Natural Heritage Trust
Helping Communities Helping Australia
An Australian Government Initiative

Search Project Report

Section 1 – Summary

Demonstration tree belt at McFarlane's property, Doodlakine (Photo: Jerome Carslake)

Final report for NHT Project 973849

There are no Appendices 9 & 10

July 2004

Government of Western Australia
Department of Conservation and Land Management
Conserving the nature of WA

Authors

Graeme Olsen[1]
Don Cooper[2]
Dan Huxtable[2]
Jerome Carslake[2]
John Bartle[2]

This report has been prepared to assist with assessment of potential new commercial opportunities based on woody perennial plants in the wheat-sheep agricultural zone of southern Western Australia. However, the work reported here is of a preliminary nature. While care has been taken in the report's preparation, no responsibility is taken by the authors or publisher for omissions or inaccuracies, or for the use of this information by any other party.

ISBN No: 0 7307 55509

[1] Olsen & Vickery, PO Box 357 Waroona, Western Australia 6215.

[2] Department of Conservation and Land Management, Locked Bag 104, Bentley Delivery Centre, Western Australia 6983.

Acknowledgments

This project drew generous support from numerous people committed to improving natural resource management in our agricultural regions. These people ranged from scientists to farmers; from those with an interest in the business of farming to those concerned by the impact of salinity-afflicted agriculture in the greater environment; to those in government from the local, State and Commonwealth levels; and from local community groups up to regional catchment groups. With their support this project was provided with a substantial allocation of funds and other resources to undertake the first uncertain steps in creating new industries based on native plant crops.

The prospect of developing new perennial crops and new industries was made more credible by the progress achieved in the development of mallee. The hundreds of mallee growers, their representative body, the Oil Mallee Association and the Oil Mallee Company were an inspiration to the project team.

As it had done for mallee, the Department of Conservation and Land Management (CALM) provided fertile ground for the emergence of the concepts and actions to create new crops from native plants. Former Executive Director Syd Shea was prepared to underwrite long-term, innovative development with a serious commitment of resources. Former CALM Wheatbelt Regional Manager, Ken Wallace, was ardent and convincing in his advocacy of exploring the native flora as the priority source of germplasm for new crops. Along with Ken Wallace, David Bicknell of the WA Department of Agriculture was party to the preparation of the original project proposal. Both helped steer the project especially in its early formative stages.

The WA Herbarium played a special role in providing access to its extensive databases and knowledge on the WA flora, which gave strong direction to selecting taxa suitable for testing. As well, the Herbarium helped with plant identification, and is the repository for all vouchers of specimens collected during this project. Many Herbarium staff contributed to the project, and we would like to specifically acknowledge Neville Marchant, Bruce Maslin and Paul Gioia.

The Rural Industries Research and Development Corporation's Joint Venture Agroforestry Program was quick to appreciate the significance of the search concept and to fund high priority research and development targets indicated by the project. The Co-operative Research Centre for Plant-based Management of Dryland Salinity established in 2001 dedicated a major sub-program to continuing search work. The interaction with these organisations provided considerable stimulation to the project.

Finally we acknowledge the Natural Heritage Trust (NHT) for providing generous support for the project. Thanks are due to the farmers and other volunteers on the NHT Regional and State Assessment Panels who strongly supported the concept of 'commercial revegetation' and helped win funds for the project. Thanks also to John Holley and his staff at the NHT State Secretariat who were always cooperative in the way they exercised their administrative obligations. Although the concept of changing the commercial plant base within agriculture to combat salinity and loss of biodiversity was not a major NHT theme, this project was supported because of its longer-term potential to make large, positive contributions to those goals. We hope we have justified the confidence NHT placed in this project.

Personnel

The project employed three staff full time within the Department of Conservation and Land Management (CALM). Don Cooper was employed as project scientist under the Farm Forestry section of the project. Dan Huxtable and Jerome Carslake managed the Bushcare section.

Graeme Olsen of Olsen and Vickery was contracted to provide management services to the project and, in particular, to oversee the technical and commercial aspects of the Farm Forestry section.

Wayne O'Sullivan of Arboressence Consultancy was contracted intermittently to collect plant specimens, seed and wood samples from the native flora of the south-west of WA. Wayne also provided invaluable advice on species selection and other technical matters.

David Kabay was contracted to supervise the Bushcare field operations in 2002 and provide support in 2003.

The project also received willing assistance from other members of CALM's Revegetation Systems Unit, including Wally Edgecombe (species selection and advice on sample collection), Pat Ryan (species selection and seed collection), Gary Brennan (species selection and assistance with solid wood testing), and Richard Giles (harvesting and logistics), as well as other CALM employees, including Peter White (species selection and general advice), Ray Cranfield (species selection), Rob Davis (species selection and seed collection) and numerous staff within CALM's Science Division.

Finally, Matthew Rumenos carried out nursery trials at Kensington, and a long list of casual workers made light work of tasks such as seed collection and cleaning, wood debarking, planting and trial measurement.

Sections in this report

Section 1	Summary
Section 2	Background
Section 3	Search Methodology
Section 4	Product Assessment
Section 5	Species Selection
Section 6	Feedstock Testing
Section 7	Economic Analysis
Section 8	Demonstration and Resource Plantings
Section 9	Propagation Project
Section 10	Project Administration
Appendices	

Contents of this section

Section 1 Summary 7

1.1 Background 7

1.2 Objectives 7

1.3 Methods 8

1.4 Results 9

1.5 Economic analysis 10

1.6 Productivity analysis 11

1.7 Demonstration plots and resource plantings 11

1.8 Conclusion 12

Section 1 Summary

This report is the final report for the "Search Project", formally known as Natural Heritage Trust (NHT) Project 973849, "Selection and development of multiple purpose species for large scale revegetation".

1.1 Background

The scale of revegetation required to make a significant contribution to salinity control and other natural resource management (NRM) objectives, is larger than was assumed in the 1980s and early 1990s. It has become clear that the business of farming would not be viable if non-commercial revegetation were undertaken on the scale necessary to control land and water degradation, even if the cost of planting were met by public investment through programs such as the NHT.

In concept, this dilemma is easily resolved. If perennial woody crops could be developed to make "revegetation" a commercially viable agricultural activity, then sound NRM practice could be achieved within normal agricultural practice. The Search Project aimed to build a foundation for the development of such "NRM friendly" woody crops.

This project's field of view was the Western Australian wheatbelt - the agricultural region of the south-west of Western Australia that has less than 600 mm rainfall per year. The project was restricted to domestication of native species, to avoid the introduction of exotic species that may pose a weed risk, therefore making them incompatible with the biodiversity conservation objectives of NHT. A principal hypothesis was that short-cycle woody crops in the wheatbelt could produce industrial wood chip at a similar or lower cost to conventional high-rainfall industrial forestry plantations, providing an opportunity to develop new, large-scale industries around processing infrastructure located in wheatbelt towns.

The mallee industry in WA pioneered new woody crop development of this type. The Search Project sought to extend the mallee experience by starting the development of a suite of new, large-scale woody crops. Small-scale industries were not considered in this project, since they provide only small-scale NRM benefits and are best developed by private entrepreneurs.

1.2 Objectives

The project had the following objectives:

1. Search process: to develop a procedure that systematically analyses plant and product attributes and identifies the best prospects for development.

2. Pre-feasibility investigation: to assemble technical, economic, biodiversity and other information to select and rank a shortlist of the 12 most prospective species for development.
3. Industry Exploration:
   - to make a preliminary selection of "best-bet" species for demonstration trials.
   - to plan and commence building industries, in particular, build a viable resource utilising best practice and planting design for prospects identified in 1 and 2.

1.3 Methods

Objective 1 involved coarse screening of species and products. Various methods involving databases and decision-making mechanisms, including expert systems, were explored in an effort to develop a suitable method for identifying combinations of species and products for more intensive testing under Objective 2. All such systems were rejected because they needed more detailed information than was available. Instead a simple six-step process was adopted where each step provides an increasingly rigorous filter of products, species, or combinations of products and species. The effort required, both in time and money, increases rapidly at each step, demanding that the early steps filter out as many poor prospects as possible, while rejecting as few prospective options as possible.

Product selection was the first step taken because it is a logical starting point for new industries, and it required fewer choices to be made than species selection. More importantly, it was not possible to select appropriate criteria for species selection until target products had been identified.

Paper, made from chemical pulp, panel boards (particle board, and medium density fibreboard, or "MDF"), and solid fuel for bioenergy were identified as the most prospective large-scale products. The potential for extra revenue from extraction of chemicals was treated as a subordinate prospect, to be investigated for species that showed promise for one or more of the other products.

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

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

The third step involved three levels of progressively more intensive testing of wood properties on decreasing numbers of species, proceeding to the final stage of manufacturing sample panels and paper. All wood samples were collected from the best stands that could be located within the time constraints of the project, from individual plants that represented the age and form that might be obtained from cultivated stands.

The first characteristic tested was wood density (by more comprehensive field coring); followed by a second level of tests that required the collection of 10 kg samples of debarked wood from 51 prospective species. The second level of tests included chipping, wet chemistry and fibre characterisation. As well, chemical pulping was performed on all samples, as it is a relatively inexpensive process that provides information on the pulp yield of each species – a critical factor for this product. At the third level, some 30 of the pulped species progressed to paper manufacture and testing, while a further 150 kg of wood was collected for species selected for panel board manufacture (18 species for MDF, and 15 species for particleboard). *Pinus radiata* was used as an "industry standard" control.

Combustion tests and ash analyses were also carried out on selected species, partly for bioenergy use, but also as a potential reductant in mineral processing.

Some investigation of the sawn timber properties of twelve prospective long-cycle timber species was also undertaken, although this was a minor part of the total project. The species selected for solid timber assessment were those that appeared to have adequate form and growth rates, but which had not previously been tested.

1.4 Results

Results from pulp and paper testing varied widely. The best four species (*Taxandria juniperina, Grevillea leucopteris, Alyogyne huegelii* and *Grevillea candelabroides*) indicated considerable promise, and deserve more intensive investigation.

Selected species for MDF and particleboard production were all successfully converted into panels with minor variations in panel quality. The lower density species among those tested (*Taxandria juniperina, Eucalyptus rudis, Viminaria juncea, Anthocercis littorea, Gyrostemon ramulosus, and Codonocarpus cotinifolius*) should be tested further to optimise MDF and particleboard production by investigating and optimising a range of production variables. In the case of MDF, optimising process variables to reduce the 'fines' content would have high priority.

Particleboard 'furnish' (the wood particles used in the manufacturing process) was not optimised in this study. Future trials should include waferising or flaking of woodchips to produce more commercially relevant particle geometries. Furthermore, the conformability of wood particles (that is, their ability to deform and pack tightly within a particleboard panel) was generally poor for the species tested. The most promising species in this respect were *Codonocarpus cotinifolius* and *Gyrostemon ramulosus.*

The wood samples used for pulp and paper testing, and for panel board manufacture were from a single collection of wood from (mostly) native populations. There is almost certainly scope to improve their performance through genetic selection, plant breeding, development of appropriate management systems, choice of harvest age and optimisation of processing variables.

Work on charcoal as a reductant and the combustion properties of residues of the most prospective paper and panel species also indicated promise. For example, a number of species had low ash content, and require further investigation of their potential as reductants. Combustion tests confirmed that a large number of species are suited to bioenergy uses. The species tested were within the normal range of calorific values, were not prone to cause excessive fouling or corrosion in conventional boilers, and compared well with other potential bioenergy materials. Major factors in their use would be the cost of production and delivery, and the feasibility of reducing their moisture content prior to combustion.

The examination of the sawn timber potential of a number of previously untested species indicated considerable variation in performance and some potential options to add to the selection of currently used species. In summary, all of the eucalypts and one of the acacias (*Acacia bartleana*) produced reasonably high yields of good quality timber suitable for commercial use. The potential of these species to be grown for commercial sawn timber depends on factors such as their growth rate, form, and the potential impediments of long drying times and poor gluing performance when laminated. These issues would need further investigation if any of these species were to be developed commercially.

Based on the results for the various product types, the project’s objective of identifying twelve prospective species for further development was met. Since a wide range of species showed potential as feedstocks for the products tested, further work should be targeted first at those species likely to have other advantages such as high growth rate, wide genetic variation, ease of propagation and establishment, and simple management requirements within integrated farming systems.

1.5 Economic analysis

Economic analysis was undertaken of three distinct crop types – traditional long-cycle tree crops for solid wood products, and short-cycle phase crops and short-cycle coppice crops, both suited to uses requiring woodchips or bulk biomass.

The results show that long-cycle tree crops have poor economic prospects in medium and low rainfall areas, due to the large cash outlay at establishment, and the long wait for returns from the crop. Using discount rates applicable to private growers, long-cycle crops are unlikely to be profitable, unless a substantial value can be attributed to indirect benefits. Long-cycle tree crops grown in blocks were especially unprofitable, while the same trees grown in belts were less unprofitable, due to their higher productivity per tree.

In contrast, under the assumptions used in this study, farming systems incorporating short-cycle phase crops, or coppice crops in belts, were competitive with annual agriculture over the period of analysis (20 years). Indirect benefits resulting from these crops, such as on-farm improvements in sustainability or productivity, or downstream ecological services, would be a bonus, and did not need to be incorporated into the analysis to make the crops profitable.

Indirect benefits were deliberately excluded from this analysis for two reasons. Firstly, in the case of on-farm benefits, their potential value is difficult to calculate, and secondly, in the case of carbon sequestration and downstream ecological services, markets have not yet emerged. Markets for ecological services may be instituted in future in certain circumstances, but their potential value and the circumstances in which they might apply are still uncertain. Above all, ecological services markets will always be artificial constructs vulnerable to political change and may therefore be heavily discounted by potential growers when evaluating long-term options.

This suggests that it would be desirable to develop new short-cycle crops for medium and low rainfall agricultural areas, rather than relying on ecological services markets to encourage long-cycle tree crops into drier areas beyond their limits of profitability.

1.6 Productivity analysis

Water is the basic constraint to tree crop productivity in agricultural areas. The Search Project initiated a new productivity analysis of generic woody crops based on the availability of surplus water in the agricultural landscape. By using relationships developed experimentally in other projects, available water was converted into an average (year-in, year-out) production rate of woody material.

This analysis demonstrated the effect on woody crop production, and hence the economics of woody crops, of capturing surplus agricultural water, and therefore the importance of designing woody crop layouts that optimise water capture. The relationship between water and biomass production was in turn used to calculate regional production capacities (or biomass production density) and then linked to the potential for processing industries of different scales to secure access to sufficient raw material within an economic transport horizon of various locations.

A developmental version of this analysis is presented in this report. Preliminary results suggest that typical panel board industries could source adequate feedstocks for their needs from most agricultural areas in Western Australia, but that large scale state-of-the-art chemical pulp mills (requiring up to 3 million tonnes of feedstock per year) would probably exceed the wheatbelt’s supply capacity. This indicates that if such industries were to be developed they would need to be located adjacent to high rainfall areas to increase biomass production density within a feasible transport radius.

The new analytical method presented in this report appears promising and warrants further work to both refine the method, and to collect more accurate data for the critical components of the analysis.

1.7 Demonstration plots and resource plantings

The third objective of the Search Project was to explore the industry potential of selected native woody species by establishing demonstration plantings and larger scale plantings by farmers. In theory this part of the project should have followed the identification of the most prospective species so that they could be subject to extensive planting and testing. However, it was not possible to do this within the prescribed 3-year term of the project. Hence a wide range of subjectively selected species was used, especially in the earlier years of the project. The aims of this part of the project were to engage farmers in planting and managing potentially commercial native species, to demonstrate particular important management factors, and to begin building up a potentially commercial resource.

Over four winters, 107 demonstration sites were planted and 6.3 million seedlings drawn from 158 species and provenances were established in bulk plantings by 610 farmers. The performance of the early-planted demonstration sites was recorded. Data relating to all plantings are accessible within geographic information systems and are summarised in this report.

1.8 Conclusion

This project has firmly established the objective of domestication of native woody species on the national natural resources management agenda. The project has taken the first three steps in the Search process, provided a large body of data on wood properties of many species, and produced a short list of the more prospective products and species. It has also established extensive plantings of prospective commercial species. The concepts presented and explored by this project have been adopted in emerging projects by the Joint Venture Agroforestry Program and the CRC for Plant-based Management of Dryland Salinity.

Natural Heritage Trust

Helping Communities Helping Australia

An Australian Government Initiative

Search Project Report

Section 2 – Background

Salt lake near Tincurrin (Photo: Graeme Olsen)

Final report for NHT Project 973849

July 2004

Government of Western Australia

Department of Conservation and Land Management

Conserving the nature of WA

Authors

Graeme Olsen [1]
Don Cooper [2]
Dan Huxtable [2]
Jerome Carslake [2]
John Bartle [2]

This report has been prepared to assist with assessment of potential new commercial opportunities based on woody perennial plants in the wheat-sheep agricultural zone of southern Western Australia. However, the work reported here is of a preliminary nature. While care has been taken in the report's preparation, no responsibility is taken by the authors or publisher for omissions or inaccuracies, or for the use of this information by any other party.

ISBN No: 0 7307 55509

[1] Olsen & Vickery, PO Box 357 Waroona, Western Australia 6215.

[2] Department of Conservation and Land Management, Locked Bag 104, Bentley Delivery Centre, Western Australia 6983.

Sections in this report

Section 1	Summary
Section 2	Background
Section 3	Search Methodology
Section 4	Product Assessment
Section 5	Species Selection
Section 6	Feedstock Testing
Section 7	Economic Analysis
Section 8	Demonstration and Resource Plantings
Section 9	Propagation Project
Section 10	Project Administration
Appendices	

Contents of this Section

Section 2 Background **5**
2.1 Brief history of plant domestication 5
2.2 Plant introduction 6
2.3 Previous ‘searches’ of Australian flora 9
2.4 Tree crops in Western Australia – case studies 10
2.5 Salinity 13
2.6 Biodiversity issues 16
2.7 Agricultural issues 17
2.8 Designing a new woody perennial crop 18
2.9 References 22

Section 2 Background

2.1 Brief history of plant domestication

Man commenced the transition from hunter-gatherer to agricultural man only some 11,000 years ago. This milestone in human evolution came with the beginning of domestication of plants and animals. It arose spontaneously at several locations at different times and diffused at different rates between locations until today the major domesticated species are utilised globally and the hunter-gatherer existence is nearly extinct (Diamond 1997).

For most of the period of evolution of agricultural man domestication has not been a conscious process. Diamond (1997) has woven the extensive literature on this subject into a fascinating synthesis of the recent history of man called ‘Guns, Germs and Steel’. This is the main source for this brief review of plant domestication.

Domestication commenced when man’s impact on the selection pressure applying to local plant and animal populations became significant. Man selected desirable species, and within species, individuals with particular desirable attributes. The motivation was to collect material that was better to eat or use. These more desirable wild selections became the cultivated population, and received favoured management. Over the millennia with continuous application of selection they became progressively more distinct from their wild ancestors, both morphologically and genetically. They were also spread widely, usually far beyond their natural range.

Today the selection criteria that were consciously or unconsciously applied are intuitively obvious. For plants they include:

- Eating quality including: tastiness, absence of bitterness or toxicity, good nutritional value, seedlessness in vegetatively propagated fruits (e.g. banana).
- Convenience in collection and use including: large fruit or seed size, retention of seed or fruit on the plant, easy preparation for eating, large proportion of usable fruit, storability.
- Ease of cultivation including: ready germination of seed, large seed size, high yield, short production cycle, adaptability to a range of soil and climate conditions, resistance or tolerance of pests and diseases.
- Reproductive biology: gains from selection and favourable mutants are not preserved if the species freely interbreeds with its wild neighbours. Hence self-pollinating and vegetatively propagated species were the only ones where selection was reinforced and rapid domestication could proceed.

By Roman times almost all of today’s leading crops were in cultivation. Man had sorted through some 200,000 wild flowering plants, chosen to take food from a few thousand and had taken the steps towards domestication of a few hundred. Today 12 of these species contribute more than 80% of global food production. In this context it is not surprising that a whole continent like Australia has made no contribution to the major food crops of the world.

In contrast to the ancient origins of domesticated food and fibre crops much of the biomass for forage, fuel, construction and more recently, industrial feedstocks, has come from ‘hunter-gatherer’ utilisation of natural forests or woodlands (30% of global land area) and grasslands. It is likely that some forage, fuel and construction material was provided as by-products of food crops. Also some forages like lucerne did have ancient origins (Mathison 1983). However, these non-food crops (or products) generally did not attract the high selection pressures applied to the major food crops and their domestication is mostly a twentieth century phenomenon.

Domestication of forages was particularly active in Australia where the native flora was deficient in productive species (McIvor and Bray 1983). The cultivation of selected tree crops had expanded to 187 million ha or 5% of total global forest area by the year 2000. Half of this area is less than 15 years old reflecting a rapid increase in the proportion of production coming from cultivated tree crops, in part driven by concern about over-exploitation of native forests (FAO 2001).

