from biomass (Bartle 2006, Bartle *et al.* 2007).

The progress in mallee domestication led to the obvious question of whether there were other native species that might be suitable candidates for short cycle crop development. Native species were seen as having several advantages for crop development: notably their evolutionary adaptation to target landscapes and their low risk of becoming weeds. This gave rise to the Search Project, sponsored by the Natural Heritage Trust (NHT), to screen the WA flora for potential commercial species. The project was implemented during 1999-2003. Large scale, bulk industrial products were the target: including reconstituted wood products, chemical feed stocks and bio-energy. The project included the manufacture of sample products as part of its assessment and specified a priority list of 20 species for domestication, based on product feed stock attributes and agronomic factors. *Eucalyptus rudis* was ranked highly in this project (Bartle *et al.* 2002, Olsen *et al.* 2004).

In summary, *Eucalyptus rudis* was selected as a candidate for domestication based on the following factors:

- A high ranking in tests of physical properties, especially its relatively low wood density.
- Its tolerance of a range of adverse environmental conditions, especially its water logging and salinity tolerance, and hence its ability to grow on land of low opportunity cost
- An observed fast growth rate, erect plant form and strong coppicing ability.
- Its wide range of natural occurrence, suggesting a broad genetic base for breeding selection.
- Ready access to germplasm and known ease of propagation.

In 2001 the Joint Venture Agroforestry Program (JVAP) decided to support a national scale project called FloraSearch in conjunction with the Cooperative Research Centre for Plant-based Management of Dryland Salinity (CRC PBMDS). The continuing work on the domestication of *E. rudis*, which includes this knowledge review, is part of the FloraSearch Project.

Taxonomy and Ecology

Taxonomy and distribution

Eucalyptus rudis belongs to *Eucalyptus* subgenus *Symphyomyrtus* section *Exsertaria* (the red gums) because the buds have two opercula, ovules are in 6(8) rows, seeds are ± cuboid, cotyledons are oblong-reniform, adult leaves are concolorous, and the buds have a shallow hypanthium and a conical operculum (Brooker *et al.* 2002). It is a tree form eucalypt which attains a height of 15-20m in natural stands.

Eucalyptus rudis occurs in the SW corner of Western Australia, west of a line running approximately from Dongara to Albany (Fig. 49). 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*. A review of *E. camaldulensis* complex is being undertaken by Maurice McDonald from the Commonwealth Scientific and Industrial Research Organisation (CSIRO) (McDonald per comm. 2006). This review has included observations of *E. rudis* over a period of several years, and McDonald considers that there may be three entities in the species, provisionally described as:

- The ‘typical’ form, which is a substantially rough barked tree or mallee (Fig. 50);
- The large fruited *cratyantha* subspecies, of the coastal southwest, and
- The ‘smooth barked’ form in the northern part of the range (Fig. 51).

Brooker *et al.* (2002) consider that *E. rudis* grades into *E. camaldulensis* in the north and north-east of the *E. rudis* distribution, based largely on the description of seed coat and colour. The occurrence of trees with intermediate characteristics is extensive around the northern and north eastern part of the distribution, from York to at least Cockleshell Gully north of Jurien. The status of these ‘intergrade’ populations is unclear at this stage. There is very little *E. camaldulensis* adjoining this zone, and such ‘intergrades’ may indicate a relictual distribution of these species. Anecdotally, some populations are said to produce seedlings with variable leaf morphology, while others appear to represent the parent trees. Further work on these populations would require a closer examination of this variation, which may represent the difference between hybrid and intergrade populations. McQuoid (2001), in a short article discussing this species, suggests the difference between an intergrade and a hybrid is that a hybrid occurs as a few individuals on the interface between species, while an intergrade occurs over a wider transition zone. These intergrades have attracted interest as they often show good form, and appear to suffer less insect attack than the populations in the core of the species distribution.

Eucalyptus rudis hybridises with a range of other eucalypts. FloraBase lists hybrids with *E. camaldulensis*, *E. drummondii*, *E. gomphocephala*, *E. loxophleba*, *E. occidentalis* and *E. wandoo*

(Western Australian Herbarium, 1998). A genetic analysis of *Eucalyptus graniticola* (Scarp Rd mallee) conducted in 1997 showed it to be a hybrid between *E. rudis* and *E. drummondii* (Rossetto *et al.* 1997).

Fig. 49. The natural distribution of *Eucalyptus rudis* in Western Australia.

Compiled from herbaria records. Shaded region indicates the FloraSearch study zone.