The science of genetics is a very recent development. It has greatly enhanced the rate of genetic improvement of the ancient crops and has aided the domestication of new minor crops. However, even with the advantage of modern genetics, it seems unlikely that the domestication of new species will dislodge the ancient food crops from their position of dominance. Not only is there an enormous genetic investment in the ancient crops but there is also a large cultural commitment. This issue has been raised in the debate about the potential for domestication of *Acacia* as a food crop in Australia (see Section 4.2).

However, in the case of new crops for production of industrial commodities science may be on the brink of major advances. The emerging capability of genetic engineering may see the creation of new metabolic pathways and crop species to produce specific industrial product feedstocks (Renewables Vision 2020 Executive Steering Group 1999).

2.2 Plant introduction

2.2.1 Global perspective

The regional diffusion of crop plants is as old as plant domestication. The process of introduction of plant crop germplasm to new locations by humans extended over many millennia. Diamond (1997) reviews how this diffusion of plants was influenced by geographic and ecological conditions. For example, South-west Asia was the centre of origin of a package of temperate crop species. This package was able to spread rapidly east and west across Europe, Africa and Asia in the band of temperate latitudes where comparable day length, climate and seasonal cycles prevail. This dispersal was completed before the time of Christ. In contrast these species did not spread south into the hotter and less seasonal environments of Africa north of the equator. Tropical and sub-tropical African native species were domesticated at separate centres of origin south of the Sahara and these contributed to a wave of southwards diffusion that passed readily through the tropical latitudes. But being summer growing, frost sensitive species they could not penetrate the Mediterranean climate zone of South Africa. The introduction of suitable crop species for this zone, such as those of South-west Asian origin, had to await the arrival of European colonists. This did not occur until some 2,000 years after South-west Asian species had completed their dispersal across Europe and Asia.

One of the motivations of Europeans in the colonial period was exploration of the economic flora of the world, its commercial exploitation and trade in its products. The millennia of passive diffusion of crop plants had resulted in wide dispersal of some species but plenty of opportunity for more deliberate introduction remained. The Americas provided a rich harvest including maize, potato, beans, chilli, cotton and tobacco, while Asia was the centre of a flourishing trade in spices.

As trade and colonisation accelerated it increased awareness of the diversity and economic value of crop plants and drove a period of intensive, undisciplined plant introduction on a global scale. There were early attempts to limit the dispersal of plant pests or plants that might become pests. This process was particularly active in Australia.

2.2.2 Australian perspective

A striking feature of Australian pre-history is retention of the Aboriginal hunter-gatherer lifestyle in spite of long-standing exposure to agricultural people and trade from the islands to the north. What constrained agricultural development in pre-European Australia? Diamond (1997) ascribes this to geographic and ecological barriers. The species immediately available for introduction, Asian tropical crops, were not suited to the coastal monsoonal tropics or the semi-arid interior of Australia. Other barriers to agricultural development on the continent included the generally arid climate, substantial climatic variability, infertile soils and the paucity of native species suited to domestication. Like South Africa the large agricultural potential of the temperate regions of the southern Australia had to await the more deliberate introduction of South-west Asian germplasm before agriculture could begin.

British settlement of Australia occurred late in the colonial period. By this time the first fleet and subsequent colonists had access to many sources of germplasm and were able to provide the continent with a substantially new economic flora.

Burt and Williams (1989) review the history of plant introduction to Australia. They refer to the period up to 1930 as ‘the undisciplined years’. By 1804 (16 years after the first fleet) the colony’s botanist Robert Brown recorded 29 non-crop species growing wild in the Sydney area. By 1820 the colony had a stable ‘European’ agriculture. A list of plant introductions cultivated in the Government Botanic Garden, Sydney published in 1857 contained 3,000 species and varieties.

Plant introduction was motivated by economic objectives and nostalgia; it was undertaken by new settlers, experts and enthusiasts; and it occurred passively accompanying fodder, animals, seed and soil. The *Xanthium* species, Bathurst burr (*X. spinosum*) and Noogoora burr (*X. pungens*), were passively introduced and first recorded in the wild in 1840 and 1860 respectively. The earliest woody weed was blackberry (*Rubus fruticosus*) first recorded in the wild in Victoria in 1843 closely followed by lantana (*Lantana camara*) in Queensland in 1869.

By the 1850s it was clear that considerable damage was being done by uncontrolled plant introduction. Noxious weed control legislation was introduced in South Australia in 1851 and Victoria in 1856. Acclimatisation societies also emerged at this time. They aimed to bring some order to selection and testing of new introductions but were often more strongly supported by enthusiasts than scientists and attracted some disdain.

However, these developments marked the early signs of a new phase of planned plant introduction that eventually led to the establishment of the CSIRO Plant Introduction Section in 1929. Then, as now, national collaboration was complicated by state's rights issues. However, by the 1930s there was practical co-ordination if not formal procedures for national plant introduction, including:

- Systematic and accessible documentation.
- Scientifically planned collections targeting new germplasm for specific purposes.
- Improved facilities for testing and assessment.
- Rationalisation of quarantine procedures.

This gave rise to a period of ordered, scientifically based, plant introduction that lasted nearly to the present. This phase saw the collection of a large range of germplasm of economically important species, and of species with potential to fill gaps in the coverage of available economic species. This occurred in the face of rapid erosion of global 'wild' genetic resources through human population growth and intensification of land use, and also the emergence of ownership of genetic resources as an issue.

It is striking in the review by Burt and Williams (1989) that Australian governments and institutions tolerated the 'undisciplined' years of plant introduction up to the 1930s, despite the manifest shortcomings of this process, and despite some progressive moves to control noxious weeds and impose quarantine dating from the mid 1800s. Burt and Williams (1989) were apparently well satisfied with the belated transition to an ordered, science-based regime during the 1930s and were uncritical about its performance up to the time of their review. However, strong critical commentary soon followed.

For example, Lonsdale (1994) compared the rate of introduction of useful species with that of weeds in exotic pasture plant introductions into northern Australia in the period 1947 to 1985. He examined 463 grass and legume species in 2,033 accessions and found 21 species were useful while 61 were listed as weeds. Of the useful ones 17 were also weeds in some situations. Hence only 4 species were useful without causing some form of weed problem. He challenged the viability of extensive pasture plant introduction.

This type of criticism stimulated a period of intense scrutiny of the issue of plant introduction in general that remains active today. Although not clearly articulated in the literature the argument for plant introduction is strongest where there is a prior investment in domestication of the particular species in its source area, and a managed production system within which it might be confined after introduction. If these conditions do not prevail, as in the Lonsdale example, the risk of an adverse cost/benefit outcome will be large.

Biosecurity has become a global concern (FAO 1995), with activity in many countries. In Australia's case, a National Weed Strategy was prepared (Anon 1997). Goal number 1 was to avoid new weed problems by preventing introduction of new species with weed potential. It was proposed that this be achieved by:

- Strengthening entry protocols for assessing the weed potential of all proposed new plant imports.
- Initiating community education programs to increase awareness of the use of native plant species in preference to importing new plants

Pheloung (2001; 1999) developed a scoring system for ‘weed risk assessment’ in Western Australia, based on a series of questions covering a plant’s domestication, climate preferences, weed history, undesirable traits, growth form, reproduction, dispersal and persistence attributes (Virtue not dated (approx 2000)). This system was adopted by Biosecurity Australia, and has been used to define a ‘permitted list’ for plant introduction (Walton 2001). Pheloung’s system is finding wider applicability, and has been tested in Hawai’i in a slightly modified form (Daehler and Carino 2000). There it was successfully validated by assessing a wide range of exotic plants and comparing their objective assessment with known outcomes and expert opinion (Daehler and Denslow not dated (approx 2002)).

It was against this background of heightened consciousness of the potential dangers of introduced species that the Search project was developed in 1997. Its objective was to fill the perennial crop void in the WA wheatbelt. There were no obvious existing woody crop candidates either locally or overseas. Desirable candidates would need to have attributes of rapid growth, adaptability to a range of sites and tolerance of a low input management regime. As argued by Lefroy (2001) in relation to fodder shrubs, these are also the capabilities of weeds. The Search Project therefore chose to pursue the domestication of native species rather than introduce new species.

Although domesticates might be strongly preferred they are not without problems. A domesticated population may transfer genes to an adjacent native population via pollen. This process of introgression or gene flow between populations can occur naturally but when induced by man has been called ‘genetic pollution’. Potts et al. (2003) review this phenomenon, particularly in relation to *Eucalyptus*, and identify significant concerns. Where there are receptive native populations pollen can be invasive, in an analogous way to seed, and diminish the value of the wild genetic resource. On the other hand introgression of new genes from domesticated plantings may also improve the vigour of inbred isolated native populations (Byrne 1999; Byrne and McDonald 2000). Potts et al. (2003) propose a framework for assessment of the risk of genetic pollution.

2.3 Previous ‘searches’ of Australian flora

In the broadest sense the English navigator William Dampier began the search of the native flora of Western Australia with collections taken in 1699. Some 70 years later Sir Joseph Banks arrived on Captain James Cook’s first voyage (1768-71) and with a small team of naturalists made collections at several locations. A portent of the importance of the work they began was preserved in the name of one of their locations, Botany Bay. In contrast to the chaos of plant introduction, the concurrent activity documenting and collecting the native flora was scientifically rigorous. Within 90 years of the first settlement in 1788, George Bentham, was able to complete *Flora Australiensis*, consolidating the knowledge of the flora by systematically describing 8,168 species in

1,400 genera. This was all done without having visited Australia and was based on collections preserved in Europe, especially Kew Herbarium in London.

Part of the motivation for scientific investigation of the flora was practical and economic. But in terms of early opportunities for agriculture and trade the flora was not rich. However, the negative balance of trade has been partly offset in the twentieth century with the recognition of the forestry potential of *Eucalyptus* and *Acacia* and more recently the floriculture potential of many genera. It is estimated that the global area of *Eucalyptus* plantation was 14.6 million ha in 1995 (Coppen 2002). Australia has been a conscientious exporter of germplasm for forestry and floriculture. It has traditionally imposed no restrictions on the private export of seed. Indeed it has provided a national scientific tree germplasm export service, the CSIRO Australian Tree Seed Centre, whose collection of germplasm is based on sound 'search' principles. This passive policy is now being examined in the light of Australian responsibility and commitments under the Convention of Biological Diversity (CBD) and emerging issues related to bio-prospecting (Australian Tree Seed Centre 2003).

There have been previous 'searches' for germplasm of large trees for timber, shrubs and grasses for forage and higher value chemicals. However, the Australian flora has not previously been explored for its potential to provide feedstocks for large-scale industries making reconstituted wood products and energy.

2.4 Tree crops in Western Australia – case studies

All the successful tree crop developments in Western Australia have involved State government investment in the early, or pre-feasibility stages, usually continuing until the new industry is sufficiently well established to attract private investors.

2.4.1 Pine development

In contrast to other southern Australian states WA chose to initiate its pine plantation development with *Pinus pinaster* rather than *Pinus radiata.* Pinaster was chosen because of its greater tolerance of the infertile soils and lower rainfall that predominated in WA. Planting commenced on a small scale in the 1920s but only 1,000 ha had been planted up to the end of the Second World War. Planting of *Pinus radiata* commenced in the mid 1950s by which time total planting was 2,700 ha (all statistics from Wood *et al*. (2001). Gerrand et al. (2003) in a recent national overview of plantations categorise this early phase as 'softwood import replacement'. The objective was to provide a domestic source of non-hardwood timber. This early development was publicly funded and conducted on public land, often cleared native forest.

The second phase of development extended to the mid 1970s and had the greater ambition of self-sufficiency in timber production. It added another 25,000ha to the planted area with the planting rate of *Pinus radiata* exceeding *Pinus pinaster* for the first time. During this period the states had access to Commonwealth funds under the Softwood Forestry Agreement. This period saw the emergence of significant private investment in plantations as well as significant areas of planting on farmland. It also saw the beginnings of community opposition to the plantation forestry being conducted on both farmland and cleared native forest land.

Pine establishment reached its peak in the period up to the end of the 1980s with an additional 43,000ha being planted. Private ownership and farmland planting exceeded planting by public investment on public land. This period saw the hardening of the position on access to land. A new Government elected in 1983 terminated public investment in the clearing of native forest for plantation establishment while Government purchase of farmland for plantation establishment also became politically impossible. This led to a review of forest industries in WA and preparation of a new Timber Strategy (Department of Conservation and Land Management 1987). The directions that emerged were for new production capacity to have an export orientation and scale, to engage farmer participation in timber production through sharefarming arrangements and to design sharefarm planting to capture environmental benefits (Shea and Hewett 1997).

Pine planting contracted in the 1990s with only 23,000 ha established in that decade. However, *Pinus pinaster* regained its ranking as the major species being more suitable for the lower rainfall, lower fertility soils that were the most accessible for farm forestry. Under its new 'Infinitree' program the Forests Products Commission (2003) is aiming to extend the rainfall range and scale of pine farm forestry activity at least some way in the direction that the name implies.

2.4.2 Blue gum development

The reduction in pine planting in the 1990s was much more than offset by the rapid emergence of planting blue gum (*Eucalyptus globulus*). This development was precipitated by the entrepreneurial effort of CALM, which conceived that coordination of several key factors might stimulate commercial activity:

- After more than a decade of under-investment in pulp and paper manufacture there appeared to be strong emerging demand for blue gum fibre in Asia.
- The sharefarming arrangements that were being developed to form partnerships with farmers and win access to land for pine planting could be applied to blue gum.
- Blue gum had been shown to have good water use and salinity control potential.
- Blue gum could be 'integrated' with conventional farming activities.
- A declaration of confidence through initial public investment in large scale planting.
- At least one major Japanese paper manufacturer had to be attracted to invest in the industry.

This was achieved over the period 1988 to 1994 (Bartle 1991, 1993; Bartle and Shea 1989; Shea and Bartle 1988; Shea *et al.* 1992/93; Shea and Hewett 1997).

Some 200,000 ha of blue gum were established in the decade. The indication of serious interest by the Oji Paper Company was enough to release a wave of domestic investment in planting. Unfortunately it happened too fast. The substantial investment in the development and demonstration of integrated planting, designed to form partnerships with farmers and achieve salinity and other landcare benefits, was not realized. Only some 2% of planting was integrated or multiple purpose farm forestry. Most of the planting was on land purchased by investors and converted to plantation and categorised by Wood et al. (2001) as industrial forestry. Competition increased the price of land and farmers who had been in depressed agricultural industries for decades were happy to sell and retire. The farm plan illustrated in Bartle (1991), specifically developed to demonstrate integration for multiple benefits, was on a property that was subsequently sold and converted to plantation.

This rapid large-scale conversion to plantation caused antagonism in local communities, resulted in a significant proportion of poor quality land being planted and failed to capture the greater yield that belt or targeted block planting could achieve. It will not return as great a dividend in the form of off-farm benefits as the public investment might reasonably have expected.

However, blue gum was constrained to areas with greater than 600mm rainfall per year, which is only a small proportion of the farmland that could benefit from tree crops. The methods developed and lessons learned in blue gum could be applied to new tree crop opportunities in lower rainfall areas. This was always part of the plan (Bartle 1993; Shea *et al.* 1992/93).

2.4.3 Mallee eucalypt development

Development of a mallee industry in WA was commenced by CALM in 1992. The objective was to create a new large-scale industry based on a tree crop that would be profitable for farmers to grow as well as being a major part of their capability to control salinity (Bartle and Reeves 1992). Bartle and Shea (2002) reviewed progress in this development. They identified five major strategies that appear to have been important in the success of the development to date:

1. A conceptual plan: all planning was conducted within a framework that was designed to maintain coherent development. This framework evolved over several years to become the development model used in the Search Project and presented in Section 2.8. There was a considerable body of previous work that had identified mallee as a prospective crop. Thus the ‘search’ step in the development process has already been taken. A comprehensive pre-feasibility investigation was conducted during 1992-4 (Bartle *et al.* 1994). Perhaps the major accomplishment of the mallee development was to identify and systematically conduct the step called ‘industry exploration’. This pre-commercial work included many aspects of the technical, environmental and socio-economic aspects and it was the foundation upon which the feasibility investigation (Enecon Pty Ltd 2001a) and engineering demonstration (Chegwidden *et al.* 2000) could be built.

2. Assured ‘pre-commercial’ investment: The absence of woody crops in the wheatbelt might be taken to indicate that no such crop could ever be commercially viable. Alternatively, it could indicate that the risk and uncertainty of new large-scale woody crop development presents an insurmountable barrier to even the most venturesome entrepreneur. Mallee industry development was predicated on the latter assumption. The working hypothesis was that with sufficient start-up investment the ‘industry exploration’ step could be taken and a commercially viable industry created. However, the speculative nature of the investment and the fact that a significant proportion of the expected return was public benefit, dictated that the investment should come from the public sector. Given the major financial commitment of CALM, the mallee development was able to attract such investment capital.

3. Integration: tree crops need to capture extra water (more than just rainfall) to achieve viable yields in the wheatbelt. This can be done by clever design (Section 7). The bulk of mallee planting has been in belt or ‘alley’ systems on good quality cropland. Mallee is tolerant of grazing, and if managed correctly, does not require fencing.

4. Farmer ownership: the success of integrated productions systems requires active and committed involvement of the farmer. Belts of trees dispersed across farmland are vulnerable to adverse impact from fire, grazing and agricultural chemicals, and can benefit substantially from sympathetic management of the adjacent agricultural land. Also, farmer confidence in a new industry will facilitate rapid growth. For these reasons a substantial and united position of farmer involvement in mallee production developed. Farmers have built a strong growers’ association and control the production end of the development.

5. Scale: mallee development set out to utilise the considerable economies of scale that make WA wheatbelt farmers strong commercial competitors. Scale of production also demands total utilisation of harvested mallee biomass and development of products and markets for residues. The development recognised that a combination of higher value uses for the wood chip, and bioenergy uses for residues would be essential (Bartle 2001; Bartle *et al.* 1996).

Although it is not yet a commercial reality, the promise revealed in mallee has given confidence that there is serious commercial potential in new woody crops. The mallee development was the motivation and model for the Search Project. It demonstrated that novel ‘short-cycle’ crop types might be feasible and revealed the native flora as a prospective source of germplasm.

2.5 Salinity

2.5.1 Introduction

Dryland salinity is a pervasive and increasing problem in the agricultural landscapes of southern Australia, especially in the south-west of Western Australia, where its expression is most advanced. State government reports that describe the processes involved in dryland salinity in Western Australia, and outline strategies and actions to combat salinity include *Salinity; a Situation Statement for Western Australia* (Agriculture Western Australia *et al.* 1996a), the *Western Australian Salinity Action Plan* (Agriculture Western Australia *et al.* 1996b) and the *Salinity Strategy* (State Salinity Council 2000). A review of the WA Department of Conservation and Land Management’s programs under the *Salinity Action Plan* adds extra perspective to the task of salinity management, with particular emphasis on the interaction between salinity and nature conservation (Wallace 2001).

2.5.2 The nature of the problem

The generic nature of the salinity problem is now well defined but there remains a considerable lack of knowledge and contention about the detail. This is a major impediment to designing more effective treatments, especially woody perennial crops.

The south-west of Western Australia consists mainly of an ancient, highly weathered granite plateau of low relief. Prior to European colonisation winter dominant rainfall was effectively captured in the deep (about 25 m) weathered layer on the plateau surface, and discharged in the summers through transpiration by the deep-rooted native vegetation. The approximate equivalence of rainfall and evapotranspiration in the water balance meant that the trace of salts arriving in rainfall accumulated in the profile and that the proportion of stream flow was low (less than 5% of rainfall). In the natural condition weathered profiles were kept relatively dry, salt was in stable storage, groundwater systems were not extensive and stream flow was intermittent but relatively fresh.

European agriculture removed the native deep-rooted woody vegetation and replaced it with shallow-rooted annual agricultural species. This reduced plant water use by interception (less evaporative loss direct from the plant surface) and by transpiration (rainfall infiltrating below the shallow root depth of the annual plants could no longer be extracted). There is general agreement that this reduction in plant water use leads to about 10% of rainfall infiltrating beyond the agricultural plant root zone. This is a relatively small reduction in evapotranspiration, but it forces a very large change in the storage and stream flow components of the water balance, such that the hydrological character of the whole landscape is changed.

The surplus rainfall progressively wets up the weathered profile and accumulates as groundwater. Groundwater systems progressively expand in thickness and area to intercept and mobilise previously stable salt storage. The conductivity and slope of the saturated layer or aquifer is generally low, so groundwaters build up substantial thickness and move downslope only slowly. On the plateau the groundwater flow path from divide to valley floor is usually less than 10 km. Groundwater eventually intersects the surface on lower slopes, valley floors or streamlines and discharges saline water. In the wheatbelt region this discharge is often as salty as seawater.

2.5.3 Predicted extent

This process of accumulation of groundwater is not yet in equilibrium with discharge. This means that the degradation now being expressed is not yet fully developed. The extent of damage at full development, probably several decades away, constitutes the State's most serious environmental risk (State Salinity Council 2000). The type and projected extent of damage, mainly based on State Salinity Council (2000) is as follows:

- Loss of agricultural productivity: the National Land and Water Resources Audit (2001) estimates that salt-affected soils will increase from the present 1.8 million ha to 7 million ha by 2050. This indicates that the whole valley floor component of wheatbelt landscapes will have shallow saline groundwaters that reduce productivity and utility.
- Water resources: all rivers emanating from the wheatbelt are saline. Even streams in higher rainfall areas that have a partly cleared catchment have increasing salinity

concentration. Some 36% of previously usable water has been lost and another 16% is marginal. Several key catchments have been targeted for recovery.

- Biodiversity: the change to valley floor hydrology will impose severe adjustment on the biota. Some 450 endemic vascular plant species alone will be under threat of extinction.
- Infrastructure: all fixed structures on valley floors will be subject to an increasing degree of waterlogging of their foundations, increasing costs of maintenance and reducing working life. For example, road life expectancy can be reduced by 75%.
- Flood risk: intense rainfall events are buffered by the capacity of water to quickly infiltrate into the soil. If 30% of the landscape is already saturated to the surface the proportion of immediate runoff in peak events is dramatically increased. Hence flood frequency and height will be increased further putting infrastructure at risk.
- Social implications: these biophysical impacts would impact severely on the economic and social circumstances of wheatbelt communities. These regional communities face the risk of intervention by the wider community, both domestically and internationally.

2.5.4 Strategies for management

Conceptually there are three management options:

- Learn to live with the problem.
- Use more water within agricultural systems.
- Devise acceptable means to extract and discharge groundwater.

These are not alternatives. In reality it will take elements of each to improve the management of salinity in future agricultural systems. To a large extent the reduction of recharge through increasing the water use within agriculture will reduce the scale and cost of extraction and discharge of groundwater.

Two key issues are briefly dealt with here to indicate some of the directions of debate about salinity management and major policies and programs that are working towards solutions. The key issues are:

2.5.4.1 Effectiveness of perennial plant water use

The thesis is that agricultural recharge can be significantly reduced by a sufficient proportion of perennial plant cover. This has been an article of faith in the considerable investment in revegetation with trees that has been promulgated in Government programs such as the One Billion Trees Program and NHT for more than a decade. However, Peck and Hatton (2003) in reviewing the case say ‘the likelihood of reversing or containing salinity and recovering rivers through recharge control is low…’. Bartle (1999a) characterised this position as too pessimistic because it assumes that perennials are only active in preventing recharge on the immediate area on which they stand, and that they would therefore need to occupy most of the landscape to be effective. He defined the three conceptual flow paths along which ‘water comes to trees’, thus increasing the effectiveness of the trees in capturing the surplus from adjacent area under annuals. There is good recent physiological evidence (to complement the numerous earlier reports) that belts of trees do indeed consume more than rainfall

(White *et al.* 2002; Wildy *et al.* 2003). However, these studies do not clearly distinguish whether the extra water consumed is supplied by lateral flows or is extracted from deep storage. The Cooperative Research Centre (CRC) for Plant-based Management of Dryland Salinity has initiated research designed to explore this issue.

This is a vital question because, as shown in the analysis in Section 7, the capture of water in addition to rainfall is a key determinant of yield and commercial viability. If lateral flows turn out to be available only on limited areas then the role of permanent belts of coppice crops will be diminished and the role of phase crops will be enhanced.

2.5.4.2 Commercial perennial plants versus volunteer planting

A clear outcome of the debate concerning the effectiveness of perennial plants is that there is now a better acceptance that the scale of adoption required is much larger, and the value of the benefit per treated hectare is smaller, than has been previously assumed. This weakens the position that salinity might be treated by volunteer, non-commercial revegetation (Pannell 2001). Hence the salinity problem should be seen as a need to modify the suite of commercial crop plants within agriculture, not only as an opportunity for public investment to restore modest areas of bush on farms. The Search Project is a substantial NHT project that has recognised this position.

2.5.4.3 Money hitting the ground

Farmers have expressed great frustration with what they see to be excessively bureaucratic procedures slowing the implementation of publicly funded revegetation on their farms. They have pushed for a greater proportion of funds to be directed to 'on-ground works'. As discussed above it appears that volunteer, non-commercial revegetation does not have the potential to control salinity alone, and that commercial perennial crop options need a large investment in R&D before they can be ready for adoption. The issue of money 'hitting the ground' is not helpful to fostering the R&D that is required for woody crops.

2.6 Biodiversity issues

Natural biodiversity is under severe threat from salinity. However, the threat is not direct as would be the case in new land clearing. The threat is a consequence of salinity generated by agriculture, leading to the loss in area and viability of wetlands and remnant native plant habitat. The projected expansion in salt affected land from 1.8 to 7.0 million hectares over the next 50 years (National Land and Water Resources Audit 2001) will see the demise or decline of the remnant vegetation component in an additional 5.2 million hectares. Assuming a wheatbelt average of 10% remnant vegetation that is uniformly distributed, the potential loss of more than 0.5 million hectares of bush or about 10,000 hectares per year is indicated. This loss will be confined predominantly to the valley floor landform, thus generating potential for mass extinction of the biota endemic to that landform.

Two complementary strategies have been adopted to address this issue:

- Develop economically viable salinity mitigation, both recharge control and discharge management (such as groundwater pumping and deep drainage), so that a generic solution is achieved.
- In the meantime, select high priority biodiversity conservation targets and implement currently available (but expensive) salinity mitigation measures to protect them from degradation until more economically feasible treatments are developed.

The Search Project and the new woody crop industries it plans to generate are a vital component of a generic solution. Its focus on native species only is an added biodiversity protection tactic, reducing the risk of weeds and providing more favourable habitat for native biota than would exotic woody crops. The issue of genetic pollution (Section 2.2.2 above) is a concern, but is considered to be subordinate to the imperative to develop large-scale native woody crops.

A program for protecting high biodiversity areas from salinity was initiated in the Western Australian Salinity Action Plan (1996b). Called ‘natural diversity recovery catchments’ these are areas of biodiversity value threatened by salinity. One of the challenges for this program is to develop, finance and implement the scale of pre-emptive treatment that will be required. Discharge controls using engineering methods can provide rapid relief at a manageable cost to small targets like Toolibin Lake. However the cost of such treatments on the larger scale is prohibitive. It appears that longer-term recovery will also require recharge control treatments. Indeed there is good potential for public investment to establish woody crop resources in recovery catchments, thereby facilitating both recovery and commercial development.

2.7 Agricultural issues

The development of woody crops should aim to make them directly competitive with the long-term average returns from alternative annual crops and pastures. This is a sound principle because farmers will select the most viable business options. They are also unlikely to adopt any new, long-term crop that relies on payments for environmental services that may have a short political life.

A commercially competitive woody crop, or ideally a suite of woody crops, could bring important farm business and regional economic benefits. Wheatbelt agriculture is currently locked into a narrow range of farm business options – grains, meat and wool. There are several potential benefits that woody crops may deliver in addition to being commercially attractive on their own account, including:

- Primary commodity products are exposed to long-term decline in terms of trade where real values have declined from an index of 100 in 1950 to 42 in 1990 (Chisholm 1992). Farmers have substantially offset this by increasing their productivity and farm size. Diversification into industrial commodities that are not exposed to the same economic forces may provide farmers with better short-term management of price volatility, better long-term terms of trade, and better-balanced cash flows.
- Woody crops offer biological diversification. The perennial habit may significantly buffer seasonal and short-term fluctuation in production and income. Woody crops

open the potential to achieve better utilisation of water and to have this expressed in increased overall farm productivity.

- Woody crops will have different seasonal workloads, with more flexible timing for some operations, providing the opportunity to more efficiently utilise labour.
- Large-volume woody crops are likely to require value-adding operations based locally, bringing the opportunity for new regional industries

2.8 Designing a new woody perennial crop

2.8.1 Introduction

This project's aim is to evaluate the potential for developing new woody crops for the wheatbelt of Western Australia.

In this section, we give a brief outline of the constraints and opportunities for designing a new type of woody crop for agricultural areas in southern Australia. These ideas have been presented to various conferences and workshops over the last few years to stimulate discussion about how best to realise multiple benefits from new woody crops (Bartle 1999a, b; 2001). The features required in woody crops, and the strengths and weaknesses of different crop types were discussed in a recent review of the opportunities for woody crops in mid to low rainfall areas (CSIRO Land and Water *et al.* 2001).

To be successful, prospective new woody crops should satisfy three essential conditions. They should marry the goals of biodiversity conservation and sustainable agriculture, be suited to extensive planting in medium to low rainfall areas of southern Australia, and have the potential to generate commercial returns to growers.

2.8.2 Focus on native species

In considering the options for selection the history and science of plant introduction and domestication, both globally and within Australia, has been reviewed. The issue of weed risk (section 2.2.2 above) is a major consideration, particularly for relatively unimproved woody species, and particularly in Western Australia, where there has been comparatively little previous history of woody plant introduction. The Search Project has therefore focused exclusively on the domestication potential of species native to Western Australia's agricultural region.

2.8.3 The imperative of scale

The scale on which the new crops and products might be grown is of particular importance. It is clear that the scale of perennial plant cover necessary to arrest salinity is very large. The project has therefore chosen to focus on products and markets that have the capacity to absorb large volume production (Bartle 2001; Bartle and Shea 2002). This choice results in a very different pathway for selection than would be taken in pursuit of high value products such as flowers, fruits, nuts or pharmaceuticals - more specialised products with comparatively small markets. They might be more competitively produced in horticulture, and if they become commercially viable, there is risk of over-supply of markets. Some of the issues involved in this decision are canvassed in the analysis of the potential of *Acacia* seed as a food product (see Section 4.2.2).

The project will therefore give particular attention to bulk commodity products where substantial scale of production may be possible without over-supplying markets. Large potential scale is also important to achieve economies of scale, low cost of production, large production volumes, and to generate regional land, water and biodiversity benefits, as well as making other significant contributions such as carbon sequestration.

Economies of scale are particularly important in the Australian farming context. Australian grain farmers are among the most efficient in the world, producing commodity products at world competitive prices. To manage this feat, they employ large-scale mechanised production systems to capitalise on the advantages of cheap land, generally flat terrain, large farm size, and efficient, nimble management provided by family units and small partnerships. These advantages need to be exploited in order to overcome the disadvantages of relatively infertile soils and long transport distances to market. To integrate well into these agricultural systems, new woody crops will most likely need to be suited to the same management approach. Any new crop that will be large enough to provide land management benefits on a regional scale will automatically be locked into bulk production of a relatively low-value commodity, with efficiency of production, security of supply and achievement of quality standards being the most important determinants of market success.

Preliminary economic assessment indicates that if growers of new woody crops can take advantage of large-scale production systems, continuous biomass harvesting systems, and process all biomass at a centralised processing centre into multiple products with no waste, then they could produce wood fibre at a cost that is similar to, or lower than currently achieved by conventional forestry systems in higher rainfall areas, while achieving returns comparable with conventional agriculture.

2.8.4 Layouts

A key to productivity and profitability for new woody crops will be the configuration in which they are arranged within farming systems. Traditional block plantings of trees will not be profitable in most parts of the low to mid rainfall zone, because their productivity per hectare is too low in this water-limited environment. Instead, dispersed layouts are required that maximise access to water but minimise interference with other agricultural enterprises. Some feasible layouts are described in 2.8.5 below.

2.8.5 Tree crop archetypes

There are currently no large-scale tree crops in use in the wheatbelt regions of southern Australia. As discussed in 2.8.4 above, dispersed layouts will be required if woody crops are to grow productively in lower rainfall agricultural areas. Different types of species and crops are suitable for each type of layout, so they are discussed here in terms of ‘crop archetype’. Three potential crop archetypes can be defined:

- **Short-cycle coppice crops** (short name: coppice crop, symbol C) are long-lived species that readily re-sprout or coppice from the cut stump and can therefore be harvested on a regular short cycle. Harvest frequency is likely to be in the range 2 to 5 years – a frequency that strong coppicing species such as mallee can tolerate indefinitely. Coppice crops are well suited to planting in permanent belts oriented along the contour, or in other strategic alignments, to intercept downslope water movement. In belt formation they are readily integrated into large-scale annual cropping systems commonly called ‘alley farming’. They are most likely to perform best on sites that favour lateral movement of water and extensive, long-term root development. Interest in coppice crops has been stimulated by the experience with mallee in W.A. (Bartle and Shea 2002).
- **Short-cycle phase crops** (short name: phase crop, symbol P) are short-lived, fast-growing woody perennial species suited to planting over the whole paddock for a short period. Phase crops can be used as a de-watering or ‘discharging’ phase alternating with ‘recharging’ annual crops or pastures. The phase crop might be harvested at age 3 to 6 years, after which the land reverts to annual crop or pasture. The duration of the phase crop in the overall rotation will depend on the rate of recharge during the conventional annual plant phase. Phase crops will be most useful where soil profile characteristics or slope limit the rate of lateral movement of surface and subsurface water. The phase crop has potential to improve soil structure, and utilise leguminous species to enhance subsequent annual crop production, but this is offset to some extent by clean-up costs after harvest, and risk that dewatering of the soil profile will reduce yield in the following annual crop (Mele and Yunusa 2001). Phase crops have yet to attract serious R&D investment despite being conceptually attractive.
- **Long-cycle timber crops** (short name: timber crop, symbol T) are based on tree species of erect form, selected and managed to produce timber over a growth period of 10 to 100 years. They are suited to planting in timber belts (T-Be) or timber blocks (T-Bl), and in addition to timber products, can provide shelter and aesthetic benefits. They have greatest potential in the wetter wheatbelt regions where growth rates are higher, crop cycle will be shorter and where they will be comparatively close to current timber industries (Moore 2001).

The most prospective coppice and timber species occur in the genus *Eucalyptus* and are small-seeded (e.g. oil mallee species have a seed mass of 0.1 to 0.5 mg). With present technology small-seeded species must be propagated as seedlings. This imposes establishment costs that are much greater than for fine-seeded agricultural species or large-seeded tree crops that are direct seeded. The high cost of seedling propagation is a significant potential impediment to development of phase crops (Harper *et al.* 2000). However, some potential phase species are large-seeded (e.g. *Acacia*) and are suited to direct seeding.

2.8.6 Terminology

The previous section proposes a tree-crop terminology designed to facilitate clear definition and communication. It is re-presented here in Table 1.

Table 1. Terminology for tree crops.

	Crop cycle	
Crop Layout	**Short**	**Long**
Belt	Coppice (C)	Timber belt (T-Be)
Block	Phase (P)	Timber block (T-Bl)

Note: There may be situations where coppice crops might be grown in blocks rather than belts and in this form the belt (Be) and block (Bl) suffixes could be applied, as for timber crops.

In this report the traditional forestry term 'rotation' (that is, the period from establishment to harvest) has not been used with its forestry meaning. This is to avoid the confusion that might arise in agriculture, where it is also a traditional term (meaning the alternation of crop types).

Precedence has been given here to the use of 'rotation' in the agricultural sense because this will be most familiar to the farmers who will manage these tree crops. The traditional forestry meaning of rotation has been replaced in this report by 'cycle'.

2.8.7 Tree crop economics

The three woody perennial crop types defined above could fill quite different roles in wheatbelt agricultural systems. Bartle *et al.* (2002) present an economic comparison of these roles. In this analysis they compared discounted cash flows for each crop type, and for conventional agriculture based on annual-plants, over a 25-year period for the 400 mm rainfall zone in the WA wheatbelt.

Production cost and yield were estimated for each crop type, and then used to calculate the 'stumpage' (selling price of the crop standing in the field) that would be necessary for each crop type to achieve an equivalent return to conventional agriculture (averaging $65 per ha annually over a 25-year period in this exercise). The calculated 'break even' stumpages were then compared with estimates of stumpages that are likely to be paid by potential new timber and biomass industries. The analysis also contrasts two establishment techniques, conventional seedling establishment and direct seeding. Note that no allowance is made in this analysis for any positive or negative indirect effects of woody perennial crops such as erosion control, shelter, salinity control, and interaction with other crops.

The results are summarised in Table 2.

Table 2. Impact of establishment technique on the economics of woody crop types in the 400 mm/year rainfall zone.

	Seedling establishment			Direct seeding			
Crop type	Break even[1]	Average Debt[2]	Calculated stumpage[3]	Break even[1]	Average Debt[2]	Calculated stumpage[3]	Estimated stumpage[4]
C	14	931	14	8	332	8	15
P	16	432	32	8	126	14	15
T-Bl	25	1,417	130	25	696	87	60

1 Years to break even.

2 Average debt ($ per hectare) from establishment to break even.

3 Selling price necessary to make return equivalent to that of conventional agriculture, in $/tonne of biomass for coppice (C) and phase crops (P), and $ per cubic metre of wood for long-cycle timber crops in blocks (T-Bl).

4 Estimate of stumpage likely to apply for each crop type (same price basis as 3).

In the integrated mallee processing feasibility study Enecon (2001b) showed a stumpage price of $15 per tonne to be a commercially viable purchase price for mallee biomass feedstocks. This has been used here as an indication of a likely competitive price for biomass feedstocks for industrial products.

Table 2 shows that coppice crops established by planting seedlings can produce biomass for a stumpage of $14 per tonne. If these crops could be established by direct seeding, biomass could be produced for as little as $8 per tonne, a price likely to stimulate large-scale demand by wood processing and bioenergy industries. In contrast, phase crops established by planted seedling would produce biomass at $32 per tonne, over twice the likely price. But if direct-seeded, phase crops could be produced for only $14 per tonne, making them a commercial possibility.

The economics of timber crops appear less favourable. Even using direct seeding, the selling price would have to be above the estimated stumpage of $60 per cubic metre for timber at final harvest (or its equivalent in other products).

For timber crops the average debt load of $1,417 per hectare over the 25-year period to harvest indicates a major financing constraint that is likely to be beyond the resources of most farm businesses. For this reason, timber crops are unlikely to be planted by farmers on a large scale, unless long-term arrangements involving external finance are developed. Compared to timber crops, the debt level for coppice and phase crops is much lower, and also needs to be carried for a shorter period, because the time to break even for these crops is shorter than for timber crops. Coppice and phase crops are therefore more likely to be within the financing ability of farm businesses.

An important outcome of the superior potential profitability of short-cycle crops compared to long-cycle crops is that there will be a stronger economic incentive for farmers to grow short-cycle crops than long-cycle crops, and hence produce small dimension woody material rather than sawlogs. This small dimension material will be best suited to industries such as pulp and paper, panel board, and bioenergy. Therefore, the physical and commercial environment determines the type of crops that can be grown, which in turn affects the types of products that can be made.

A more recent and more elaborate treatment of woody crop economics is presented in Section 7.

2.9 References

Agriculture Western Australia, Department of Conservation and Land Management, Department of Environmental Protection and Water and Rivers Commission (1996a). Salinity; A situation statement for Western Australia, Government of Western Australia.

Agriculture Western Australia, Department of Conservation and Land Management, Department of Environmental Protection and Water and Rivers Commission (1996b). Western Australian salinity action plan, Government of Western Australia.

Anon (1997). The national weeds strategy: a strategic approach to weed problems of national significance, ARMCANZ, ANZECC.

Australian Tree Seed Centre (2003). General Information about the Australian Tree Seed Centre. Accessed: 08 October 2003. http://www.ffp.csiro.au/tigr/atscmain/whatwedo/background/background.htm

Bartle, J (1991). "Tree crops for profit and land improvement." WA Journal of Agriculture **32**(13): 19-21.

Bartle, J (1993). Commercial tree crops: concepts and practice. WA State Landcare Conference: Landcare 93, Perth, Western Australia.

Bartle, J (1999a). The new hydrology: new challenges for landcare and tree crops. State Landcare Conference, Esperance Civic Centre, Western Australia.

Bartle, J (1999b). Why oil mallee? The oil mallee profitable landcare seminar, Pastoral House, 1/277 Great Eastern Highway, Belmont, Western Australia, The Oil Mallee Association of WA (Inc).

Bartle, J (2001). Mallee eucalypts - a model, large scale perennial crop for the wheatbelt. Outlook 2001, Parkroyal Hotel, Canberra, Australia, ABARE.

Bartle, J, C Campbell and G White (1996). Can trees reverse land degradation? Australian Forest Growers Conference, Mount Gambier, South Australia.

Bartle, J, D Cooper, G Olsen and J Carslake (2002). "Acacia species as large-scale crop plants in the Western Australian wheatbelt. Conservation and utilisation potential of Australian dryland Acacias. Acacia Symposium Dalwallinu WA July 2001." Conservation Science Western Australia **4**(3): 96-108.

Bartle, J and R Reeves (1992). Promising products derived from woody species. RIRDC/LWRRDC Planning workshop on low rainfall agroforestry, Perth, Western Australia.

Bartle, J, P Scott, C Campbell and A Barton (1994). Oil Mallee Industry Pre-feasibility Report. CALM.