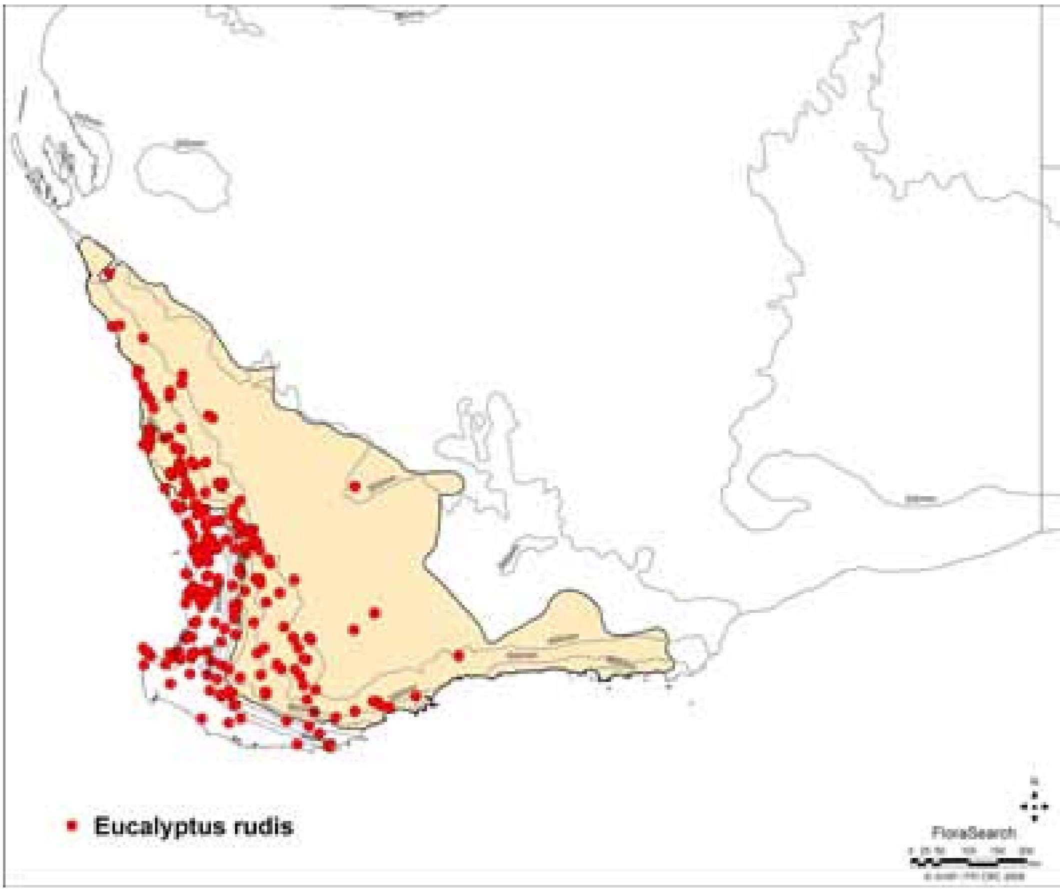

Fig. 50. Bark variation in a natural stand of *Eucalyptus rudis* (typical form) north of Bolgart WA, in the north-eastern part of the species range (Photo: W. O'Sullivan).

Fig. 51. Bark variation in a natural stand of *Eucalyptus rudis* (smooth form) at Cockleshell Gully, north of Jurien WA, in the north-western part of the species range (Photo: W. O'Sullivan).

Ecology and biology

Eucalyptus rudis is a dominant species of the riparian zone of rivers and water courses of south-western Western Australia (Pettit and Froend 2001a) (see Fig. 52). 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). Within the broad Northcote classification, these can be classed as Sands (Uc), Loams (Um) and Yellow duplex soils (Dy) (Northcote 1979).

Pettit and Froend (2001b) describe *Eucalyptus camaldulensis* and *E. rudis* as "taxonomically and functionally very similar species [in being] riverine trees which grow to 20m tall and fill the same ecological niche in the riparian zone, occupying the river bank and in some instances the adjacent floodplain" (p 16).

Species associations

In some instances *E. rudis* is the only large tree in the riparian zone, particularly in the central and south west parts of its range, including the principal river of the southwest, the Blackwood River (Pettit and Froend, 2001a). In other parts of its distribution it co-occurs with other tree species, including *Eucalyptus occidentalis* in the south east part of its range, *E. patens, E. decipiens, Banksia littoralis* and *Corymbia calophylla* in the south west, *Casuarina obesa, E. loxophleba* ssp. *loxophleba* and *E. wandoo* in the eastern and northern part of the distribution. Frequently the tree will co-occur with a tall understorey of arborescent melaleucas, principally *M. raphiophylla, M. cuticularis, M. preissii, M. raphiophylla, M. halmaturorum* and *M. strobophylla*. Smaller shrub melaleucas, such as *M. viminea, M. incana* and *M. lateritia* are also common as understorey plants, as are *Calothamnus spp*., *Acacia spp*., and sedges in the *Baumea, Lepidosperma, Juncus* and *Lepyrodia* genera. The salt tolerance of the species is supported by observations of it co-occurring with *Casuarina obesa, Halosarcia* spp. and *Sarcocarnia* spp.

Biology and physiology

Reproductive phenology

Brooker and Kleinig (2001) record the flowering season to be between July and November. Pettit and Froend (2001b) report the trees flowering from August to November on the Blackwood River (the major river system in the range of the species). Flowering in this area was observed by the authors to start in late July in 2007. 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). Seed collections made by the authors frequently contain two age classes of seed from the same tree. The reproductive phenology is reported to be similar to that of *E. camaldulensis* on the Murray River of Eastern Australia (Pettit and Froend, 2001b).

Plant chemistry

In a high pressure liquid chromatography (HPLC) analysis of the tannins of samples of *E. rudis, E. camaldulensis* and *E. globulus* grown in two geographically distant arboreta in Spain, Cadaia *et al.* (1997) concluded that "the geographical origin factor has a significant influence on the four variables studied, being particularly important in *E. camaldulensis"* (p.79). The study also concluded while significant differences existed in the flavinoids of *E. rudis* and *E. camaldulensis*, discrimination between *E. camaldulensis* and *E. globulus* was not possible. An earlier paper by the same authors discusses thin layer chromatography (TLC) as a technique for the study of flavinoid extracts from the same three species of eucalypts. The paper focuses on the use of this technique as a means of identifying the various eucalypt flavonoids. The methodology is described in detail, and the discussion of results suggests that "two dimensional chromatography on cellulose is the best separation method for most of flavonoids groups and could be advantageous for the analysis of the complex vegetal extracts. However, chromatography on silica layers provides important structural information… therefore, we suggest the use of both techniques to achieve a more complete elucidation of flavonoid structure" (Conde *et al.* 1992, p.423).

He *et al*. (2000) report on measurement of emissions from a range of common eucalypt species, and considers the role of non-methane hydrocarbons in tropospheric photochemistry. The paper places *Eucalyptus rudis* among the 'high emitter' category for monoterpene and isoprene emissions. The emission rates showed an exponential relationship with temperature. This paper suggests that biogenic emissions are more significant than anthropogenic emissions, on a global scale.

Fig. 52. Riverine environment dominated by *Eucalyptus rudis* at Sue's Bridge, on the Blackwood River, WA, in the south-western part of the species range (Photo: W. O'Sullivan).

Pests and diseases

Insect pests

The use of *Eucalyptus rudis* for revegetation is frequently questioned on the basis of the conspicuous defoliation it undergoes in a significant part of its range in most years. Assessment of the impact of insect predation and investigation of strategies for control or resistance will need to be a major part of any development work for the species. Insect herbivory will be a major area for investigation in the domestication of this species and it is therefore reviewed in some detail here. A good, brief summary of the significant insect pests attacking *E. rudis* is given in Clay and Majer (2001), (pp5-7). The most significant are the leaf miner and the psyllid, described in some detail below

Psyllids

Psyllids are sap sucking insects, *Creiis periculosa,* 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 (Fig. 53), 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. Morgan (1984) and White (1993), both cited in Clay and Majer (2001), give evidence that psyllids are selective about the trees on which they feed and breed.