Bartle, J and S Shea (1989). "Developing a pulpwood cropping industry in WA." Land and Water Research News(1): 5-9.

Bartle, J and S Shea (2002). Development of mallee as a large-scale crop for the wheatbelt of WA. Australian Forest Growers 2002 National Conference: Private Forestry - Sustainable accountable and profitable, Albany, WA, Australia.

Burt, R and W Williams (1989). Plant introduction in Australia. p448 *In* Australian science in the making. RW Home, Ed. Cambridge, Cambridge University Press.

Byrne, M (1999). "High genetic identities between three oil mallee taxa based on nuclear RFLP analysis." Heredity **82**: 205-211.

Byrne, M and M McDonald (2000). "Phylogeography and conservation of three oil mallee taxa." Australian Journal of Botany **48**: 305-312.

Chegwidden, A, D Harrison and P Weir (2000). Mallee eucalypts for electricity, activated carbon and oil, a new regional industry. Bioenergy 2000: Making a

Business from Renewable Energy for Society and the Environment, Gold Coast, Qld, Australia, Bioenergy Australia.

Chisholm, A (1992). "Australian agriculture: a sustainability story." Australian Journal of Agricultural Economics **36**(1): 1-29.

Coppen, J (2002). Appendix 2: Estimates of eucalypt plantations worldwideEucalyptus - the genus Eucalyptus. J Coppen, Ed. London, Taylor & Francis.

CSIRO Land and Water, CSIRO Forestry and Forest Products, Australian National University Department of Forestry, Rural Industries Reseacrh and Development Corporation, Olsen and Vickery and HGa Associates (2001). The contribution of mid to low rainfall forestry and agroforestry to greenhouse and natural resource management outcomes, Australian Greenhouse Office and the Murray-Darling Basin Commission. 72p.

Daehler, CC and D Carino (2000). "Predicting invasive plants: Prospects for a general screening system based on current regional models." Biological Invasions **2**: 92-103.

Daehler, CC and J Denslow (not dated (approx 2002)). Progress Report. Testing an objective method for identifying invasive plants. Accessed: 08 October 2003. http://www.botany.hawaii.edu/faculty/daehler/WRA/

Department of Conservation and Land Management (1987). Timber production in Western Australia. A strategy to take WA's south-west forests into the 21st century. Department of Conservation and Land Management.

Diamond, J (1997). Guns, germs and steel, Chatto & Windus.

Enecon Pty Ltd (2001a). Integrated tree processing of mallee eucalypts. Rural Industries Research and Development Corporation. Report 01/160. 81p.

Enecon Pty Ltd (2001b). Integrated tree processing of mallee eucalypts. Report 01/160. Rural Industries Research and Development Corporation. Report 01/160. 81p.

FAO (1995). International Standards for Phytosanitary Measures, Section 1—Import Regulations: Guidelines for Pest Risk Analysis. Secretariat of the International Plant Protection Convention of the Food and Agriculture Organization (FAO) of the United Nations.

FAO (2001). State of the world's forests 2001. Food and Agriculture Organisation.

Forest Products Commission (2003). Growing a sustainable future - Infinitree. Pamphlet. Forest Products Commission.

Gerrand, A, R Keenan, P Kanowski and R Stanton (2003). "Australian Forest plantations: an overview of industry, environmental and community issues and benefits." Australian Forestry **66**(1): 1-8.

Harper, R, T Hatton, D Crombie, W Dawes, L Abbott, R Challen and C House (2000). Phase farming with trees: a scoping study of its potential for salinity control, soil quality enhancement and farm income improvement in dryland areas of southern Australia. Rural Industries Research and Development Corporation. Report 00/48.

Lefroy, EC (2001). Forage trees and shrubs in Australia - their current use and future potential. RIRDC/LWRRDC/FWPRDC Joint Venture Agroforestry Program. Report RIRDC Publication No 02/039.

Lonsdale, WM (1994). "Inviting trouble: introduced pasture species in northern Australia." Australian Journal of Ecology **19**: 345-354.

Mathison, MJ (1983). Mediterranean and temperate forage legumesGenetic resources of forage plants. JGaB McIvor, R.A., Ed. Melbourne, Vic, Australia, CSIRO.

McIvor, J and R Bray (1983). Genetic resources of forage plants. Melbourne, Vic, Australia, CSIRO.

Mele, P and I Yunusa (2001). Cereal yields associated with changes in soil characteristics following six years of acacia. 10th Australian Agronomy Conference, Hobart.

Moore, R (2001). Eucalypts for high-grade timber in the medium rainfall zone of WA - a feasibility study for a new industry. Forest Products Commission, Department of Conservation & Land Management, and the Water & Rivers Commission.

National Land and Water Resources Audit (2001). Australian dryland salinity assessment 2000. National Land and Water Resources Audit. 129p.

Pannell, D (2001). Economic dimensions of landcare. Sustainability and Economics in Agriculture UWA 251. Grains R&D Corporation project. Report Working Paper 01/08.

Peck, A and T Hatton (2003). "Salinity and the discharge of salts from catchments in Australia." Journal of Hydrology **272**(1-4): 191-202.

Pheloung, P (2001). Weed risk assessment for plant introductionsWeed Risk Assessment. R Groves, F Panetta and J Virtue, Eds. Melbourne, CSIRO Publishing.

Pheloung, PC, P Williams and S Halloy (1999). "A weed risk assessment model for use as a biosecurity tool evaluating plant introductions." Journal of Environmental Management **57**: 239-251.

Potts, B, R Barbour, A Hingston and R Vaillancourt (2003). "Turner Review No 6: Genetic pollution of native eucalypt gene pools - identifying the risks." Australian Journal of Botany **51**: 1-25.

Renewables Vision 2020 Executive Steering Group (1999). The technology roadmap for plant/crop-based renewable resources 2020. Research priorities for fulfilling a vision to enhance US economic security through renewable plant/crop-based resource use. Office of Industrial technologies, Energy Efficiency and Renewable Energy. US Department of Energy.

Shea, S and J Bartle (1988). "Restoring natures balance." Landscope, CALM(Autumn 1988).

Shea, S, J Bartle and G Inions (1992/93). "Tree crops for farms." Landscope, CALM(Summer 1992/93).

Shea, S and P Hewett (1997). Development and future potential of tree crop industries on farmland in Western Australia. Invited paper to NZ Forest Research Institute's 50th Jubilee Forestry Celebration, Rotorua, New Zealand.

State Salinity Council (2000). Natural Resource Management in Western Australia: The Salinity Strategy. Perth, Government of Western Australia.

Virtue, J (not dated (approx 2000)). Weed Risk Assessment – recent developments in Australia. Accessed: 08 October 2003. http://www.cwss-scm.ca/pdf/RecentDevelopmentsinAustralia.pdf

Wallace, KJ (2001). State Salinity Action Plan 1996; Review of the Department of Conservation and Land Management's programs; January 1997 to June 2000. Department of Conservation and Land Management, Government of Western Australia. 179p.

Walton, C (2001). Implementation of a permitted list approach to plant introductionsWeed risk assessment. RH Groves, Panetta, F.D. and Virtue, J.G., Ed. Melbourne, Vic, Australia, CSIRO.

White, D, F Dunin, N Turner, B Ward and J Galbraith (2002). "Water use by contour planted belts of trees comprised of four Eucalyptus species." Agricultural Water Management **53**: 133-152.

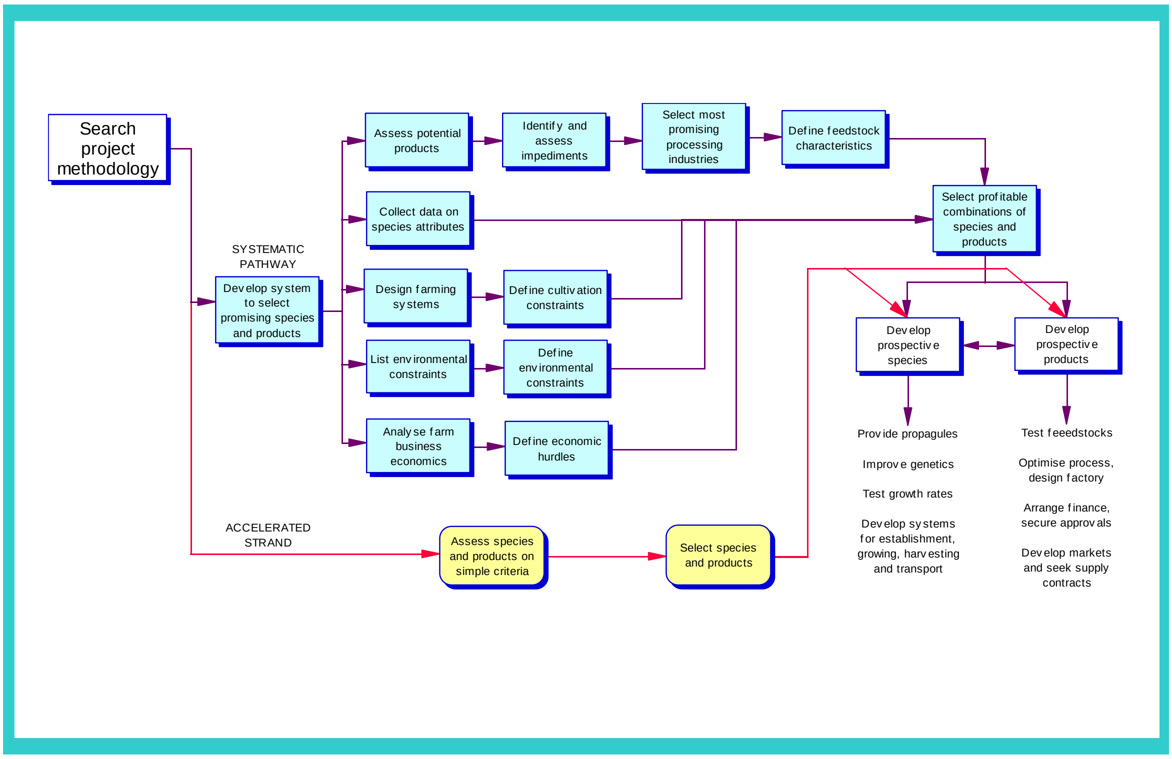
Wildy, D, J Pate and J Bartle (2003). Silviculture and water use of short-rotation mallee eucalypts. RIRDC/Land & water Australia/FWPRDC/MDBC Joint Venture Agroforestry Program. Report RIRDC Publication No 03/033.

Wood, MS, NC Stephens, BK Allison and CI Howell (2001). Plantations of Australia - a report from the National Plantation Inventory and the National Farm Forestry Inventory (abridged version). National Forest Inventory, Bureau of Rural Sciences. 12p.

Natural Heritage Trust
Helping Communities Helping Australia
An Australian Government Initiative

Search Project Report

Section 3 – Search Methodology



Conceptual development of Search process

Final report for NHT Project 973849

July 2004

Government of Western Australia
Department of Conservation and Land Management
Conserving the nature of WA

Authors

Graeme Olsen[1]
Don Cooper[2]
Dan Huxtable[2]
Jerome Carslake[2]
John Bartle[2]

This report has been prepared to assist with assessment of potential new commercial opportunities based on woody perennial plants in the wheat-sheep agricultural zone of southern Western Australia. However, the work reported here is of a preliminary nature. While care has been taken in the report's preparation, no responsibility is taken by the authors or publisher for omissions or inaccuracies, or for the use of this information by any other party.

ISBN No: 0 7307 55509

[1] Olsen & Vickery, PO Box 357 Waroona, Western Australia 6215.

[2] Department of Conservation and Land Management, Locked Bag 104, Bentley Delivery Centre, Western Australia 6983.

Sections in this report

Section 1	Summary
Section 2	Background
Section 3	Search Methodology
Section 4	Product Assessment
Section 5	Species Selection
Section 6	Feedstock Testing
Section 7	Economic Analysis
Section 8	Demonstration and Resource Plantings
Section 9	Propagation Project
Section 10	Project Administration
Appendices	

Contents of this Section

Section 3 Search Methodology 1

3.1 Step 1 - Initial assessment of potential products 6

3.2 Step 2 - Initial assessment of species 10

3.3 Step 3 - Test selected plant material for suitability as feedstock 13

3.4 Step 4 - Detailed selection of species 14

3.5 Step 5 - Detailed testing of products and production processes 15

3.6 Step 6 - Design new integrated industries 15

3.7 References 16

Section 3 Search Methodology

An important task early in the project was to develop a method for implementing the first two stages of the industry development model described in the NHT application for this project. The model is reproduced here as Figure 1. For more detail, see Section 10, which contains a reference copy of the NHT application.

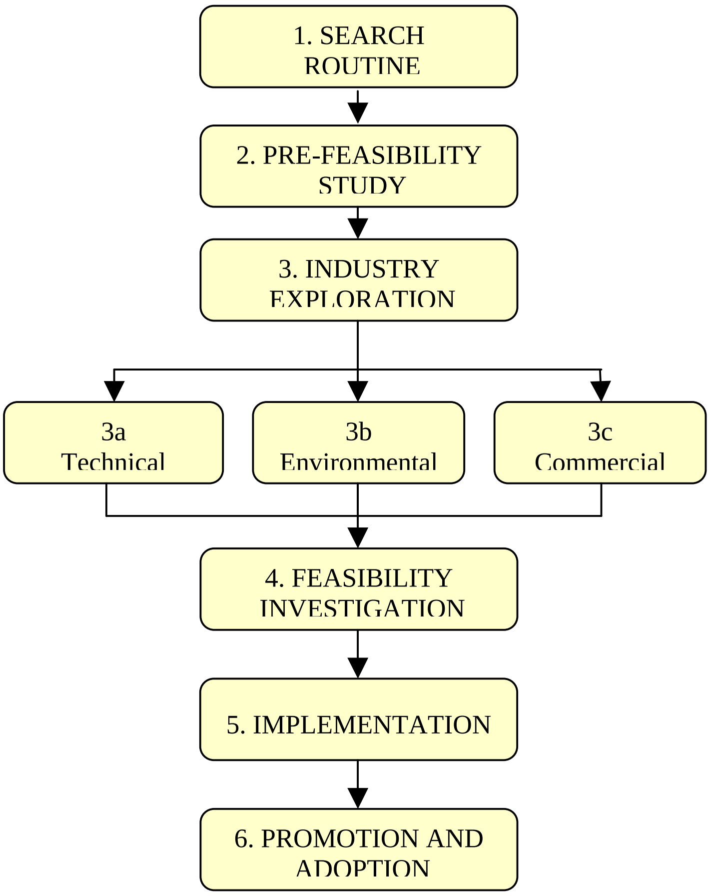


Figure 1. Industry development framework.

In the early stages of the project, various methods involving databases and decision-making mechanisms, including expert systems, were explored in an effort to develop an objective method for identifying combinations of species and products for subsequent testing and development. All such systems hinged on having sufficient detailed and accurate information about products and markets, and species and their characteristics, to allow a useable decision-making system to be designed.

An early conceptual model developed in the Search Project is shown in Figure 2.

This path did not prove to be very fruitful, for a number of reasons:

- Lack of useful data. Much of the data that was available in various sources, such as the REX'96 Revegetation Expert System (Robin Road Software *et al.* 1996) and other published sources concerned species attributes that were valuable for cultivation, aesthetic or taxonomic purposes, but were only weakly linked to commercial potential, or had ambiguous commercial significance.
- Generating new information about a large number of species and product options was beyond the scope and resources of the project, especially as it is likely that much of the information would subsequently be found to be for species of little or no commercial interest.
- Linking large-scale products and plant species through a decision-making system proved not to be feasible, since little of the information needed to link species to these products exists.
- Few of the characteristics of plant species and products are reliable discriminators in all circumstances – most are context sensitive, or can be modified by management practices, or interact in complex ways with other characteristics.
- Much of the available information about products (markets, feedstock requirements etc.) was straight-forward, and was unlikely to reveal deeper truths by being interrogated through a complex decision-making system.
- The complexity of the systems and information needed to make a workable model were judged to outweigh the benefits likely to be gained.

Once this situation was appreciated, a new approach was developed. It had its genesis in the process shown in Figure 3, where an attempt was made to define two pathways – one in which adequate information was available (so-called "systematic strand") and a more stream-lined pathway (so-called "fast-track strand") – that could both be pursued simultaneously.

The reason for entertaining a "fast-track" process was to ensure that some of the laboratory testing could be started for some of the more obvious prospects earlier in the project. The "fast-track" strand is not a different, or "un-systematic" method. It employs the same steps as the "systematic" strand, but instead of waiting until all information is available at each step, moves on quickly, based on the best information available. Eventually, further information needs to be collected or generated about the most prospective species, but in this method, this task is limited to species that have already shown themselves to be of potential commercial interest.

In practice, the "fast-track" strand dominated this project, and proved to be the more useful method for the types of products that were chosen for investigation. It was subsequently developed into a simple, six-step sequence, that is described in more detail in the following pages. Hence instead of a complex decision-making system, the Search Project adopted a simple, transparent process.

The six steps in the "fast-track" pathway are:

1. Initial assessment of potential products
2. Initial assessment of species
3. Test selected plant material for suitability as feedstock
4. Detailed selection of species
5. Detailed testing of products and production processes
6. Design new integrated industries

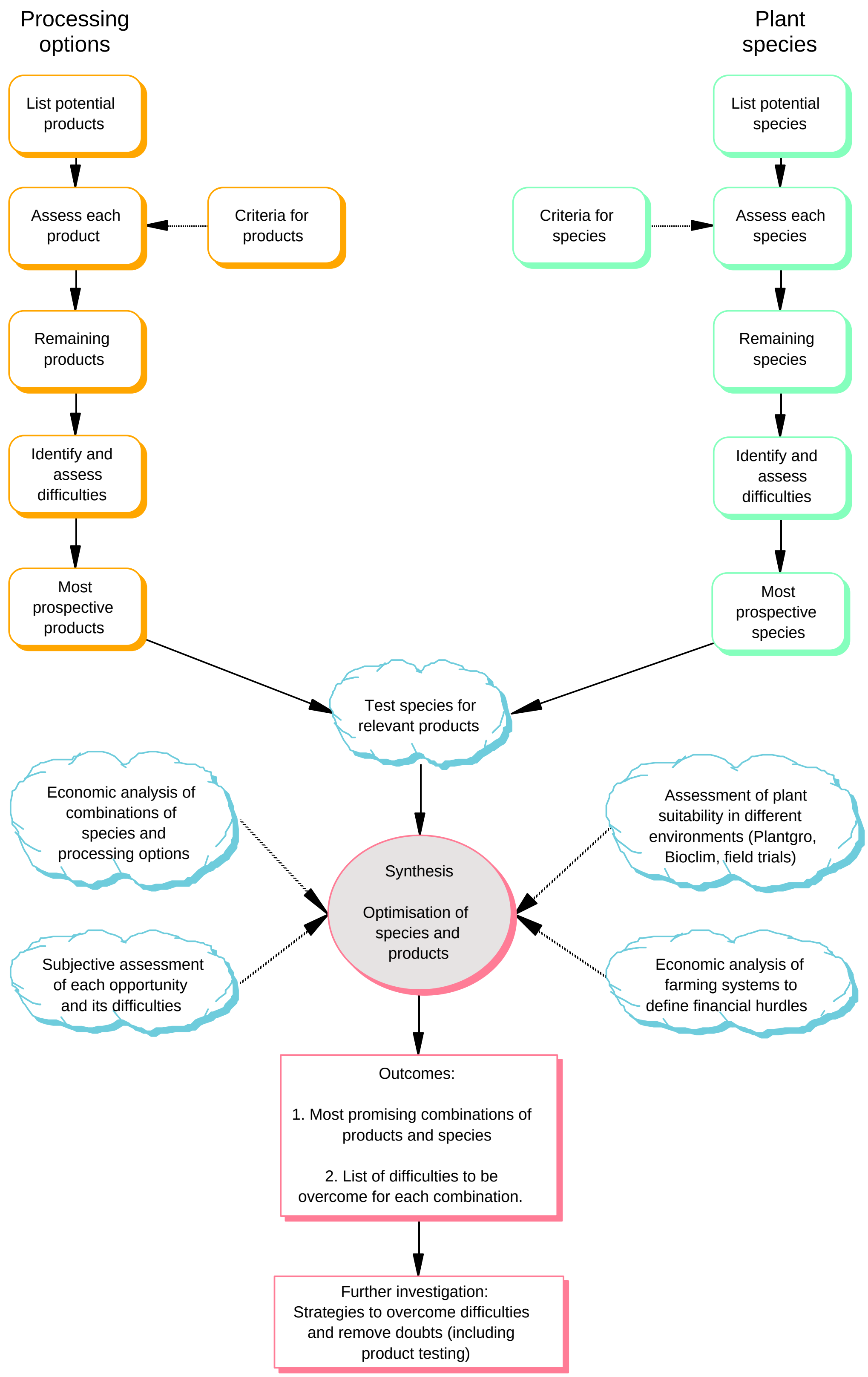


Figure 2. Early diagram showing conceptual process for search routine and pre-feasibility study.