The importance of psyllids to eucalypt culture is highlighted in Halbert *et al.* (2003) and Paine *et al.* (2006), who describe as significant the impact of two other species, *Glycapsis brimblecombei* and *Blastopsylla occidentalis* on *E. camaldulensis*, *E. rudis* and other 'red gums' in the USA. The *Glycaspis* in particular is noted as being able to defoliate the trees. This species is not in Australia at present, but *Blastopsylla occidentalis* is a native species in WA (Allan Wills, pers. comm. 2007). Halbert *et al.* (2003) lists factors correlated to increased pest populations as low fruit production, low level of attack from leaf beetles, good soil moisture, drought the previous year, and elevated temperatures during autumn and winter months. Paine *et al.* (2006) 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.

Fig. 53. Sap sucking psyllids, *Creiis periculosa,* are most conspicuous in the nymph to young adult stage when they build and feed beneath a sugary cover, the 'lerp', Lake CY O'Conner, west of Perth (Photo: W. O'Sullivan).

Leafminer

This insect is conspicuously present in all populations of *E. 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 of the genus *Perthida* 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 (Fig. 54). Maximum feeding damage is caused in late September-October (Mazanec 1980). The larvae are physiologically adapted to life within the confines of the eucalypt leaf, which offers protection from predation. It gains further protection by taking a section of the leaf with it to the soil surface for the next phase of its life cycle, and by making this transition at night.

The pest is considered to be separate but closely related to the jarrah leafminer *P. glyphopa* (Mahon *et al.* 1982). Research by Mahon *et al.* (1982) showed the pest on *E. rudis* to be significantly different at a genetic level to those infesting *Eucalyptus marginata*, but they were unable to relate these differences to any morphological characters, meaning that the differentiation could only be made if the host plant was known.

Wallace (1970) describes in some detail the life cycle of the leaf miner. At the time of publication the jarrah and flooded gum infestations were considered to be the same species with no difference in life cycle. Wallace lists observations about the variation in intensity of infestation within populations, including; that foliage near the ground often has the heaviest attack, and that younger and more succulent leaves were more prone to attack. The paper considers a range of factors that may influence abundance of the insect, including predation, ecology of soils and plant population density (severe insect attack was correlated with more open country, either natural or cleared).

Due to its economic significance, much greater study has subsequently been conducted on the impact of the pest on *E. marginata* (jarrah) rather than *E. rudis*. However, given the close similarity of the pest species, observations of life cycle, damage and potential control can offer some guidance in assessing the impact on *E. rudis*. In *E. marginata* that was susceptible to attack, girth increment was reduced on all sites studied, with the reduction ranging from 33-71% compared to resistant trees.

About a quarter of trees in the study areas were considered to be resistant to the leaf miner (Mazanec, 1980). Mazanec (1980) says that the leaf miner will not kill jarrah, but crown damage as a result of their attack is a characteristic of this species. Increased damage is associated with years preceded by low rainfall.

Work on *E. marginata* showed high levels of predation of larval cells that had fallen to the ground by ants in the genera *Pheidole*, *Rhytidoponora* and *Iridomyrmex*. The ants were observed collecting the cells from the ground, and large numbers were found stored in their nests (Mazanec 1980). Ten species of parasitoids of the larvae have been recorded, as well as predation by arthropods and birds (Mazanec 1987). In *E. rudis*, Yeomans (1999) recorded a greater survival of larvae in larval cells at sites with lower canopy density and increased percentage of weed species. Possible explanations offered for this correlation were; less habitat for nectar feeding parasitic wasps, less habitat for insectivorous birds (supported by Ford and Bell, 1980), and less favourable conditions for fungal hyphae that can consume the larvae.

Mazanec's (1980) work did not find an obvious physiological explanation for the greater resistance to leaf miner displayed by some trees but some valuable observations were made. The resistant trees were less attractive to female moths (less eggs laid on the leaves), and had a higher rate of larval mortality after hatching. Healing tissue on the edge of the larval mine developed more rapidly in the resistant trees. It was also noted that feeding larvae avoid oil glands when eating the leaves.

Fires of 'appropriate intensity' (a high incidence of crown scorch) can reduce populations by denying oviposition sites to female moths and by reducing food supply as well as destroying pupae in the soil. Moths from adjoining areas will soon reinvade burnt areas (Abbott *et al.* 1999).

Fig. 54. Leaf miners, of the genus *Perthida*.

Main photo of serious infestation at Minyulo Brook, west of Dandaragan, WA. Insert photo of 'shot hole' damage typical of the insect (Photos: W. O'Sullivan).

Other invertebrate pests

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 (*E. 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). Laboratory trials on *E. rudis* seedlings by Hanks *et al.* (1999) suggested a 'clear association' (p 406) between bark moisture content and resistance to the wood borer. 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.

Factors affecting insect attack

White (1984) in developing the *plant stress hypothesis* says a range of physiological mechanisms can stress plants, but the common response in the plant is the mobilisation of nitrogen, which is then accessible to invertebrate herbivores. Factors that may produce this (stress) effect include: site conditions (soil, depth, pH, acidity, waterlogging, salinity etc), fire, irradiation, mechanical damage to whole or part of the plant, exposure to pesticides (eg herbicides, insecticides), and changes in nutrient levels in the soil. Occupying low lying sites in the highly altered environment of the WA agricultural regions exposes *E. rudis* to most of these influences, often compounded on a single site (Fig. 55).

Changes in weather (especially rainfall and temperature) and climate are also significant in the mobilisation of nitrogen. Working with other eucalypts White (1969) asserts that any large departure from the usual range of weather conditions will induce stress, and correlates weather induced moisture stress and outbreaks of insect populations. Mazanec (1980) also noted increased levels of leaf miner attack on *E. marginata* following years of below average rainfall.

This focus on nitrogen mobilisation may be a simplification, as more recent work by Abbott *et al.* (1993) on seven species of eucalypts in the Manjimup district shows that although *E. rudis* had the highest levels of N and P, and the third highest levels of K, and the highest levels of insect damage, *E. diversicolour* had the second highest nutrient levels, but the lowest levels of damage. Mazanec (1980) was unable to find any significant difference in the nitrogen levels of the foliage of leaf miner susceptible and resistant trees in *E. marginata*. Acknowledging that there are a range of susceptibilities within a population. Wallace (1970) suggests that the vulnerable trees may to some extent be self perpetuating. As the tree recovers from defoliation, it produces abundant new growth, which is favoured by the next generation of pests. Thus the "resistant trees" may appear so at least partially because their retained older foliage is less attractive to the pests.

Price's (1991) *plant vigour hypothesis* states that plant modules that have been or are growing vigorously enough to become relatively large within their population are favourable to certain herbivores. The preferences exhibited by herbivores can be assessed relative to rates of growth and/or relative to levels of stress in the plants. It is suggested by Yeomans (1999) that the *plant vigour hypothesis* should not be viewed as an alternative explanation for herbivory to the *plant stress hypothesis*, but the different hypotheses may be seen as the two ends of a spectrum, where differing conditions will preferentially favour one species of herbivore over another.

Fig. 55. The conditions for growth of these two trees in the upper landscape near Williams, WA are indistinguishable, but the tree on the right has suffered repeated attack from leaf miner. **(Photo: W. O'Sullivan)**

Vertebrate pests.

Emmott (2002) describes damage from the 'twenty eight', or 'Australian ringneck' parrot (*Barnardius zonarius*) as severe on trees planted in the agricultural zone. The birds feed on the cambium layer and on phloem sap of young green stems often severely affecting the form of the tree (Fig. 56). This is only a management problem with trees planted for sawlog production. There may be between-species or within-species variation in vulnerability to parrot attack. Matt Edmonds, a farmer near Bolgart WA has observed significantly higher rates of parrot attack on one provenance of *Eucalyptus camaldulensis* in a trial plot on his farm compared to the adjacent *E. rudis* (pers. comm., 2007).

The impact of these pests and diseases on the likely productivity and viability of commercial plantings is unknown. Further evaluation of natural and experimental plantings of *E. rudis* will be necessary to build on the knowledge of pests and diseases. This will be a major focus early in the domestication program.

Fig. 56. Bark stripping and stem damage typical of attack by the Australian Ringneck Parrot *Barnardius zonarius*, seen here on *Eucalyptus kondininensis* at Toolibin Lake WA. (Photo: W. O'Sullivan).

Agronomy

Agronomy refers to the application of scientific knowledge to the growing of crops. It encompasses crop plants, their interface with other organisms in the environment and the soils and landscapes in which they are grown. It could be argued that the analogous forestry term 'silviculture' should be preferred to agronomy. The agricultural terminology has been adopted here because the focus is on the integration of woody perennial plants into the wheatbelt farming system. The woody crop will occupy only a small proportion of the farm, usually dispersed amongst the other crops and pastures. In this section, agronomic information relevant to the development of *Eucalyptus rudis* as a crop plant for dryland farming in Western Australia is reviewed.

Propagation and establishment

Seed collection

Provenance collections of seed currently have been made to capture the variation across the geographic range of the species, with a bias toward the low rainfall area of its distribution. There is a potentially significant variation in the economic traits (such as form, insect resistance, and tolerance of adverse environmental conditions) across the range of a species within eucalypts (Eldridge *et al.* 1994). The collections to date have been made in accordance with the protocols defined by Eldridge *et al.* (1994). Seed collections from individual trees, generally separated by 100m or more have been kept separate. The collections to date are listed in Table 10.

Table 10. Provenance collections held by the WA Department of Environment and Conservation.

Collection	Provenance	No. of families	Collection area
1	Arthur River	20	33° 14’ S 117° 05’ E
2	Balgarup River	20	33° 46’ S 116° 54’ E
3	Dingo Rd	21	30° 54’ S 115° 28’ E
4	Gordon River	20	34° 15’ S 117° 26’ E
5	Hill River	21	30° 18’ S 115° 11’ E
6	Kalgan River	22	34° 33’ S 117° 57’ E
7	New Norcia	20	31° 00’ S 116° 12’ E
8	Thompsons Lake	20	32° 09’ S 115° 45’ E
9	Toodyay	20	31° 31’ S 116° 27’ E
10	Toolibin Lake	20	33° 55’ S 117° 36’ E
11	Wandering	20	32° 41’ S 116° 41’ E
12	West Dale	20	32° 19’ S 116° 41’ E
13	Williams	20	33° 04’ S 116° 50’ E
14	Muir-Unicup	22	34° 20’ S 116° 45’ E

Seed viability

Germination tests were performed to assess the viability of *E. rudis* seed collections. Variation in seed coat colour had been observed, (black and/or white seed) and the work was extended to determine whether seed viability varied with these colour differences. Germination tests were performed on families that exhibited one colour or the other, and on colour-separated batches of seed from mixed colour families.

Fifty seeds from each of 41 seed lots were used for the testing. Normal seedlings, those with a well developed radicle, hypocotyl and cotyledon, were counted at intervals of 13, 19 and 30 days. The two provenances under test were similar in overall germination results, $F(1, 39) = 1.782$, $p>.10$, and were subsequently combined for further analysis. The results showed similarities in the viability of the colour categories, except the mixed white which performed significantly worse. There was, however, an observed difference in the germination patterns of the seed categories.

Visually and statistically it became obvious that the white seed was slower to germinate than the black. At 13 days there was a large difference in germination between the white and black seed, $F(1, 39) = 14.026$, $p=0.01$. In post hoc comparisons statistically significant differences ($p<0.05$) were seen between the means of mixed black and straight white seeds as well as between mixed black and mixed white seeds. It was also observed that the germinated white seedlings were smaller than their black counterparts.

The differences between white and black seed germination were still present at 19 days, $F(1, 39) = 13.50$, $p=0.01$. Post hoc comparisons showed the significant mean differences were still present between the mixed black and the mixed white seed ($p<.05$), although the straight white seed no longer exhibited significant differences in germination.

The final count at 30 days showed an overall viability of 92 percent for *E. rudis* seed. This observation was, however, purely the result of the lower performance of the mixed white seed, which was significantly different in comparison to both the straight black and mixed black seeds ($p<0.05$). This difference also resulted in the white and black seed still exhibiting a statistically significant difference, $F(1, 39) = 13.960$, $p<.01$. The straight white and straight black seed showed no significant difference when compared, $F(1, 19) = 3.119$, $p>.05$, and there was also no distinction between the straight black and mixed black seed or the straight white and mixed black seed.

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.