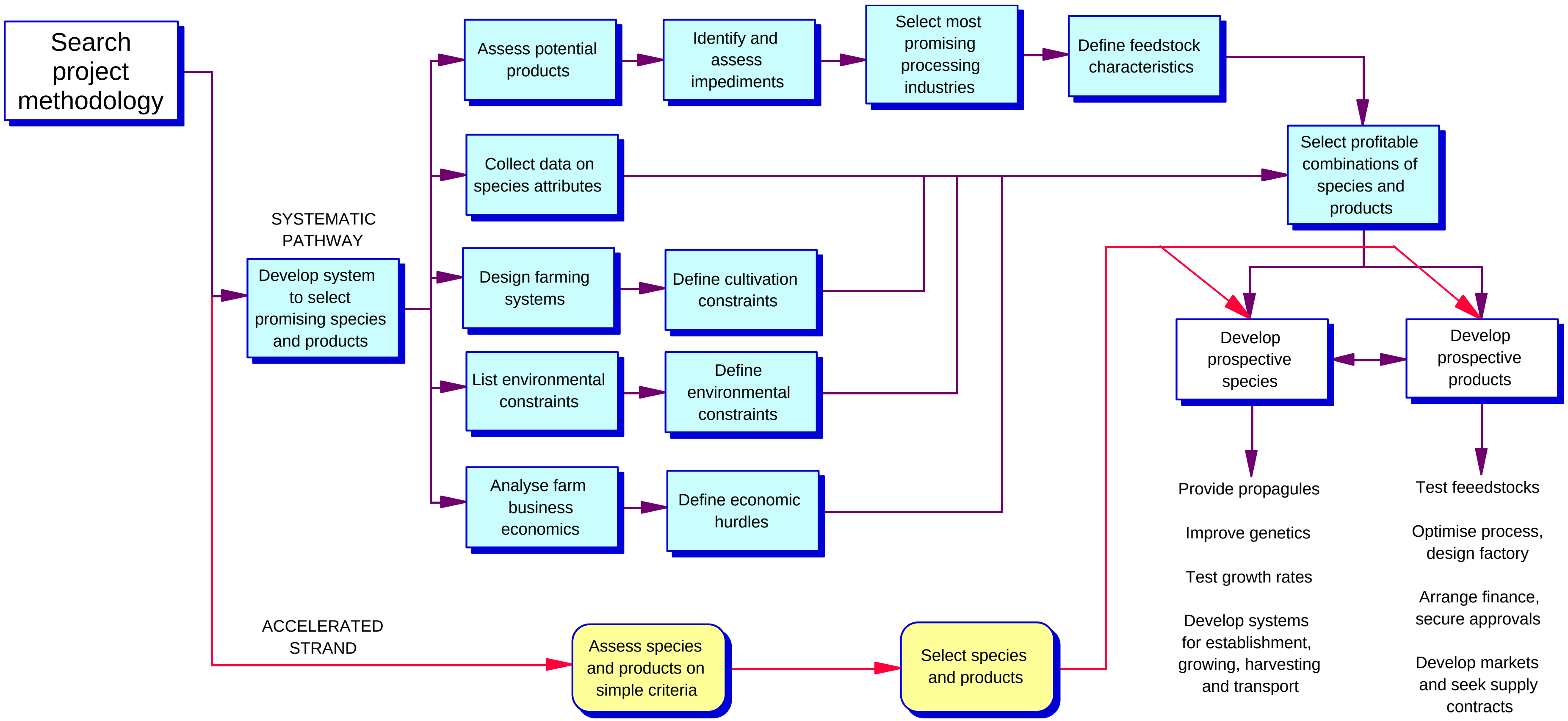


Figure 3. A later version of the conceptual process for conducting a search routine and pre-feasibility study.

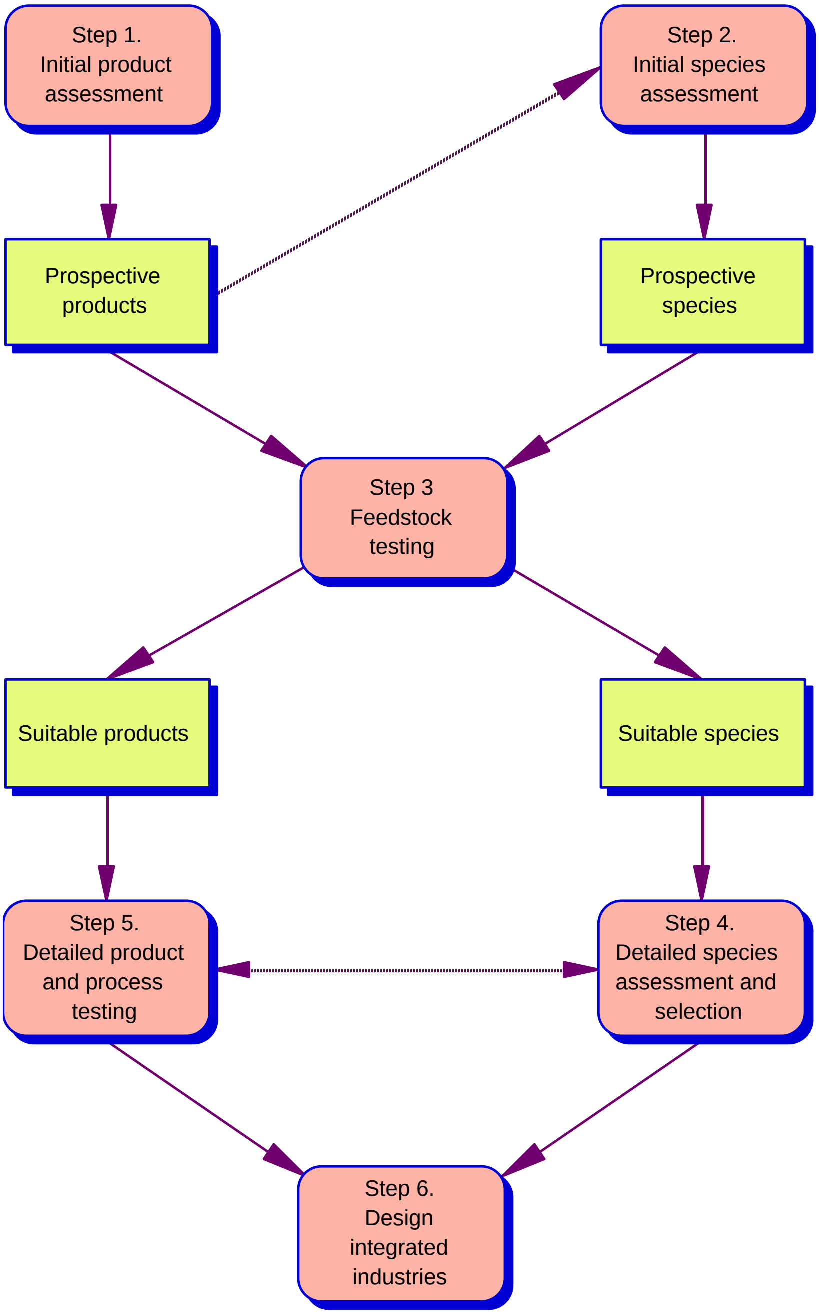


Figure 4. Diagrammatic representation of the simplified Search six-step process.

A diagrammatic representation of the six steps in the "fast-track" methodology is given in Figure 4. With respect to the industry development model described in Figure 1, the first two steps belong under 'Search routine', while the remaining four steps are best described as 'Pre-feasibility studies'.

These six steps are sequential (apart from steps four and five, which occur concurrently, and interact with each other), but with the provision to return to a previous step after assessing the results of each step. For example, the successful production of sample products for a species in step 3, may lead back to further assessment of closely related species in step 2.

Each step along the pathway provides an increasingly rigorous filter of products, species, or combinations of products and species. The effort, both in time and money increases rapidly at each step, demanding that the early steps filter out as many poor prospects as possible, to reduce costs in later steps, while rejecting as few potential winners as possible.

The six steps in this methodology are described briefly below. Work done by the Search project on each of the first three steps is described in greater detail in later sections – Section 4 (Product Assessment), Section 5 (Species Selection) and Section 6 (Feedstock Testing).

3.1 Step 1 - Initial assessment of potential products

3.1.1 Rationale

Preliminary product assessment was selected as the first step (rather than preliminary species selection) because there are more different species than different products, and because it is very difficult to select species without a product in mind. The approach adopted in this project was to assess the range of potential products first, choose those that appeared to have the best potential to be made from plant material from agricultural areas, then seek suitable species.

3.1.2 Outline

This step has three components, each of which is described in more detail below:

- Choose selection criteria
- Identify and evaluate product options
- Rank products in order of potential

3.1.3 Selection criteria

Criteria by which the potential of each product option may be assessed include:

- Domestic market size
- Export market size
- Growth rates of domestic and export markets
- Market stability (probability of rapid change in demand or supply)
- Accessibility of markets
- Flexibility of the product to use a range of feedstock sources and attributes

- Sensitivity of product cost to feedstock cost (to maximise advantage of low-cost wheatbelt producers)
- Competitive position of wheatbelt based industry (growing and processing) relative to existing suppliers.
- Potential for regional processing to improve competitive position
- Size of processing plant, and amount of raw material needed
- Scale and cost of processing and delivery infrastructure
- Potential efficiency in integrated multiple product processing (co-product synergy)

3.1.4 Identify and evaluate potential products

A list of product categories and product types that are likely to be suitable for production using material from woody crops in the wheatbelt is given in Table 1.

In order to select the most promising of these options an assessment of the industries and markets for each product category is required, based on the selection criteria above. A broad assessment is adequate for the first stage of species testing (step 3), but more comprehensive industry analyses will be required before embarking on steps 5 and 6.

Broad initial assessments were made by the Search project, to allow species selection and feedstock testing to proceed. More elaborate product assessments have been completed for some products and are nearing completion for others. Some of these assessments have been carried out in collaboration with other projects such as the RIRDC-CSIRO ‘best bets’ project.

3.1.5 Rank products in order of potential

Table 2 contains an example of a summary assessment of one group of products in the target zone - wood products. The most promising wood products from this preliminary analysis are pulp and paper, and two panel board products, particle board and medium density fibreboard (MDF). These products were selected by the Search project as the primary ones for which to test wood from targeted native species.

The rating system used in Table 2 involves two factors:

- Market size that could be available to new industries in the target zone.
- Feasibility of making products of adequate quality at the required scale, and at a competitive price from feedstocks grown in the target zone.

The ‘feasibility’ rating is an amalgamation of many factors. For example, construction timber is given a low feasibility rating because although the market is large, long-cycle sawlogs are not likely to be profitable for growers in most of the wheatbelt, and are therefore unlikely to be grown at a large scale. (Note that long-cycle sawlogs have better prospects along the wetter margins of the target zone, where their development is being actively pursued). Products were given higher ratings if they can be made from the type of material that is most likely to be produced by new woody plant industries – chipped material from short-cycle woody crops. They also received higher ratings if they could be made from a blend of material. For example, a pulp mill may not be able to obtain sufficient feedstock within an economic transport distance in drier parts of the wheatbelt, but a pulp mill located at the southern or western boundary of the wheatbelt could blend material drawn from both higher and lower rainfall areas.

Table 1. Product categories.

Product category	Product Subcategory	Examples of particular products
Wood products	Solid wood	Specialty timbers Appearance grade timbers Construction grade timber Packaging grade timber Round wood
	Panel Board	Particleboard Medium density fibreboard Oriented strand board Parallam Wood/cement composites
	Laminated wood	Plywood (structural and appearance) Laminated veneer lumber Other engineered wood products
	Processed wood	Pulp and paper Wood plastics Charcoal Activated carbon
Energy (bioenergy)	Solid fuel	Electricity Industrial heat Desalinated water
	Liquid fuel	Alcohols Biodiesel Pyrolytic liquids
Industrial products	Chemicals by transformation	Pyrolytic products
	Extracted chemicals	Oils, solvents, tannins, gums and resins (including pharmaceuticals)
Food and flowers	Specialist foods	Bush tucker, special diet foods
	Staple foods	Bulk grain
	Food ingredients	Oil, protein, carbohydrate, edible gums
	Flowers	Cut flowers
Fodder	Direct gazing	Drought fodder reserve
	Manufactured animal feed	Feed pellets

Other products that are highly ranked (but not included in Table 2) are energy products, especially electricity and heat production from the combustion of woody residues, liquid fuels, especially ethanol by fermentation of residues. The need for significant development expenditure lowers the short-term potential of ethanol, although it could have a very bright longer-term future, depending on developments in the transport fuels industry.

Table 2. Assessment of wood products. Products with the highest rating (1) are most suitable for development as large-scale new industries. Those with the lowest rating (4) are least suitable.

Product group	Examples	Market	Feasibility	Rating
Solid timber	Specialty	Tiny	High	4
	Appearance	Medium	Low	4
	Construction	Large	Low	4
	Packaging	Medium	Low	4
	Posts, rails, piles, poles	Medium	Medium	3
Wood panels	Particleboard	Large	High	1
	Medium density fibreboard	Large	High	1
	Oriented strand board	Medium?	Medium	3
	Parallam	Small?	Low	4
	Scrimber	Small?	Medium	3
	Cement composites	Small?	Medium	3
Laminated wood	Plywood	Medium	Low	4
	Laminated veneer lumber	Small	Low	4
	Other engineered products	Small	Low	4
Processed wood	Pulp and paper	Large	High	1
	Export woodchips	Large	Low	4
	Wood plastics	Small	High	3
	Charcoal	Medium	High	2
	Activated carbon	Small	High	3

Other products with potential for large-scale development as agricultural woody crops are of a more speculative and long term nature. They include:

- Pyrolytic oils. Research into wood pyrolysis has become more active in recent years, due to a growing acceptance of the possibility of producing large volumes of liquid fuels, and a wide array of chemicals that could be used in their own right as commercial products, or as precursors in the manufacture of other chemical products.
- Potential emergence of a ‘carbohydrate economy’, in which many of the products currently made from cheap hydrocarbons could in future be manufactured from the carbohydrates in biomass.

Both of these potential industries have the attraction of being relatively undiscriminating on feedstock, while allowing the manufacture of a wide range of commercial products. However, in both cases, R&D is at an early stage, and much more pre-commercial investment is likely to be needed before they become main stream industries.

See Section 4 (Product Assessment) for further details of work done on this step in the Search Project.

3.2 Step 2 - Initial assessment of species

3.2.1 Introduction

In this step, readily available, or easily obtainable information is used to reduce the number of plant species to be tested in Step Three. The aim is to minimise work and cost, by sifting out species least likely to have commercial potential, so that effort can be concentrated on a smaller number of more prospective species.

In this project, information was sought on plant characteristics that were likely to be closely related to their suitability as crop plants. However, as discussed earlier, the project did not seek to generate new, detailed species information, as this would have required considerable time and resources, and in many cases would have provided information for species that turned out to have low commercial potential and were of no further interest to the project.

This early process of elimination was conducted at two levels:

- Species were assessed within broad 'suitability' categories (see 3.2.2 below), so that each species was assessed in the roles for which it appeared to be best suited. Furthermore, these suitability categories were allocated a relative priority so that investment could be weighted to reflect the likely benefit from each.
- Within each category, species were assessed on their likely productivity and adaptability within agricultural systems. Information that is useful for this task includes plant morphology, distribution, habitat and growth rate.

3.2.2 Suitability categories

Two categories were used – crop type, and product type.

3.2.2.1 Crop type

The three most prospective woody crop archetypes for agricultural areas were described in Section 2. They are:

- **Short-cycle coppice**, or 'sprouter' crops: where harvest occurs every 2 to 5 years from successive crops grown from the same root-stock that regenerates or coppices after each harvest. Coppice crops are readily integrated into agricultural systems and there is considerable current investment in them.
- **Short-cycle phase**, or 'seeder' crops: where the crop is established from seed as a woody crop phase within the annual crop rotation and is harvested at age 3 to 6 years. This form of crop is absolutely dependent on direct seeding to be profitable. It is conceptually attractive, and provides the best opportunity to utilise nitrogen-fixing species, but is still undeveloped as a practical part of conventional crop rotations.
- **Long-cycle** crops: where the production cycle (or harvest frequency) is usually greater than 10 years but may be as long as 100 years. Long-cycle crops require large, long-term capital investment but this may be offset to some degree by additional benefits in shelter and aesthetics. Long-cycle crops will commonly produce conventional timber products for which markets already exist.

The relative importance of these crop types for new crop development in low and medium rainfall areas, as assessed by Search, is given in Table 3. These percentages are based on a subjective assessment of the likelihood of new industries being established within each crop type, the likely size of these new industries, and their potential importance in terms of land management benefits.

Table 3. R&D priority for each crop type

Crop type	%
Short-cycle coppice (SCC)	35
Short-cycle phase (SCP)	50
Long-cycle (LC)	15
Total	100

Among the short-cycle crops, phase crops were allocated a greater share than coppice crops. Phase crops were recognised as being even less well developed than coppice crops, despite an abundance of potential species worth testing, and a large area of land potentially suited to them. Coppice crops, on the other hand, had a head start, with considerable research already completed for the traditional oil mallee industries in NSW, Victoria and a new industry under development in Western Australia. Furthermore, coppice crops are also a focus of investigation in the U.S. and Europe, albeit with different species. In contrast research into short-cycle woody phase species has no known precedents in Australia. They are the preferred alternative archetype to coppice where lateral flows of water are absent or small and where extraction of groundwater is not likely to occur and hence require additional development.

In Western Australia, as in the rest of Australia, the extension of conventional long-cycle forestry into the medium rainfall zone has been the subject of considerable study in the past, and is the subject of ongoing research projects. However, there is very limited potential for long-cycle forestry in the drier part of the agricultural zone, where few perennial crop options exist, but the need for them is great. For these reasons, the share of the Search budget that was devoted to long-cycle forestry products was limited to 15%, as shown in Table 3.

3.2.2.2 Product type

The second category is based on the type of product for which a species may be suitable. There are a number of broad categories, each of which requires different plant components to be maximised. Some examples are:

- Maximum biomass - bioenergy uses
- Maximum wood - panel board, pulp and paper
- Maximum foliage - grazing and browsing
- Maximum extractive bearing tissue (eg. bark, foliage, wood) - specific for particular groups of extractives

The Search project limited its first round testing of species to the first two categories – species for maximum biomass and wood production, with a bias towards ‘maximum wood’, because ‘wood’ uses are likely to support higher prices for feedstock and be more demanding in terms of feedstock specifications than ‘biomass’ uses such as energy production. The species that show the best potential for use in biomass and wood products can then be tested for attributes that indicate potential for various co-products, especially extractives and bioenergy.

Reasons for adopting this approach included:

- Biomass and other large wood-fibre uses (pulp, paper and panel boards) are the largest potential users of farm-grown feedstock, and therefore have the best potential to stimulate large-scale woody crop development,
- Research into extractive content of plants is both complex and expensive. Search will enable future extractives work to focus on species that have been identified as having high potential for one or more large-scale uses for their wood.
- A likely workable combination of products includes at least three products – a high value wood use (paper or panel boards), a high value extractive, and a use for all residues (bioenergy). These three product categories are complementary, each extracting revenue from a single feedstock.
- The ‘maximum foliage’ category received little attention in the Search Project. Other studies of the grazing and browsing potential of native species have demonstrated that the perennial component of Western Australia’s native flora lacks species with sufficiently high digestibility for use as the sole diet of sheep and cattle, and lacks species with sufficiently high production rates to be commercial (Lefroy 2002). Also, the market for greatly expanded livestock production needs further assessment. Other reasons for not pursuing fodder species at this stage are that a collaborative, JVAP funded project between SARDI and NSW Agriculture has been established to investigate the fodder potential of native perennial shrubs, beginning with a literature review. Issues such as growth rates in cultivation, and fodder value in mixed grazing systems will be evaluated. Finally, grazing industries are also the focus of a large investment by the Cooperative Research Centre for Plant-based Management of Dryland Salinity to improve herbaceous perennials, especially lucerne.

3.2.3 Criteria for ranking species

Once target suitability categories have been selected, selection criteria can be established for the chosen category(ies). Some examples are given below.

3.2.3.1 Growth rate and yield

Any species being considered for use as a commercial crop must grow well and produce a high yield of the target material. In this project, with high wood and total biomass production being sought, where there was no existing data for growth under cultivation, easily collected data such as size and vigour of growth in native or unmanaged stands were used as indicators of potential yield.

3.2.3.2 Morphology

Plant morphology will affect a species’ commercial potential, and determine the range of products for which it is suited. Each of the product types above could require plants of different morphology. An overriding requirement is that plants can be harvested efficiently. For example, erect straight stemmed form is likely to be desirable for crops harvested for wood products, and was one of the desirable attributes sought in this project.