Natural populations seed readily and regeneration can usually be established simply by controlling weeds adjacent to established trees.

Vegetative Propagation

There is no work known to the authors dealing specifically with vegetative propagation of *E. rudis*. However, for eucalypt forestry the production of rooted cuttings has become a major source of propagation material, with the production of tens of millions of seedlings annually in a number of countries (Zobel 1992). The techniques for production have been refined by industry and well developed methods are now used successfully to quickly and cheaply produce a range of a species. The advantages and disadvantages of clonal propagation and factors determining the decision of when the use of vegetative methods is appropriate is well discussed in Leaky (2004).

Establishment and site preparation

In south-western Australia containerised seedlings are the most common mode of establishment due to their 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 (see Fig. 34 and Fig. 35). In Western Australia, soil cultivation methods have been developed to facilitate ease of planting, increase survival and growth, and overcome site constraints. Weeds, which can cause partial or complete establishment failure, primarily due to competition for moisture, are normally controlled using a combination of pre-emergent and knockdown herbicides, or by mechanical methods. (Angell and Glencross 1993, Tiedeman and Johnson 1992, Mullan and White 2002a). Good weed control in the first two years of field establishment is normally recommended to improve survival and growth.

Response to soil type and nutrients

The authors know of no studies which have specifically examined the impact of different soil substrates on the biomass yields of *E. rudis*.

Other environmental factors

In the south west of Western Australia, the performance of crop plants can be affected by soil salinity, seasonal waterlogging and frost. While imposing limits on agriculture and many other potentially productive tree and shrub species, these constraints may increase the land available for *E. rudis* to be grown productively.

Productivity

Growth rate and form

There is little published information on the growth performance of *E. 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 some site types.

Two trials were established by (the then) Department of Conservation and Land Management in WA in 2005 with families selected for greater than average resistance to the common insect pests of the species (

Fig. 57). These selections were from the eastern and central part of the species range and therefore are not representative of the whole distribution. No detailed data collection or analysis has been undertaken but some preliminary data are presented in Table 11 and Table 12. They indicate apparent difference between families, with some families performing well at both sites, despite a separation of some 220 km and different climatic and edaphic conditions.

Fig. 57. Variation in form. After health and relative resistance to insect attack, trees were chosen for form.

Selected Parent trees from the Gordon River (left) and Moore River east (right) (Photos: W. O'Sullivan).

Table 11. *Eucalyptus rudis* 2005 family trials - best ten families at age two, ranked by tree height.

Rank	Gillingarra trial site	Mean ht (cm)	Crossman trial site	Mean ht (cm)
1	Pumphrey's Bridge	310.3	Toolibin	353.8
2	Glenorchy	301.3	Marradong Rd	350.0
3	Marradong Rd	287.0	Toolibin	339.3
4	Congelin	280.8	Ulbrich Rd	334.5
5	Williams-Darkan Rd	275.8	Glenorchy	328.6
6	Toolibin	268.5	Harvey Quindanning Rd	327.6
7	Ulbrich Rd	257.8	Glenorchy	327.1
8	Toolibin	249.0	Glenorchy	321.8
9	Williams-Darkan Rd	232.5	Brookton Hwy	321.1
10	Collie River	232.3	Williams Darkan Rd	313.1

Table 12. *Eucalyptus rudis* 2005 family trials - best ten families at age two, ranked by stem basal area.

Rank	Gillingarra trial site	Mean sba (cm) at dbh	Crossman trial site	Mean sba (cm) at 10cm
1	Maradong Rd	51.9	Strange Rd	288.3
2	Collie River	44.1	Ulbrich Rd	178.5
3	Pumphrey's Bridge	42.7	Harvey Quindanning Rd	159.6
4	Glenorchy	41.6	Maradong Rd	154.9
5	Collie River	36.0	Toolibin	150.5
6	Toolibin	34.0	Brookton Hwy	148.6
7	Congelin	34.0	Toolibin	147.9
8	Ulbrich Rd	33.1	Toolibin	145.4
9	Williams-Darkan Rd	32.7	Glenorchy	145.2
10	Toolibin	31.4	Williams Darkan Rd	139.3

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 age four for a P2003 trial site in Katanning (Fig. 58) which had three replicates of each of two provenances. Trees in the core of each plot were measured (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 (Fig. 59). These data are summarised in the table below (Table 13).

Table 13. Whole tree biomass, projected biomass yield and MAI of *Eucalyptus rudis*.

Trial location	Trial age	Density (spha)	plot biomass (green t/ha)	MAI (green t/ha
Bolgart	3 years	1666	10.5	3.2
Katanning plot one	4 years	1350	22.8	5.3
Katanning plot two	4 years	1511	24	5.5
Katanning plot three	4 years	800	13.5	3.1
Katanning plot four	4 years	1125	20.8	4.8
Katanning plot five	4 years	1325	25.5	5.9
Corrigin	4 years	1600	14.9	3.4

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*. *E. rudis* obtained a maximum height of 6.43m. Increments of tree growth were recorded bi-annually over the first five years of the trial.

Fig. 58. Four year old *Eucalyptus rudis* in a Search project plot at Katanning WA. The form of these trees has been severely impacted by parrot attack.

Fig. 59. Planted stand of 3 year old *Eucalyptus rudis* on farmland north of Bolgart, WA.

Seed from local provenance (Parent tree population shown in Fig. 50). (Photo: W. O'Sullivan).

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. The wood fraction was consistently ~56% of total biomass across the range of tree size classes (see Table 14).

Table 14. Green woody biomass >2cm as a percentage of total green biomass, age 4 years.

Plot	Number of trees	Survival %	Mean biomass (wood > 2cm diameter).(kg)	Plot biomass (wood >2cm) (gt/ha)	MAI woody biomass >2cm (gt/ha/yr)	Wood >2cm as % of total plot 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%	9.78	11.92	2.8	55.9%

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 (Fig. 60). 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, however this work was performed on young plants.