3.2.3.3 Adaptability

For species with no record of performance in cultivation, existing records of attributes such as natural distribution, environmental range and genetic diversity were used as indicators of likely adaptability as a managed crop. Absence of obvious pest and disease problems in native stands is also favourable. Good data are available on tolerance of waterlogging and salinity for many species for discharge sites, but these were not the primary target sites for this project.

Details of the selection process used in this project, and its results are provided in Section 5 (Species Selection).

3.3 Step 3 - Test selected plant material for suitability as feedstock

In this step, species selected in Step Two are tested to evaluate their feedstock characteristics for the products chosen in Step One. Tests are conducted in a progressively more intensive sequence (low cost, quickly executed tests first) so that species can be progressively discarded if they fail to pass early tests.

3.3.1 Preliminary tests

In this step, specifications are listed for feedstock characteristics for each product. For example, desirable attributes for wood intended for panel board manufacture include:

- Low density
- Pale colour
- Long fibre length
- Low sugar
- Low silica (wears out machinery)
- Low extractive content in the wood (reduces % yield from raw material and can interfere with resin setting and bonding)

Attributes such as these can be tested relatively quickly and cheaply, to shorten the list of prospective species before more expensive tests are performed.

3.3.2 More complex tests

The next level of testing may involve manufacture of sample products. In the Search Project, a major part of the project's expenditure was on the test manufacture of products such as medium density fibreboard, particleboard, chemical pulp, and paper handsheets.

This level of testing is the first opportunity to judge the performance of test species against industry-standard materials, and subject them to industry-standard tests. Species that perform well in these tests show sufficient promise to justify a significant increase in resources for further investigation.

See Section 6 (Feedstock Testing) for details of work done on this step in the Search Project.

3.4 Step 4 - Detailed selection of species

The first three steps deliver a short-list of species that warrant intensive investigation. Step Four consists of intensive investigation of the biological attributes of species and their biological and economic suitability as crop plants.

This involves detailed field experiments and extensive survey of native and planted populations of the short-listed species, and design and analysis of integrated farming systems. Factors to be considered include:

- Yield potential and environmental tolerances (climate, soil, herbicides).
- Biological interactions (nitrogen fixing, parasite/host relationships, allelopathy, pests and diseases, grazing, shelter).
- Water use physiology and ecology including rooting depth and lateral extent.
- Weed risk and management options to reduce it where necessary.
- Ecosystem value, to favour species that are compatible with, or add value to local and regional nature conservation.
- Genetic structure of populations, breeding systems, systematic germplasm collection, progeny testing, seed production and propagation methods, management of the risk of undesirable genetic transfer into native populations.
- Crop establishment, management attributes and practices.
- Economic analysis to estimate feedstock production costs, and returns to farmers under a variety of conditions and layouts.

It is important to note that many of these factors are not black and white selection criteria – rather they are factors to take into account when designing a production system. For example, high palatability may be an advantage for a fodder crop but a disadvantage in a timber tree. So if a highly palatable plant is to be grown for non-fodder purposes, the farming system needs to include measures to separate stock from the crop at susceptible times. Farming systems designed for new perennial crops will need to take all the factors above into account, to ensure that they can be managed in ways that take advantage of an individual species' strengths, and avoid the consequences of its potential weaknesses.

The output of Step Four includes proposed strategies for development of promising species as crops.

3.5 Step 5 - Detailed testing of products and production processes

Detailed technical testing will be needed to:

- assess the potential of new feedstocks to make quality products,
- determine appropriate modification to existing processes or develop new processes to gain greatest value from new feedstocks.

This step is likely to be more expensive than any of the preceding steps. It requires sophisticated and repeated testing and analysis of raw materials, processes and products. It will require the manufacture and testing of sample products made from material from a range of ages and environments. As well, variations in processing conditions will need to be explored, to find the optimum combination of feedstock characteristics and process conditions.

Because initial testing work is likely to have used unimproved germplasm, the full range of material that each species can provide (from different populations, or even individual plants) will need to be explored, to provide guidance for subsequent plant breeding work.

This step is likely to see the rapid development of relationships with industry partners who have a commercial interest in the outcome, and are prepared to either finance or carry out some of the work. Although the majority of the work up to this stage is likely to require a high percentage of public funding, there are several reasons why transfer to private interests is appropriate at this step:

- high cost of this work
- specific, directed nature of the work, meshing with existing production infrastructure and product ranges
- commercially valuable outcomes are likely, and are best controlled by entities that are well placed to further develop and implement them.

3.6 Step 6 - Design new integrated industries

The final step is the design of new integrated industries, using workable combinations of species and products that have been identified by the process thus far. The goals of this step include:

- Finding profitable uses for all parts of the biomass produced.
- Selecting compatible processing options for integrated production.
- Optimising profitability for both growers and processors.
- Determining the water requirements of the crop, to enable appropriate farming systems to be developed, and to enable the calculation of maximum potential feedstock production within designated transport horizons (this issue is discussed further in Section 7 (Economic analysis).
- Developing crop resources in a coordinated way.

- Developing efficient techniques for coordinated harvesting, transport and segregation at the factory.
- Developing strategies to secure access to the required infrastructure, or locating new industries where infrastructure needs are most easily met.
- Resolving waste management and environmental issues as required.
- Tailoring new industries to regions where they are best suited, after considering factors such as complementarity with existing industry or infrastructure, competition from other industries or sources of feedstock, cost of production, proximity to markets, and availability of government incentives. This step is likely to reveal strong regional difference in the optimal design of new industries, due to the unique factors that affect new industry optimisation in each region.

3.7 References

Lefroy, E (2002). Forage trees and shrubs in Australia - their current use and future potential. Rural Industries Research and Development Corporation. Report 02/039. 69p.

Robin Road Software, Agriculture Western Australia, Department of Conservation and Land Management and Greening Western Australia (1996). REX'96 Revegetation Expert System, PCWARE Australia Pty. Ltd.

Natural Heritage Trust
Helping Communities Helping Australia
An Australian Government Initiative

Search Project Report

Section 4 – Product Assessment

Western Power’s Integrated Treatment Plant at Narrogin (Photo: Graeme Olsen)

Final report for NHT Project 973849

July 2004

Government of Western Australia
Department of Conservation and Land Management
Conserving the nature of WA

Authors

Graeme Olsen[1]
Don Cooper[2]
Dan Huxtable[2]
Jerome Carslake[2]
John Bartle[2]

This report has been prepared to assist with assessment of potential new commercial opportunities based on woody perennial plants in the wheat-sheep agricultural zone of southern Western Australia. However, the work reported here is of a preliminary nature. While care has been taken in the report's preparation, no responsibility is taken by the authors or publisher for omissions or inaccuracies, or for the use of this information by any other party.

ISBN No: 0 7307 55509

[1] Olsen & Vickery, PO Box 357 Waroona, Western Australia 6215.

[2] Department of Conservation and Land Management, Locked Bag 104, Bentley Delivery Centre, Western Australia 6983.

Sections in this report

Section 1	Summary
Section 2	Background
Section 3	Search Methodology
Section 4	Product Assessment
Section 5	Species Selection
Section 6	Feedstock Testing
Section 7	Economic Analysis
Section 8	Demonstration and Resource Plantings
Section 9	Propagation Project
Section 10	Project Administration
Appendices	

Contents of this Section

Section 4 Product assessment 1

4.1 Introduction 1

4.2 Food 3

4.3 Fibre for pulp and paper 5

4.4 Fibre for panel boards 7

4.5 Chemicals 9

4.6 Energy 10

4.7 Energy – solid fuel 11

4.8 Energy – liquid fuels 12

4.9 References 19

Section 4 Product assessment

4.1 Introduction

This section contains a brief description of step one in the Search methodology “initial assessment of potential products” (Section 3). It includes an assessment of the major product categories that may be suitable for material grown in dryland agricultural areas.

4.1.1 Products suited to new perennial crops

The large scale on which short-rotation perennial crops need to be grown if they are to make a significant contribution to salinity management, and the corresponding large amounts of produce they would supply dictates that these crops require large industries with large markets (Bartle 2001). Some potential industries are listed below.

- Human food commodities: World food markets are large, but are supplied from a quite narrow base of only twelve major crops (Diamond 1997). Global food production capacity comfortably exceeds demand at present, causing food markets to be very competitive for suppliers. New, large-scale food industries based on perennial plants are likely to be difficult to establish in this environment.
- Pulp and paper: There is good scope for new, low-cost raw materials to compete in existing domestic and export markets. Profitability in this industry is closely linked to the availability of suitable feedstock at a competitive price. Part of these large global markets could be captured if new raw materials of suitable quality can be produced at low cost. Australian pulp and paper companies have expanded in the past decade to become global businesses, and are well placed to exploit new opportunities.
- Panel boards: The comments for pulp and paper also apply to panel boards. There is good scope for new, low-cost raw materials to compete in existing domestic and export markets. Australia is already a net exporter of high quality panel products into the rapidly expanding Asian market. Research and development is needed to find robust, fast-growing perennial plants with desirable feedstock attributes, and to develop processing techniques adapted to their characteristics.
- Chemicals: Two types of chemicals can be identified:
    - Commodity chemicals can be made from a variety of organic sources, for use in the synthesis of a wide range of industrial products. At present, oil and gas are the dominant raw materials for carbon-based chemical manufacture, because of their abundance and low price, but biomass is equally well-suited, and could play a larger role in future. Even if a small part of the world’s commodity chemicals were sourced from biomass, it could represent a very large market for woody plant material. The opportunity for Australian growers is limited at present by the current small size of the domestic chemical manufacturing industry, but the long term potential for this product is high.

  - Specialist chemicals can be extracted or produced from the complex secondary metabolites produced by plants. The Australian flora is rich in these chemicals, making this an attractive product area. Many of these chemicals have been restricted to small-scale uses in the past due to high production costs, but new short-cycle cropping methods could radically reduce costs and open up larger markets. These products are ideally suited to extraction from a stream of biomass in a panel board or paper pulp plant, to both improve the quality of the fibre feedstock, and to add extra revenue to the venture.
- Bioenergy: Energy is potentially the largest market for perennial crops, and could accept a variety of different types of feedstock of various qualities. However, further technical development of bioenergy processes, and structural changes in solid and liquid fuel markets are needed before bioenergy can become a major source of demand for plant biomass.
  - Liquid fuels: A decline in the availability of cheap oil and gas would stimulate structural change in transport fuel markets, and could encourage increased investment in bioenergy development, but the timing of future changes in petroleum availability and price is very uncertain (Deloitte Research 2001). Also, the potential role of biomass in future transport is very unclear, due to the plethora of competing transport technologies and fuels in this rapidly changing field.
  - Solid fuels: Greenhouse gas issues could weaken coal's position as the major source of solid fuel, but it is not clear which alternative energy sources would be most favoured by a reduction in coal usage. Biomass fuels are most likely to be competitive where three conditions are satisfied
    - generation at points on the grid remote from base load power stations,
    - made from low-cost residues after higher value co-products have been removed,
    - able to meet the criteria to earn CO_2 emissions credits, such as renewable energy certificates (RECs) under the Renewable Energy (Electricity) Act (2000).
- Fodder: These products fit easily into existing livestock industries, but are dependent on the fortunes of that industry – one that is characterised by trade barriers and other impediments to aggressive expansion of market share. Returns during the past decade were poor, but the outlook for livestock industries has improved recently. Asian markets for export grains and processed fodders could be targeted. This market is projected to expand significantly as meat consumption and intensive animal husbandry rise with wealth in the region (FAO 2002). An advantage of fodder markets is the ease with which they can be entered, at any scale of production, and with only modest investment in research and development. However, the foliage of native perennial Australian plants is characterised by its low digestibility and high frequency of anti-nutritional factors, which could require significant research and development to either avoid or overcome.

Some of these industries are discussed in more detail below, or are the subject of commissioned reports, or independent external projects. A rich source of useful information on many potential products from agroforestry is located on the website of the Joint Venture Agroforestry Project (JVAP) at the following URL: http://www.rirdc.gov.au/reports/Index.htm#Agroforestry___Farm

4.2 Food

4.2.1 Introduction

Although food is a large global industry, providing for more than six billion people each day, it is characterised by a surplus of productive capacity, and intense competition in global markets for the main food commodities. Higher priced niches and small industries abound, but either require a horticultural approach (usually with irrigation), or lack the scale to support a large growing industry in Australia. The opportunities for dryland production appear to be limited.

One potential opportunity is edible seed production from dryland *Acacia* crops. A review of this potential industry is contained in Appendix 07, and a brief summary is presented below.

4.2.2 *Acacia* seed

A large-scale *Acacia* seed industry, based on suitable species in the *Acacia* genus, could provide substantial land management benefits in dryland agricultural areas in southern Australia. This paper discusses market opportunities for Acacia seed, and some production issues that determine its potential profitability.

Acacia seed could be sold in a number of different sized markets, ranging from niche markets for bushfood and other specialty uses, to small to medium-sized markets for nuts, snack foods and pulses, and large markets for staple grains, oilseeds, food ingredients and stockfeed. At each step up in market size there is a corresponding step down in market price.

Acacia seed has some attributes that make it attractive in small markets, but these attributes are unlikely to attract a significant price premium in bulk markets for staple foods, food ingredients or stockfeed.

Major Australian grain and seed crops such as wheat, barley and canola are produced at very low cost in highly mechanised, extensive farming systems. These industries are under constant pressure to maximise yield, improve quality, minimise costs, and export most of their output into competitive global markets. A large-scale *Acacia* seed industry would be subject to the same pressures.

The existing *Acacia* seed industry is very small. It is based on tall shrub and tree *Acacia* species with a long history of traditional use as food by Australian Aborigines, and includes both wild harvesting and small-scale cultivation. Scaling up production will involve a change in methods, including the development of mechanised harvesting.

Acacia seed production could be suited to both of the systems that are likely to be used by farmers to integrate perennial crops into their activities:

Phase farming, in which acacias could be included for a short period (perhaps three to five years) in the sequence of crops grown in a paddock, would suit short-statured Acacia crops grown purely for seed.

Alley farming, with annual crops grown in alleys between belts of perennial plants would suit a wider range of seed production systems. As well as the short-statured, dedicated seed crop described above, alley systems also suit longer lived seed crops, such as tall shrub and tree crops, perhaps grown for multiple products. However, the feasibility of developing efficient harvesting techniques for tall trees and shrubs would need to be assessed.

The development of row-crop harvesters should bring significant reductions to harvesting costs for the *Acacia* seed species in current use. This harvester development path could suit a small to medium-sized industry based on high value seed, but it will reach its limits long before becoming competitive with broad-acre grain production systems harvested by headers.

A more promising development pathway for large-scale crops is to develop an *Acacia* crop with a different morphology – one that has many features in common with broad acre crops, enabling it to be harvested by equipment with similar efficiency to conventional grain harvesters. Desirable features in the plant include short stature, high ratio of seed production to vegetative growth, formation of pods and seeds at or near the top of the plant, large seed size, synchronous seed ripening, and reduced or inhibited pod shattering.

When developing a new crop, it is important that key aspects of farming system design are considered simultaneously. Important issues for *Acacia* seed development are species selection, crop design, management methods and harvester development.

At a broader level, requirements for new crop development include:

- suitable germplasm
- efficient, integrated farming systems
- appropriate growing, harvesting and processing technology
- acceptable product quality
- market penetration

Does *Acacia* seed have the potential to become a major food crop? It's too early to say, but further investigation is warranted. *Acacia* is an extremely diverse genus, with about 1,000 different taxa identified in Australia. A proper investigation of this variability may find suitable species or populations from which successful new crops can be developed.

In conclusion, it seems likely that further development of existing tall *Acacia* seed species and associated harvesting technology will enable the industry to grow from a niche industry to a small industry, but this pathway will not lead to the development of a large industry. To achieve that goal, and its associated land management benefits, a different development path is needed – one that selects and develops new germplasm better suited to efficient management and handling.

4.3 Fibre for pulp and paper

4.3.1 Summary

CSIRO Forestry and Forest Products produced a literature review of the pulp and paper industries for the Search project. The review confirms that growth in pulp and paper markets is likely to continue strongly, especially in the Asia-Pacific region, and that Kraft pulp from hardwoods will strengthen its dominance as the main feedstock for the rapidly-growing office and writing paper market.

The full report is contained in Appendix 1, and the executive summary is reproduced in section 4.3.2 below.

There are three hurdles to be overcome before any new source of feedstock, such as new woody fibre crops in agricultural areas, could become part of the mainstream pulp and paper industry:

- Feedstock quality must meet the requirements for the target product.
- The delivered price of the new feedstock must be competitive with existing sources of supply.
- Barriers to trying something new will need to be overcome. Conservative investment behaviour in this industry is exacerbated by the size of investment required to build a new world-class Kraft pulp mill (A$1.4 to $2 billion).

Each of these barriers deserves further investigation. Feedstock testing of a range of prospective species will clarify the potential to meet the first requirement, while economic analysis presented in Section 7 lends support to the possibility that short-cycle woody crops in agricultural areas have the potential to match, and perhaps undercut the delivered cost of fibre produced in conventional forestry systems.

A possible approach to reducing the commercial risk accompanying the adoption of a new feedstock is to provide the new feedstock to an existing pulp mill in the first instance, for blending with current feedstocks, or processing in separate batches, so that their processing characteristics can be evaluated and optimised before any decision is made to build a dedicated pulp mill.

Although it is undoubtedly not an easy task to attract investment into new areas using new feedstocks, should such a venture proceed and be successful, new woody crops have the potential to not only capture a share of growth in pulp and paper industry, but also to accelerate the retirement of some existing, less competitive pulp mills.

4.3.2 Executive summary from CSIRO pulp and paper review

This report provides an overview of the pulp and paper industry, covering markets, manufacturing processes, feed-stocks, paper types and future trends in the industry. Against this background, potential opportunities and prospects in the pulp and paper industry for woody biomass grown in low rainfall regions in WA are identified.

4.3.2.1 Key Features of the Pulp and Paper Industry

- The world consumption of paper products is currently around 330 million tonnes per annum.
- Strong growth in world demand for all the main types of paper product is expected over the next decade. Growth in the Asia-Pacific region will be particularly strong (between 6 and 12% depending on paper type).
- The technologies used to produce pulp and to manufacture paper will remain essentially unchanged for the foreseeable future. The most significant changes will occur in the value-adding sector of the industry e.g. printing, coating etc.
- Worldwide, Kraft chemical pulp and recycled fibre currently dominate the paper industry, with each providing approximately 40% of the total fibre used in the manufacture of products. The remaining fibre needs are met largely by mechanical, semi-chemical and non-wood pulps. In the Asia-Pacific region, recycled fibre comprises around 50% of paper products, and Kraft pulp around a quarter.
- Kraft pulp and recycled fibre will continue to dominate the industry in the future, and non-wood pulp will decline in importance. New Kraft mills will be constructed around the world in the next decade, with older, less competitive mills being closed.
- The current market for hardwood chips for pulping in the Asia-Pacific region is around 13.5 million bone dry tonnes per annum. Japan is the dominant consumer (87%), and Australia is a major supplier (30%). The hardwood chip market in the region will remain strong in the future, with Japan continuing as the principal consumer.

4.3.2.2 Opportunities and Prospects for Low Rainfall Woody Biomass

- Woody biomass grown in the low rainfall agricultural regions of WA would most likely be derived from hardwood species. The material could thus potentially be a feed-stock for the Kraft hardwood pulp industry.
- To penetrate the wood chip market, low rainfall woody biomass would need to be competitive with respect to price and quality, with pulp yield, wood density and fibre length being the key material properties that would need to be addressed.
- A major barrier to market entry could be the generation of feed-stocks from species which were new and unfamiliar to the pulp industry. Significant initial investments would probably be required (from growers and suppliers) to ensure that the resource became accepted in the market place.
- An ideal scenario for low rainfall woody biomass would be the construction of an ‘in-land’ pulp mill in WA, which could be supplied by wood resources derived from both high and low rainfall zones. This would reduce the impact of transport costs. However, it is likely that significant incentives would be required to persuade potential investors to fund such a venture.

4.4 Fibre for panel boards

Panels is a generic term for several types of engineered wood products for which there are two main categories:

- Veneer and laminated products are made from logs that are peeled or sliced and the thin layers glued together into solid panel products. Typical products are plywood and laminated veneer lumber (LVL).
- Reconstituted panels are made from reducing wood to small particles or fibres, mixing with glues or binders for reforming into panels. Products include particleboard, medium density fibreboard (MDF) and oriented strand board (OSB).

The size of global production of the four major panel products is given in Table 1.

Table 1. World panel production by region in 2002 in million m^3.

Region	Plywood	Particleboard	MDF	OSB	Total
North America	18.0	30.2	3.6	21.9	73.7
European Union	3.3	30.6	8.5	2.6	45.0
Asia	26.4	9.0	4.8	-	40.2
Australia	0.2	0.9	0.7	-	1.8
New Zealand	0.3	0.2	0.7	-	1.2
World total	55.2	84.1	21.3	25.6	186.2

Prices in A$ per cubic metre are in the range of $800 for plywood, $400 for particleboard and $450 for MDF. Global panel production is valued at some $100 billion.

The category of most relevance to the Search Project is reconstituted panels. Veneer and laminated products require log dimension wood as their feedstock, whereas reconstituted panels could potentially use small dimension wood from short cycle crops.

Panel products are subject to rapid technological change and there are some important market changes underway. OSB is a new product developed in the US. It has good structural properties and is eroding the previously dominant position of plywood in the structural panels market. However, its production is still substantially confined to the US. There appears to be potential for it to expand internationally and there is potential for short cycle woody crops to produce suitable feedstocks.

Another major change is the very rapid expansion in MDF production with an annual growth rate of 15.5% compared to the panels market overall at 6%. Figure 1 shows the expansion of the MDF market volume in increments of a decade. The rapid market growth and rapid product diversification marks MDF as a prime product prospect for short cycle woody crops. The following overview of MDF was extracted from an unpublished report by Hague *et al*. (in prep.).

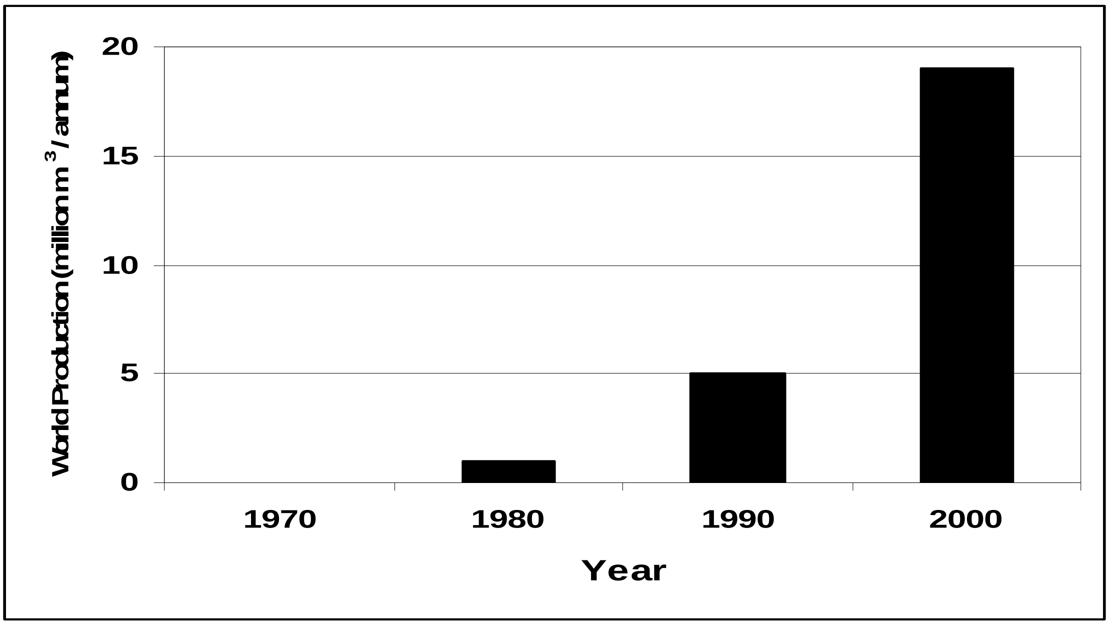


Figure 1. World production of MDF, 1970-2000.

4.4.1 MDF product properties

- It is a dry formed fibre-based product, typically produced in flat sheet form in a range of thicknesses (most commonly between 3 and 40mm). Panel density can range from around 650 to 900 kg/m^3, thinner products normally being of higher density.
- The primary bond holding fibres together is obtained by the addition of synthetic thermosetting adhesives; the choice of adhesive type is dictated by the intended end use of the product.
- A key property of MDF is its machinability (both edge and surface), which has enabled the product to penetrate furniture markets displacing solid wood, particleboard and plywood.
- MDF has developed and differentiated to such an extent that there are currently at least seven distinctly types of dry formed fibreboard now recognised in the market place. These product types are primarily differentiated by their density and durability.
- MDF is not a truly structural product, the relatively high creep coefficient of the product in particular precluding its use in long term load bearing applications. Whilst an increasing proportion of higher density fibreboard is being used for flooring applications, especially laminated flooring, the predominant use for MDF is still in furniture, millwork, mouldings and shop fitting.

4.4.2 Current Australian production capacity

The total MDF production capacity in Australia is some 860,000 m^3/year. The production capacity of individual production lines in Australia is relatively small compared with the latest installations around the world. Average capacities for the newest lines designed for commodity panel production are now around 250,000

m^3/year, with 350,000 m^3/year not uncommon. Some 50% of Australian production is exported.

4.4.3 Prospects for low rainfall woody biomass

A substantial potential export market exists for Australian produced MDF in the Asia-Pacific region. Predicted future growth in demand over the next decade alone equates to the output of between 3 and 7 modern production plants each year. Each such plant would require 1.2 million tonnes fresh weight per year of short cycle crop biomass. This would require a crop area of 100,000 ha for each plant. A goal supplying 10% of this new production would create a planting program of 30,000 to 70,000 ha/year. In order to realise such a goal, substantial R&D effort would be required to develop radical new approaches to generating low cost woody biomass with the appropriate properties.

4.5 Chemicals

Commodity chemicals were discussed briefly in the introduction, and are not discussed further here. Instead, this section deals with the potential development of products based on complex chemicals extracted from plants.

There is a vast literature on phyto-chemistry and much of this is focused on plant secondary metabolites. The distinction between primary and secondary metabolites is a useful step in trying to bring order to the maze of diversity in plant chemistry (Seigler 1998). Primary metabolism consists of the biochemical pathways that deal with the synthesis of sugars, amino acids and nucleotides, mostly in the form of polymers, that conduct the basic functions of growth common to all plants. Secondary metabolism is specific to certain plants or cells where the synthesis of specialised materials for defence against pathogens and herbivores or attraction of pollinators and seed vectors is undertaken.

Secondary metabolites include the following major groups:

- alkaloids
- glycosides
- terpenes and isoprenoids
- amines
- phenolics and flavonoids
- latex (polyisoprenes)
- minor amino acids

Seigler (1998) provides an overview of the biosynthetic pathways of these materials. Since they evolved to be biologically active and to protect plants, they form a diverse resource of materials that might be useful to man in medicine and industry. Many species have been domesticated and their secondary chemicals become commonplace e.g. *Hevea brasiliensis* the major source of natural rubber, opium poppy the source of morphine. However, the search goes on and there may be many more species and materials that could be commercialised.

There are several options to advance investigation of potential secondary metabolites in the native flora:

- Bio-prospecting is the process of systematic screening of plant material through a series of tests designed to reveal various forms of biological activity. It has been used in the search for new drugs where the high cost of such activity might be rewarded with a high value product. A form of bio-prospecting designed to reveal the presence of chemicals suited to larger scale industrial products could be developed.
- Recognised target products or plants: latex producing plants have been a target for investigation in an attempt to diversify sources of natural rubber. In the Western Australian flora, plants of the Euphorbiaceae family would be early candidates for examination. Likewise *Eucalyptus* is a recognised source of terpenes and continues to attract considerable interest (Brophy and Southwell 2002). *Eucalyptus* leaf oils research has also spawned interest in a wider range of potentially useful chemicals (Lawler and Foley 2002).
- General literature search: Humphreys and Hughes (unpublished) surveyed the literature to locate observations of chemicals present in any of the 700 legume (*Fabaceae*) species in the collection of the Genetics Resources Centre of the South Australian Research and Development Institute (SARDI). They assembled an extensive list of chemicals and references. This process could be duplicated for the native flora.
- Review of patents: perhaps a more direct way to locate compounds of interest is to search patent registers to reveal relevant commercial R&D activity.

The initial strategy likely to be adopted is to further develop recognised targets, such as terpenes in *Eucalyptus*, polysaccharide gums in *Acacia* and tannins in a variety of genera.

These and other strategies to identify and further develop potential chemical opportunities will be used to examine species that are found by the Search Project to have commercial potential for wood-based products.

4.6 Energy

Biomass was the first energy source manipulated by Man, and remains an important fuel for much of the world's population in developing countries. Although wood still retains an important role in domestic heating, the dominant sources of energy in developed countries are coal and natural gas for electricity production and oil for transport needs.

The following sections look briefly at the potential for biomass to be re-invented as a new, environmentally friendly fuel for both electricity production and liquid transport fuels.

4.7 Energy – solid fuel

Electricity from biomass has a reasonable chance of short-term success, since it requires relatively little new R&D, and the settings look reasonably attractive. However, it does require three things (Hague *et al.* in prep.):

- *One or more commercial co-products*, to lower the cost of the feedstock fraction used for electricity generation. Panel board would be one good option. A board manufacturer could afford to be selective in the quality of the chip it accepted for panel board, as all the remaining biomass could be used for electricity - assuming whole biomass harvesting and chipping followed by bulk transport to a central processing plant with integrated panel board and electricity production.

  Chemical pulp may also be attractive for this option – if there is any surplus energy after running the plant, and perhaps desalinating process water. Given that there would be large amounts of lignin produced, plus large amounts of bark, twigs, leaves and reject woodchips available for energy production, such a plant should be well into energy surplus, and could sell excess electricity.

  The other class of useful co-products are extractives of some kind, but finding extractives with both reasonably high value and large markets will be difficult. The attraction of extractives as co-products is that large amounts of biomass would remain for electricity generation, as only a small percentage of the biomass would be removed as extractive (unless the wood fraction is also used for a higher value use, which would depend very much on its wood qualities).

  The ideal would be to find species with multiple co-products. For example, good panel board species that also contain one or more valuable extractives, but in that case there not be much surplus electricity to sell, after powering the panel board plant. The integrated mallee plant being built at Narrogin (Enecon Pty Ltd 2001), where the solid wood product actually contributes energy during its processing is very favourable, but may be hard to replicate in other combinations of products. It seems likely that if the activated carbon and eucalyptus oil from the Narrogin plant both perform and sell as expected, then the cost of residue for electricity generation will be very low, or even negative.
- *A location on the grid where the delivered cost of electricity is high*, which means somewhere a long way from large electricity generating facilities. Plus local demand also needs to be fairly high, to provide a large enough local market. Suitable locations are hard to find in WA, but may be easier to find in eastern Australia, where there are more large rural towns, and where the grid is better integrated. The WA grid is fairly small, and is mainly a ‘hub and spoke’ arrangement, which makes it hard to distribute electricity efficiently from remote locations, whereas the eastern states grid has many points of generation, and is better inter-connected and cross-linked.
- *Eligibility for RECs*. This was problematic under the original form of the Renewable Energy (Electricity) Act (2000). The Act defined the use of woody crops for bioenergy under a wood waste classification where constraints designed for native forest residues compromised woody crop options. The Act was reviewed (MRET Review Panel 2003) and it was recommended that this classification be changed and the impediments to woody crop eligibility for RECs be lifted. This recommendation

was subsequently accepted by the Minister for Environment and Heritage (Kemp 2004).

As noted in Hague *et al*. (in prep.), large-scale co-firing is unlikely to be applicable for the wheatbelt, since the power stations where co-firing could apply are in coastal or near-coastal areas, and are more likely to be supplied with biomass from medium and high rainfall zones.

4.7.1 Electricity storage

The potential for equipping biomass power stations with new battery types currently under development, to provide low-cost, efficient electricity storage, thus allowing biomass electricity to be generated continuously at a steady rate, looks promising. Two contenders in the ‘flow’ battery category are the zinc bromine battery developed at Murdoch University, and now being developed by ZBB Energy in the USA, and the vanadium redox battery (VRB) developed at UNSW, currently licensed to Pinnacle and sub-licensed to various firms including Sumitomo Electric Industries and Mitsubishi Chemicals Corporation in Japan.

The commercial prospects for flow batteries look good. Kansai in Japan has a large VRB at one of its power stations, and Tasmanian Hydro has recently let a contract to install a 200kW x 4 hour VRB in conjunction with its hybrid wind, solar and diesel power supply at King Island, in Bass Strait.

Other potential electricity storage systems include the sodium sulphur battery (Tachibana 1998), which has high energy density, long life, low maintenance costs and is suited to large-scale application (6MW units being tested in operation), and the Regensys regenerative fuel cell, which can operate like a large rechargeable battery.

If large-scale commercial versions of these electricity storage technologies are developed successfully, they may expand beyond their initial role as load smoothing devices for power stations, and be installed at strategic points in the grid, to make it easier to meet variable demand with continuous supply. This could be advantageous for biomass electricity generation at remote parts of the grid, but may also strengthen the competitive position of large-scale electricity generators.

4.8 Energy – liquid fuels

The most promising liquid fuels made from biomass are the alcohols, although pyrolytic liquids and biodiesel also have some potential. Pyrolytic liquids require significant advances in R&D to be serious contenders at this stage, while biodiesel suffers from reliance on high value energy sources such as canola seed, which often have a higher value use. The discussion below is therefore restricted to fuel alcohols.

As a starting point, it must be emphasised that the potential for alcohols made from biomass to become major transport fuels is strongly linked to the future of oil and gas supplies.

4.8.1 Oil and gas reserves

4.8.1.1 Opposing viewpoints

This area defies simple interpretation, with quite plausible arguments put by opposing sides that oil and gas will either last for a very long time, or on the contrary, the age of cheap oil and gas is peaking, and within a decade or two, production will start to diminish, and prices will rise.

Those favouring the rosy scenario believe there are large amounts of conventional oil and gas still to be discovered(USGS 2000), that already discovered resources will continue to grow as they are more fully explored and exploited, that improvements in technology will bring currently non-commercial and unconventional resources into commercial reach, and that the efficiency with which fuels are used will continue to improve. The size of unconventional oil and gas resources (tar sands, oil shales, methane hydrates, etc.) are estimated to be enormous, suggesting that petroleum can be available for centuries if these resources can be exploited. If the history of human innovation is any guide, then this group of optimists would seem to have a chance of being correct.

Those with a contrary view include some very knowledgeable oil analysts (especially Deffeyes, Campbell and Laherrere) who it is hard to dismiss as mere doomsayers. Their arguments are that the areas of geological prospectivity for oil and gas are limited, well-known, and mostly well-explored already. They claim that few genuinely new, large oil fields have been discovered in the last few decades, and that most of the apparent steady increase in reserves is illusory (Laherrere, Jean 2002), due to one or more of the following causes:

- better estimation of reserves within fields (major role),
- an artefact caused by the reporting methods required by US Securities and Exchange Commission (major role),
- improved extraction technology (minor role – affects rate of extraction more than total extractable),
- deception by governments and oil companies for various political and commercial purposes (major role).

Further, they claim that all the allegedly abundant, ‘non-conventional’ oil and gas sources (such as oil shale, and ‘clathrates’ containing solid methane hydrates) will fail to be exploited in sufficient quantities to avert a looming shortage in oil and gas, because either the stated resources have been greatly over-estimated, or the recoverable portions have been over-estimated, or the likelihood of suitable technology being developed to exploit them commercially in an environmentally sound manner is low.

According to Laherrere (2001a; 2001b), many of the optimists are economists or government agencies, while many of the more credible pessimists are petroleum geologists, petroleum analysts, or retired CEOs from oil companies. He claims that the pessimists have access to confidential technical data, while the optimists have access to less accurate political or financial data, and draw incorrect conclusions.

Methane hydrates provides an example of the divergent views of different analysts. The potential to extract large volumes of commercial methane from frozen clathrates under the sea and in polar environments is rated quite highly by some (Nakicenovic et al. 2000), regarded very cautiously by others (Collett 1998), and rated as extremely low by others (Laherrere, Jean H. 1999).

Additional points made by the pessimists include:

- The rate of new oil discovery has been lower than annual consumption for over a decade (currently discoveries average around 6 billion barrels per year, compared to consumption of 27.5 billion barrels per year).
- Much of today's oil is produced from oil fields that were discovered in the 1950s and 1960s. As non-OPEC oil is depleted in the coming decade, the percentage of total oil production from old fields will increase.
- The energy profit ratio of oil and gas extraction is declining. This measure will determine when oil and gas is depleted (that is, when the energy expended in acquiring oil exceeds the energy it contains) rather than market economics (Fleay 1995).

A balanced review of the outlook for oil and gas, presenting arguments from both optimists and pessimists, but drawing no conclusions about the likely outcome was prepared recently by Deloitte Research (2001).

4.8.1.2 Sources of statistical information

BP publishes an annual statistical review of oil and gas reserves, and annual usage of all types of energy. Note that this data is not verified - BP collates and reports public data provided by oil companies and governments, without analysis or adjustment.

The 2002 review (BP 2002) shows that proved oil reserves are equal to 40 years of current annual consumption, while natural gas and coal proved reserves are 62 and 216 times current annual consumption respectively. The Middle East contains 65% of oil reserves and 36% of natural gas reserves. Concentration of reserves in this region is increasing - the Middle East produced only 30% of global oil and 9% of global natural gas in 2001.

The US Geological Survey (USGS) provides similar data on oil and gas reserves, but also estimates likely future additions through exploration (new resources) and 'reserve growth' within existing resources (USGS 2000). It estimates that oil reserves will increase by a further 147%, and natural gas reserves will increase by 173% Table 2.

Table 2. Estimates of oil and gas reserves.

	USGS 2000		BP 2001	
	Oil	Gas	Oil	Gas
Already consumed	539	150		
Current reserves	859	770	1050	975
Future 'reserve growth'	612	551		
Future discoveries	649	778		
[1] Total remaining	2120	2099		
[2] Grand total	2659	2249		

All data in billion barrels of oil equivalent.
[1] Current reserves plus estimated future increments.
[2] Sum of fuel already consumed, current reserves and estimated future increments

Oil pessimists cast doubt on the accuracy of these data sources. There is no common methodology or definition of reserves used by reporting parties, which affects the accuracy of aggregated numbers and causes large discrepancies between them (Laherrere, Jean 2002).

The USGS methodology is criticised by Laherrere (2000), on the grounds that no evidence is presented to support the forecast rapid increase in both reserve growth and new discoveries - both far above current levels. The Delphi technique appears to have been used, aggregating the opinions of a panel of experts. Laherrere argues that a more credible result would be achieved by mathematical analysis of historical trends and technical data.

Assessment of oil and gas as transport fuels

Both optimists and pessimists are likely to be right to some extent. Oil and gas will probably be major fuels for longer than the pessimists claim, but perhaps not ‘forever’ as some of the optimists claim. The optimists view of ‘forever’ in this context is that oil and gas will still be available at the time in the future when they are surpassed by cheaper or more efficient energy sources. Some new oil fields will be found, but most of them are likely to be smaller than the giant oil fields discovered in the past. Better technology will be developed for extracting oil and gas in difficult circumstances, and parts of the ‘non-conventional’ oil and gas resources are likely to be commercialised, but perhaps only a small percentage of the total resource, and perhaps at a high price. The energy profit ratio of oil and gas production are both likely to decline, making their production more expensive in terms of energy expended.

On the consumption side, fuel efficiency is likely to continue to increase, perhaps quite quickly as hybrid vehicles develop, extending the life of petroleum supplies.

All the alternatives to oil or gas powered internal combustion engines need considerable further technological development to become feasible or commercial. It’s unlikely that oil and gas will be displaced as transport fuels until their supplies become closer to depletion (30 years at least) or their use becomes unacceptable for some reason (for example, greenhouse fears, or political unrest in the Middle East). On the subject of greenhouse, Laherrere (2000; 2001a) argues that a more realistic view of potential supply, and likely improvements in fuel efficiency would lower the rate of usage of oil and gas far below some of the more extravagant extrapolations of future usage projected by the Intergovernmental Panel on Climate Change in future climate scenarios.

Developments in Australia are unlikely to have much effect on the global forces that will determine how transport is powered in future. Our market is too small, our global influence is slight, but our integration with, and dependence on global transport technology is high.

4.8.2 Potential role of alcohol fuels

It is difficult to forecast the future of alcohol fuels when the future of oil and gas is subject to such uncertainty, and wide disagreement.

As long as oil and gas are relatively cheap, there seems little scope for alcohols to take a larger share of the current Australian market for transport fuels, unless alcohols are subsidised (as at present, with an exemption from excise), or statutory requirements are put in place (similar to the requirement for 9,500 GWh of electricity to be generated from renewable sources under the Renewable Energy Act). As noted in Hague *et al*. (in prep.), diesel fuel already receives a substantial excise rebate for certain uses, undermining the competitive position of alcohols for those uses.

Because the Australian economy is relatively open, is linked strongly to the world economy, and its health depends on its trading performance (due to the small domestic market), there is limited scope for Australia to stray far from rational economics, and therefore only limited scope for stimulating alcohol use by subsidies or taxes.

Despite these uncertainties, alcohols from biomass have some strengths that might make them competitive fuels in the longer term. They are suited to a number of future scenarios, as either complete fuels or blended fuels for internal combustion motors, or as ‘easy-to-handle’ hydrogen carriers for fuel cells. Also, they can be greenhouse neutral if made from plant material (assuming concern over greenhouse persists into the future), and they are more compatible with existing storage and distribution facilities than either liquid or compressed hydrogen. A recent 'Well To Tank' analysis (General Motors Corporation 2001) found that the production of ethanol from woody plant biomass has a high total energy use, but that net energy use is low because most of the energy used in its production comes from burning lignin.