Salt tolerance

Grieve and Shannon (1999) tested a range of *E. camaldulensis* clones and one *E. rudis* clone that had shown better than average tolerance to mixed salt solutions (Na^+, $SO4^{2-}$, Cl^-, and Mg^{2+}). The clones were tested with salinities up to a level that caused a 50% reduction in growth. At this point no visible symptoms of ion toxicity or nutrient deficiency were evident. The clones fell into two groups, determined by salinity tolerance. Group A (which were all *E. camaldulensis*) were those that reached the 50% point at around $17dSm^{-1}$, and Group B, the remaining *E. camaldulensis* and the *E. rudis* clone, had tolerances of almost double this, at close to $30dS^{m-1}$. The *E. rudis* clone differed from the *E. camaldulensis* clones in that its leaf Mg^{2+} concentration remained unchanged as the irrigation water concentration increased, compared to a significant decrease in leaf concentration in all other clones. The Mg^{2+} was also more evenly distributed through the plant in the *E. rudis*, compared to its concentration in the newer foliage in the *E. camaldulensis*. Group B clones also accumulated Na^+ in their foliage, above the level of the irrigation water, when concentrations in the water were low, only excluding the Na^+ when concentrations were relatively high. The other clones (Group A) effectively excluded the Na^+ at all concentrations. The paper is inconclusive as to the reasons for the accumulation.

Grieve *et al.* (1999) showed a large variation in salt tolerance between clones of *E. camaldulensis* and one clone of *E. rudis* that had been through an initial screening process for their tolerance. The *E. rudis* clone, along with one of the *E. camaldulensis* clones was rated as the least sensitive to salinity.

Field trials by Pepper and Craig (1986) assessed the survival and salinity tolerance of 12 eucalypts (selected for their reputed salt tolerance) on a duplex soil site with a saline watertable at 1.2 m over an eight year period. They concluded that *E. rudis, E. camaldulensis* and *E. robusta* were the most salt sensitive of the species on trial. By the end of the trial the *E. robusta* were dead, and the *E. rudis* and *E. camaldulensis* were continuing to decline in health. They concluded that *E. rudis* showed poor health and vigour at salinities greater than $1000mS^{-1}$. The trial was based on single provenance collections (Mundaring in the case of *E. rudis*), and the limitations of this data are discussed in the paper, especially in relation to the widespread *E. camaldulensis*.

Van der Moezel *et al.* (1991) ranked *E. rudis* highly in a trial of salt tolerance among eucalypt and melaleuca species. The experiments were conducted at salinities up to 35mS/cm-1, maintained for two weeks. Survival remained at 100% under saline conditions, and under waterlogged conditions, but the combination of these factors saw survival decline to 6% for one provenance, and 25% for another provenance. Relative growth was reduced to about 50% of the control under either waterlogged or saline conditions, and down to 25% under saline and waterlogged treatments, however *E. rudis* rated very highly for relative growth rates under non-saline waterlogged and saline waterlogged conditions against other species on trial (e.g. Fig. 61).

Aluminium tolerance

In an investigation of species suitable for revegetation of coal mining spoil (with a pH range of 3-4.5) in an area within the natural range of *E. rudis*, Mikli (2001) concluded that the species had some potential, provided the sites were not subject to moisture stress. The free aluminium in the soils of the study site damages the plant root system, inducing a ‘physiological drought’ (p. 148), and although the *E. rudis* showed good tolerance to wet acidic conditions, greater aluminium toxicity was observed on drier sites.

Egerton-Warberton *et al.* (1993) conclude that mycorrhizal inoculation of *E. rudis* will be beneficial in acid soils with elevated aluminium levels, conferring greater resistance to aluminium toxicity in the plants. There are two potential benefits; the mycorrhiza retains the Al, preventing the root becoming a sink for the metal, and the mycorrhiza may assist in the uptake of Ca and Mg by the roots, a process usually inhibited by the presence of high Al levels.

Drought tolerance

Work by Hanks *et al.* (1999) showed *E. rudis* to be capable of surviving significant drought stress. In greenhouse trials, 3m high trees were stressed to the point where their foliage was completely wilted. Although they were damaged by the severity of the trials, losing leaves and small twigs, they later replaced most of their foliage. The study details water potential of the soil and tree, and leaf conductance over the period of the trial. These laboratory trials must be tempered by reports that drought stress can increase the severity of insect predation (see “Pests and Diseases” section of this report).

In the Mediterranean climate areas of the USA the reputation of *E. rudis* is one of reasonable drought tolerance. It is given the common name ‘desert gum’, and is frequently recommended for amenity plantings in low rainfall areas. The Department of Water Resources in Arizona, for example, list it as a species that requires minimal supplemental watering (Arizona Department of Water Recourses 2007), and it is listed as ‘drought tolerant’ in Orange County of southern California (City of Fullerton 2007).

Fig. 60. Coppice growth in natural stands of *Eucalyptus rudis*.

and (B) Multiple stems on plants in the Muir-Unicup area, east of Manjimup, (C) An example of an old tree which has been repeatedly burnt and regrown, now a ring of stems over six meters across. Darkin River catchment, east of Perth, WA (E) Multi-stemmed plant north of Arthur River, (F) Multi-stemmed plant, north of Toodyay (Photos: W. O'Sullivan).

Fig. 61. Healthy *Eucalyptus rudis*, growing among barley grass, adjacent to *Halosarcia* sp., north of Arthur River, WA.

(Photo: W. O'Sullivan)

Stand management and harvesting

Protection from stock

The foliage of *E. 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.

Harvest

Harvest methodology is one of the most important considerations in the development of short cycle woody crops. Harvesting biomass is one of the most significant production costs (McKendry 2002, Nordh and Dimitriou 2003). Almost 80 % of total energy inputs in the production of woody crops occur in biomass harvest and transport, arising mainly from the use of fossil fuels, so optimisation these stages has the potential to improve the energy ratio for the crop (Wu *et al.* 2005). Lack of suitable harvesters is a major limitation to the production of many short cycle woody crops (Hartsough and Yomogida 1996, Giles and Harris 2003).

Most research work that discusses methods for increasing the efficiency of harvest deals only with harvest methodology, or the harvester design. However it is possible that the efficiency of harvest could be improved via changes in plant morphology, such as through a reduction in near-ground-level forking (Giles and Harris 2003). Young *E. rudis* trees show a strong apical dominance, and generally good form, but attention to morphology in selection and breeding work is still prudent.

Interface with adjacent land uses

A major objective in using woody crops within wheatbelt agriculture in WA is to capture as much of the surplus water generated under annual crop/pasture as possible (Cooper *et al.* 2005). This will help with salinity control and will also improve the viability of the woody crop through better yields. There are three conceptual approaches to achieving this objective:

- woody crops can be dispersed spatially to increase the interface of woody crop and annual crop/pasture, thereby increasing the contact zone between the surplus water source and sink. In this approach the woody crop is deployed in long narrow belts often called alley farming. It is well suited to permanent coppicing woody crops but the large woody crop perimeter also generates competition with the adjacent crop or pasture (Cooper *et al.* 2005).

- woody crops could be used in rotation with annuals where the deep rooted woody crop is used as a dewatering phase. This has been called phase farming (Harper *et al.* 2000). It reduces competition with the adjacent annuals but has only stored soil water to enhance yield.

- woody crops can be placed in small permanent plantings targeting landscape positions where water naturally accumulates. This option is compromised by the water accumulating locations usually also being prone salinity.

E. rudis is likely to be well suited to belt systems based on its strong coppicing ability. It may impose comparatively strong competition on adjacent crops and pastures because its adaptation to wet sites and duplex soils may indicate an obligate shallow surface root system structure. This will need to be assessed in early development work. The strong waterlogging and salinity tolerance of *E. rudis* suggests that it may have potential to be targeted to water accumulating locations thereby reducing its interface with the annual crop and pasture.

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

Weed risk and geneflow

There is no evidence of *E. 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 *E. camaldulensis*, to which *E. rudis* is closely related, and interbreeds.

E. 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 (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).

E. 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 herbicide and allowing natural regeneration (Peter White, pers. comm., 2007). In 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.

Seedlings have been observed 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 (Peter White pers. comm., 2007).

It is common to see seed of this species germinate on the edge of areas that have been inundated, generally close to parent trees (Fig. 62). There is a chance that flood waters will move the seed greater distances however, as this is a species of the riparian zone of rivers and water courses (Pettit and Froend 2001a). Seedlings are reported as coming up in great numbers in detention basins in the metropolitan area of Perth (David Bright, pers. comm., 2007), suggesting that flowing water is at least concentrating seed locally, if not transporting them great distances. Pettit and Froend (2001a) showed the seed to be somewhat buoyant, with an average floating time of 5.6 days.

The seed of *E. rudis* does not have the morphology to facilitate wind transport, but some drift of seed and branch material is possible. Seed morphology also makes it unlikely that it could be accidentally transported by people or vehicles by adhering to clothes or in dirt. The seed will not adhere to the hair or skin of livestock, and is unlikely to be accidentally ingested by animals or to survive passage through the gut of animals.

E. rudis 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.

Increased numbers or density of this species is unlikely to significantly increase fire risk. *E. rudis* has an open 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.

Geneflow and mating systems

E. rudis is a variable species. There are nominally two subspecies (*E. rudis* ssp. *rudis* and *E. rudis* ssp. *cratyantha*), but this may not represent the entire diversity within the species. There appears to be a naturally occurring intergrade with *E. 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 were close to the average value seen in a number of other eucalypts. *E. rudis* shows mixed types of mating (self fertilisation 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 hybridises with several other eucalypt species (Western Australian Herbarium). *E. rudis* x *E. camaldulensis* hybrid trees, a product of natural *E. rudis* populations crossing with garden *E. camaldulensis* plants, are showing greater vigour than the native *E. rudis* around wetlands south of Perth (David Bright, pers. comm., 2007) (Fig. 62). There is concern about genetic pollution resulting from the introduction of *E. camaldulensis* material into the range of a naturally occurring *E. rudis/E. camaldulensis* intergrade before the potential of the existing natural diversity is better understood (Emmott 2002).

Fig. 62. *Eucalyptus rudis* seedlings germinating among flotsam on the edge of a seasonal wetland.

Pictured here in their first summer, their survival will be at least partially determined by their ability to grow above the height of the water in the lake by the next winter (Photo: W. O'Sullivan).

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).

Utilisation

The principle objective of this section is to explore the scope for *E. rudis* biomass produced in the WA wheatbelt to be used in emerging industrial biomass applications.

Utilisation options in south-western Australia

As established earlier in this document, the level of perennial planting required to effect landscape scale change to the problem of dryland salinity is such that any new perennial industries are likely to generate large volumes of relatively low value biomass. The challenge of making woody perennial crops competitive as bulk biomass feedstocks should not be underestimated. To be economically competitive, it is likely that woody crops will need to generate multiple products from different plant components within integrated processing operations (Bartle *et al.* 2002, Bartle *et al.* 2007). Additional "product value" could be afforded by the valuation of environmental services, such as carbon sequestration and the protection of biodiversity.

A detailed review of potential products from large scale woody crops grown in the Australian context was made by Olsen *et al.* 2004. The most promising candidates were panel boards, bioenergy, fodder and chemicals. These applications are reviewed earlier this document.

Historical use

There has been little use of *E. 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 (*E. marginata*) or Wandoo (*E. 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) *E. 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 (see "Solid timber" section of this report).

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, the origin of which was not recorded (G. Seimon, pers. comm. 2007).

Biomass energy

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 endemic to WA. Factors affecting the quality of biomass for use in energy conversion processes include its moisture content and ash fraction, a measure of inorganic elements. Dry biomass has a greater calorific value than moist biomass, making it more efficient to handle and convert into energy. High levels of inorganic elements, in particular alkali metals such as sodium and potassium, can cause fouling and corrosion in energy conversion equipment. The Gross Calorific Value (GCV) of *E. rudis* biomass samples; consisting of ⅓ wood, ⅓ bark and ⅓ leaves and twigs; designed to mimic whole young tree harvest yield, 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. The suitability of using the woody biomass as a gasification or BTL feed stock was not assessed, however the low ash content is an indicator of its suitability. Low ash feed stocks are also desirable for pyrolysis processes (Chiaramonti *et al.* 2007).

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 high cellulose to lignin ratio (Dinus 2000, Wyman 1999). Lignin and inorganic plant components are problematic in that they are unable to be converted into ethanol and can disrupt enzymatic hydrolysis conversion processes (Dinus *et al.* 2001). Hardwood species typically contain about 43 % cellulose, 35 % non-cellulosic polysaccharides and 29 % lignin (Downes *et al.* 1997). 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.

As indicated in the preceding discussion, it is unlikely that *E. rudis* will be competitive as a single product energy crop in Western Australia. A more plausible scenario is for bioenergy to be one of a suite of products generated via integrated biorefinery models, as has been proposed by Ragauskas *et al.* (2006).

Chemicals and biomaterials

Conde *et al.* (1997) conducted a study of the ether soluble polyphenols of *E. rudis* as an exploration of the commercial potential of three eucalypts (the others were *E. globulus* and *E. camaldulensis*). The study recognized that leaves were a significant by-product of other biomass industries, which could facilitate their recovery at a commercial scale. The components were predominantly flavanol glycosides and ellagitannins. The compounds in *E. rudis* were similar to those of *E. camaldulensis*, separating from the *E. globulus* in having a greater variety of flavanol glycosides, and lower concentrations of ellagitannins. Conde *et al.* (1997) suggest that there may be some commercial opportunity to extract quercetin-3-arabinoside, and kaempferol-3-arabinoside (low molecular weight polyphenoloic compounds) from the leaves of *E. rudis* and *E. camaldulensis*.

Eucalyptus oil is currently used for low volume specialty uses but has potential for large scale industrial use (Coppin 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. Analysis was performed by gas chromatography following solvent extraction of fresh leaf material. 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.

Environmental benefits and services

Efforts to develop woody perennial crops in Western Australia are underpinned by the principles of sustainable development: namely the attainment of economic, environmental and social sustainability. It will be difficult for woody crops to compete with other land uses purely on economic grounds. Therefore, it is important that environmental services provided by woody crops are recognised and valued where possible. Key services include biodiversity protection through landscape recharge reduction, habitat augmentation, erosion prevention and carbon emissions abatement. These values are discussed in detail elsewhere in the FloraSearch reports.

Conclusions and Recommendations

Eucalyptus rudis has many desirable attributes that make it a candidate for domestication as a woody crop for the wheatbelt region in the south west of Western Australia,

Successful domestication will require a coordinated whole of industry approach. This will include biomass production, a harvest and supply chain delivering to processors, through to product science and marketing. Although the focus of this report is on primary production and biomass supply, it is imperative that priority setting and investment in research and development also take account of the industry required to process and market products from *E. rudis.*

Hence the domestication process will require:

> 1. Taxonomy: a sound understanding of the taxonomy of the species to provide the foundation for selection of germplasm
>
> 2. Genetic improvement: germplasm selection and initiation of breeding and seed production capability.
>
> 3. Agronomy: crop agronomy knowledge base (establishment and management) and the role of the crop in whole farm production systems
>
> 4. Supply chain: harvest and supply chain capability
>
> 5. Processing and product development: all the demand side including processing, product and market sectors

Domestication requires a coordinated strategy to determine investment priority. A wide range of potential priorities have been identified and discussed in this review. This concluding section of the review specifies only the major priorities for the domestication of *E. rudis*, and distils key recommendations for further investment in Research and Development.

1. Taxonomy

The taxonomy of *E. rudis* is well understood and there is no immediate need for further work.

2. Genetic improvement

E. rudis has considerable diversity but its geographic range is well defined. There is potential to select and develop general cultivars, or site or purpose specific ones. A comprehensive germplasm collection has been completed. This can be used to establish progeny experiments to define genetic variation in important specific traits like productivity, form, coppice potential and insect pest susceptibility. The results from progeny experiments can be used to guide germplasm selection for the establishment of breeding populations.

Recommendation: Establish a range of progeny experiments.

3. Agronomy

E. rudis has many attractive agronomic attributes. Being a eucalypt the basic practices for nursery propagation, field planting and on-going management are well known. It has good yield potential, grows rapidly and appears likely to have strong enough coppicing ability to be harvested on a short (4-5 year) cycle. It is well suited to integration into dryland farming systems. It has good waterlogging and salinity tolerance and could be used strategically as a small block planting on wet or salt affected sites. It could also be used in belt systems.

E. rudis has serious insect problems. This may be at least partly managed by selection for resistance if progeny testing confirms field observation of a useful degree of natural variation. There may be cultural practices that could minimise insect damage (e.g. narrow belt planting rather than solid block planting), or other pest control options. These will need to be tested to develop a full range of options for insect control.

Recommendation: Establish small scale field experiments to develop knowledge about yield potential, coppicing ability and insect control. This should be done in conjunction with small scale operational planting by farmers to evaluate practical field establishment and management options.

4. Supply chain

Development of a versatile woody crop harvester is underway in the domestication work on mallee eucalypts. This harvester will be designed to be suitable for harvest of a wide range of woody crops including *E. rudis*. Likewise the handling and transport components of the mallee supply chain will also be readily adaptable to other species. *E. rudis* is likely to display a more erect plant form as a short cycle coppice species. This may reduce harvest costs and warrant selection for form in the breeding program. Field scale testing of mallee harvest equipment on *E. rudis* will be required.

Recommendation: Establish operational scale plantings of *E. rudis* to provide areas to test harvest operations.

5. Processing

The Search Project showed in laboratory scale tests that *E. rudis* wood had suitable properties for the manufacture of panel products and other products. As the potential for development firms up it will be important to expand the intensity and range of laboratory testing to develop a better knowledge of wood properties. Progeny experiments can be used to determine the extent of variation that occurs. It would be desirable to then conduct operational scale manufacturing tests of panels and other products.

Recommendation: Include tests of wood properties in progeny experiments and undertake operational tests of panel manufacture.

Research priorities

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

1. Establish a range of progeny experiments.

2. Establish small scale field experiments to develop knowledge about site selection, yield potential, coppicing ability and insect control. This should be done in conjunction with small scale operational planting by farmers to evaluate practical field establishment and management options.

3. Establish operational scale plantings of *E. rudis* to provide areas to test harvest operations.

4. Include tests of wood properties in progeny experiments and undertake operational tests of panel manufacture.

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Joint Venture Agroforestry Program

Rural Industries Research & Development Corporation

Forest & Wood Products Australia

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Reviews of High Priority Species for Woody Biomass Crops in Lower Rainfall Southern Australia

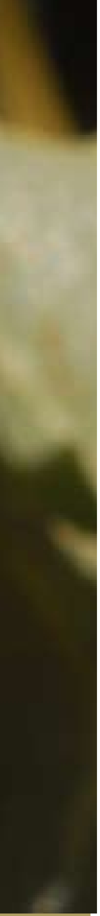
FLORASEARCH 3B

FUTURE FARM INDUSTRIES CRC

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

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

August 2009



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