The cost of alcohol production could be reduced by lowering the cost of biomass feedstocks through improvements in growing, harvesting and handling efficiency, and by manufacturing alcohols in conjunction with other co-products, to share the feedstock cost. The ideal co-product would be one that had a high value, but made up only a small proportion of the biomass, such as an oil, resin, gum or tannin, reducing the feedstock cost to ethanol production by more than the reduction in biomass volume. However, it seems likely that most high value co-products will have only small markets, and will not match the large scale of biomass needed for an efficient alcohol production plant. Lower value extractives may have much larger markets, but their potential to lower the cost of the biomass residue is also lower.

The other alternative is to link alcohol production with large-scale co-products such as pulp or panel boards. However, in both cases, the co-product would use a large amount of the biomass, and a significant proportion of the residue would be needed to supply heat and power for its production (especially for pulp). Therefore, there may be insufficient residue remaining to produce alcohol at an efficient scale, and the residue material, being mainly leaf, twigs and bark, may be a less desirable feedstock for alcohol production (especially for enzymatic hydrolysis, which functions best when using a uniform feedstock).

Despite enormous investment in research and development, the technology for making fermentation alcohol from woody biomass appears to be unable to advance to the stage where alcohol fuels can compete directly with petroleum in the open market at current oil prices, even if feedstock prices are reduced in ways suggested above (Enecon Pty Ltd 2002). Various improvements in efficiency and production process are projected for fermentation alcohols, but even assuming that best-case-scenarios are achieved, fuel alcohols made this way are unlikely to match petroleum until oil prices rise. Most economic forecasting groups expect the price of oil to be static or fall over the next decade or two (Enecon Pty Ltd 2002).

Other pathways may have better long term prospects, despite appearing to be less favourable at present, if their ultimate cost of production has potential to be reduced below that of fermentation alcohol. Direct production from syn gas, over catalysts at high pressure may offer a better long term process for alcohol production than fermentation. This process is already developed for methanol, but speculated as having potential for ethanol (Klass 1998).

4.8.3 Other competitors

It is simplistic to assume that alcohols will become important transport fuels if oil and gas become scarce, since there are other competing transport fuels that may take precedence. The most competitive are likely to be fuels generated from coal (assuming ‘clean’ technologies can be developed for converting coal to liquid or gas fuels), and hydrogen (generated from the electrolysis of water using electricity from biomass, coal or nuclear power stations).

Assuming that oil and gas become scarce, vehicles are likely to be powered by:

- fuel cells, using hydrogen, or hydrogen-rich liquids or solids, including synthetic hydrocarbons, and alcohols,
- combustion engines running on hydrogen, coal derived fuels, or alcohols from biomass
- electricity stored in batteries (becoming feasible using new ‘refillable’ battery systems such as the vanadium redox battery), or
- hybrid systems combining more than one of the above.

In the short term, hybrid systems are likely to incorporate small, efficient internal combustion engines running on petroleum liquids or natural gas, which would extend the time before these fuels were depleted.

4.8.3.1 How competitive is hydrogen?

Hydrogen is touted as the ‘fuel’ of the future, and has the great advantage of not emitting noxious tailpipe pollutants. However, it has some significant technical and commercial hurdles to overcome.

- Fuel cells are the preferred method for converting hydrogen to useable energy. However, despite the optimism of their proponents, and the large expenditure on their development so far, they are still well short of large-scale commercialisation. Nevertheless, all major car manufacturers are investing heavily in fuel cell research and development. For example, General Motors has more than 400 scientists and engineers working on fuel cell propulsion systems and their commercialisation, and claims that fuel cell vehicles will be in production by 2010 (General Motors 2002a).
- Hydrogen needs to be made efficiently from some other fuel. Nuclear, ‘fossil’ fuel, or biomass derived fuels are most likely to provide the scale of energy required. Solar and wind seem likely to be too limited or too expensive for some time.
- Hydrogen is difficult to handle safely and efficiently. It needs to be stored at very low temperatures if stored as a liquid (boiling point -253 C), or in very strong vessels if stored as a compressed gas at 5,000 psi (EPRI 1999). New tanks made of composite material and capable of storing gases at 700 bar, or 10,000 psi are under

development, and have recently been certified for use in Germany (General Motors 2002b). They could give a vehicle a range of 300 km (the increase in hydrogen storage from doubling the pressure is only 67%, due to its compressibility). Techniques to increase the energy density of hydrogen by storing it in other solids or liquids, preferably at ambient temperature and pressure, are under development. They include chemical or physical means such as chemical carriers, metal hydrides, carbon nanotubes and glass microspheres, but all have major technical hurdles to surmount before they can be considered for commercial use. If hydrogen becomes an important fuel, it may prove so difficult to handle that it will be carbonised, to produce more energy dense synthetic hydrocarbons that are easier to handle. (opinion of Pierre-Rene Bauquis, formerly President of the Association Française des Techniciens et Professionnels du Pétrole, Vice-President of the Institut Français de l'Energie, quoted in Laherrere (2000))

- It is likely that the first mass-produced fuel cells will use gasoline or alcohols as fuels (reformed on board to make hydrogen), rather than pure hydrogen. In theory, the potential efficiency of fuel cells running on hydrocarbons would further stretch the economic life of oil reserves, and postpone the time when hydrogen becomes a major fuel. (Fuel cells are not limited by thermodynamic efficiency, but exploit chemical energy directly.)
- The production of hydrogen is inefficient in energy terms, so its high efficiency in consumption is offset by its low energy efficiency in manufacture (General Motors Corporation 2001). For example, conversion of electricity to gaseous hydrogen by electrolysis is about 68-75% efficient, and subsequent liquefaction is 65-77% efficient, making the entire process from electricity to liquid hydrogen about 50% efficient (ignoring the efficiency with which electricity is produced in the first place, which is about 30% for coal-fired power stations).

4.8.4 Update on recent oil price rise (2004)

Recent rapid rises in the oil price are seen by many as the beginning of a long term permanent increase as oil supply declines. However, the present price rise (2004) has a number of other contributory factors also at work, including political instability and supply disruptions in several of the major oil producing regions, especially the Middle East, Venezuela and Nigeria. Demand is also stated as having risen sharply, with the rapid development of the Chinese and other Asian economies.

A third factor behind rising prices is the inelastic nature of both supply and demand. New production facilities are expensive and have a long lead time before they contribute to supply, while in the short term at least, demand is inelastic also. Consumers tolerate short-term price increases, but start to modify their behaviour if prices stay high for long periods, for example, by buying more fuel efficient vehicles, or choosing different fuel sources for domestic heating. At the corporate scale, decisions on equipment purchases and fuel sources are only made after careful analysis of the options and projections of likely future prices. Once decisions are made and equipment purchased, rapid change in fuel use by corporations becomes difficult, until old equipment reaches the end of its commercial life.

Investment in alternative fuel sources and energy technologies appears more attractive at times when oil prices are high, but the likely volatility in oil markets attaches a high risk premium to such investments. Regardless of whether or not a long term price shift is occurring in the oil price, it is likely that price volatility will increase.

4.8.5 Conclusion

In conclusion, alcohol fuels are not competitive with oil and gas in free markets at current prices. However, they could become competitive in future if:

- mandated by government legislation - but this is likely to be limited to a small percentage of total fuel use, to limit its cost to the economy, or
- higher value co-products can be produced from biomass, allowing the feedstock cost for alcohol production from the residue to be low or negative, or
- petroleum prices increase significantly – with Middle East oil able to be produced in large quantities at very low production cost (<$5 per barrel) for at least two or three more decades, the most likely stimulus to price escalation is political instability, or
- non-fermentation routes for alcohol production from biomass become significantly cheaper (this could be the most promising route to lower alcohol production costs).

Alcohols have some advantages as fuels. They are suited to direct combustion and use in fuel cells, and they are easier to store and distribute at high energy density than compressed or liquefied gases, especially hydrogen.

Although alcohols made from biomass require relatively high energy input (on a life cycle basis, compared to fossil fuels) most of that energy requirement is greenhouse gas neutral.

4.9 References

(2000). Renewable Energy (Electricity) Act 2000 No. 174, 2000. **174, 2000**p.

Bartle, J (2001). Mallee eucalypts - a model, large scale perennial crop for the wheatbelt. Outlook 2001, Parkroyal Hotel, Canberra, Australia, ABARE.

BP (2002). BP Statistical review of world energy. 2001 in review.

Brophy, J and I Southwell (2002). *Eucalyptus* chemistry. Eucalyptus - the genus Eucalyptus. J Coppen. London, Taylor & Francis.

Collett, TS (1998). Resource potential of natural gas hydrates. 17th WEC Congress, Houston, Texas, USA, World Energy Council.

Deloitte Research (2001). The Utility Executive’s Field Guide to the Future: Key issues 2000-2010. Part 3: Geology, geo-politics and global warming. Deloitte Research. 67p.

Diamond, J (1997). Guns, germs and steel, Chatto & Windus.

Enecon Pty Ltd (2001). Integrated tree processing of mallee eucalypts. Rural Industries Research and Development Corporation. Report 01/160. 81p.

Enecon Pty Ltd (2002). Wood for alcohol fuels. Rural Industries Research and Development Corporation. Report 02/141. 72p.

EPRI (1999). Electricity technology roadmap. Electric Power Research Institute. Report CI-112677-V1. 136p.

FAO (2002). World agriculture: towards 2015/2030. Summary Report. Rome, FAO. 106p.

Fleay, BJ (1995). The decline of the age of oil. Annandale, NSW, Australia, Pluto Press Australia Limited. 152p.

General Motors (2002a). Fuel Cell Cars Offer Solution To Curtail Greenhouse Gas Emissions. Accessed: 09 August 2002. http://www.gm.com/cgi-bin/pr_display.pl?3105

General Motors (2002b). A quantum leap in hydrogen storage for GM. Accessed: 09 August 2002. http://www.gm.com/cgi-bin/pr_display.pl?3105

General Motors Corporation (2001). Well-to-tank energy use and greenhouse gas emissions of transportation fuels – North American analysis. General Motors, Argonne National Laboratory, BP, Exxon/Mobil, Shell.

Gifford, RM (2000). Carbon content of woody roots (revision 1). Australian Greenhouse Office. Report ISSN: 14426838. 10p.

Hague, J, G Freischmidt, S Pongracic and P Fung (in prep.). Six Best Bet Products from Agroforestry Biomass Grown in Low Rainfall Areas. Project No. CSF-60A. Rural Industries Research and Development Corporation.

Humphreys, J and S Hughes (unpublished). Pharmaceutical, nutriceutical and industrial potential of legumes held in the SARDI Genetics Resources Centre.p.

Kemp, D (2004). MRET: adding muscle not fat. Accessed: 07 July 2004. http://www.deh.gov.au/minister/env/2004/mr15jun804.html

Klass, DJ (1998). Biomass for renewable energy, fuels and chemicals. San Diego, California, USA, Academic Press. 651p.

Laherrere, J (2000). Jean Laherrère comments on "Global Natural Gas Perspectives". Accessed: 09 August 2002. http://www.hubbertpeak.com/laherrere/ngperspective/

Laherrere, J (2001a). Forecasting future production from past discovery. OPEC and the global energy balance: towards a sustainable energy future, Vienna, Austria.

Laherrere, J (2001b). Future oil production. Meeting of EMF, IEA, IEW at IIASA, Laxenburg, Austria, Laxenburg, Austria.

Laherrere, J (2002). Modelling future liquids production from extrapolation of the past and from ultimates. Uppsala, Sweden**:** 19p.

Laherrere, JH (1999). "Oceanic Hydrates: an Elusive Resource."

Lawler, I and W Foley (2002). Chemical ecology of herbivory in *Eucalyptus*: interactions between insect and mammalian herbivores and plant essential oils. Eucalyptus - the genus Eucalyptus. J Coppen. London, Taylor & Francis.

MRET Review Panel (2003). Renewable Opportunities, A Review of the Operation of the Renewable Energy (Electricity) Act 2000. Australian Greenhouse Office. 265p.

Nakicenovic, Na, A Gritsevskyi, A Grübler and K Riahi (2000). Global natural gas perspectives. Hoersholm, Denmark, International Gas Union**:** 71p.

Seigler, DS (1998). Plant secondary metabolism. Norwell, Massachusetts, Kluwer Academic Publishers. 759p.

Tachibana, Y (1998). A new power supply system using NaS (sodium sulphur) battery. 17th WEC Congress, Houston, Texas, USA, World Energy Council.

USGS (2000). U.S. Geological Survey world petroleum assessment 2000.

Natural Heritage Trust
Helping Communities Helping Australia
An Australian Government Initiative

Search Project Report

Section 5 – Species Selection

Acacia microbotrya seedlings, CALM research nursery, Kensington (Photo: Graeme Olsen)

Final report for NHT Project 973849

July 2004

Government of Western Australia
Department of Conservation and Land Management
Conserving the nature of WA

Authors

Graeme Olsen[1]
Don Cooper[2]
Dan Huxtable[2]
Jerome Carslake[2]
John Bartle[2]

This report has been prepared to assist with assessment of potential new commercial opportunities based on woody perennial plants in the wheat-sheep agricultural zone of southern Western Australia. However, the work reported here is of a preliminary nature. While care has been taken in the report's preparation, no responsibility is taken by the authors or publisher for omissions or inaccuracies, or for the use of this information by any other party.

ISBN No: 0 7307 55509

[1] Olsen & Vickery, PO Box 357 Waroona, Western Australia 6215.

[2] Department of Conservation and Land Management, Locked Bag 104, Bentley Delivery Centre, Western Australia 6983.

Sections in Report

Section 1	Summary
Section 2	Background
Section 3	Search Methodology
Section 4	Product Assessment
Section 5	Species Selection
Section 6	Feedstock Testing
Section 7	Economic Analysis
Section 8	Demonstration and Resource Plantings
Section 9	Propagation Project
Section 10	Project Administration
Appendices	

Contents of this Section

Section 5 Species Selection 1

5.1 Introduction 1

5.2 SIFT 4

5.3 Consultation 9

5.4 Species selection for other products 9

5.5 Species lists 10

5.6 References 10

Section 5 Species Selection

5.1 Introduction

5.1.1 Initial approach

This section contains a description of the process followed in the Search Project to select species for further testing, and the results of this selection process. It encompasses step two in the Search methodology “initial assessment of species” (Section 3.2).

When the Search Project began, considerable thought was given to designing a decision-making system that could identify which of the many native species found in Western Australia’s agricultural zone would be suitable for development as new crops, and which products they would be best suited for.

On the biological side, the intention was to assemble existing information about local species into a database that could be interrogated to find species suited to particular environments, and suited to particular uses. Information would be sought on a wide range of factors for each species – such as plant characteristics, environmental requirements, conservation issues, cultivation issues and commercial history.

Lists of characters such as those in Figure 1 were drawn up and debated. Character sets used by others for other purposes, to describe soils, plants, habitat, or landscape were assessed for their usefulness. The list of characters used in the REX’96 database (Robin Road Software *et al.* 1996) was also reviewed, as it was thought this would be a suitable base on which to build. An assessment of these characters from the perspective of the Search Project’s requirements is included in Appendix 19. Based on this assessment, a list of characters thought likely to be most useful for the Search Project was also developed (Appendix 20), to provide a structure for data collection, storage and interrogation. This proposed database was given the working name ‘SIFT’.

However, two opposing trends led to the abandonment of this endeavour – one was the expanding complexity of the information apparently required to make a thorough assessment of each species’ suitability for commercial development. The other was the lack of information for many of these characters being proposed for inclusion. Even where information was available, it was of doubtful use. For example, information that a particular species had been used in the past for flooring, or that another was used to make barrels, or that a third had been used to make cotton reels gave little clue as to whether or not they had the fibre characteristics that would be suited to medium density fibreboard manufacture. At best, some assumptions could be made about tree size and form, and perhaps wood density from this type of historical information. Similarly, information about a species’ natural habitat describes conditions in which the plant is known to grow, in competition with other native species, and is a valuable starting point, but it does not necessarily indicate the range of cultivated conditions under which the plant may perform well.

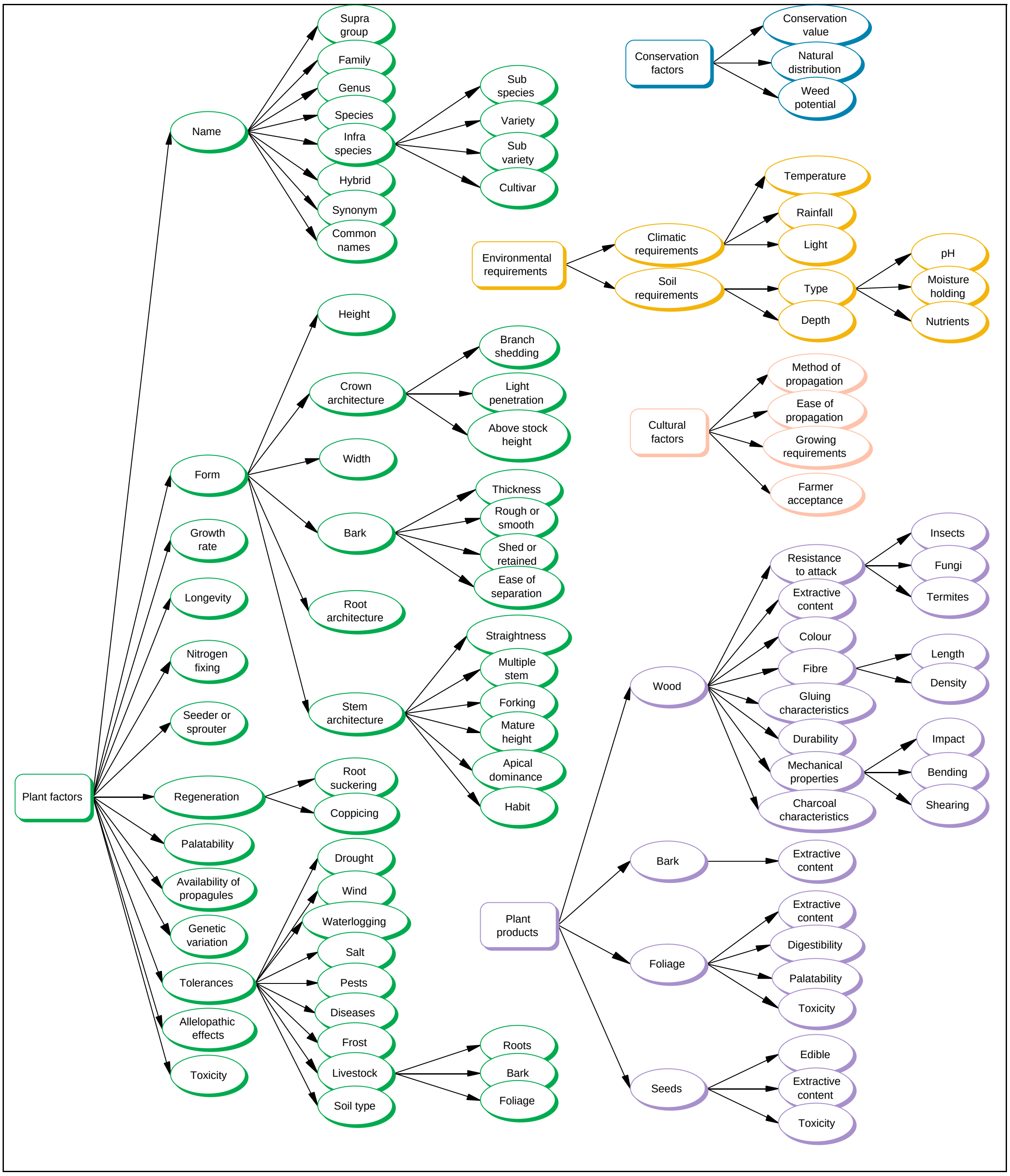


Figure 1. Example – draft lists of species' characteristics to determine commercial potential.

Bioclimatic approaches (Booth 1996, 1999), including coarse predictors of plant performance such as the Infer and 'Plantgro®' software packages (Hackett 1996a, 2000), were also explored, in an attempt to select species by identifying those with the potential to grow over a wide enough range to support new industries. It was hoped this approach would also identify species that appeared to be well adapted to particular environmental niches, to maximise the opportunities for combining a number of different species into a single industry. An industry based on multiple species would have a number of advantages – it would have resilience and diversity (from the commercial perspective) and maximise biodiversity benefits (from a conservation perspective).

This approach was also shelved, for a number of reasons. Firstly, bioclimatic matching is well-suited to estimating the likely success of introducing a well-known domesticated species, of uniform genetic composition, and with a history of cultivation, into a new location or environment (Deuter 1997). It is less well suited to the aim of the Search project, which was to select undomesticated species of unknown genetic variability, for their potential for commercial development, primarily within their natural environment. Secondly, there was insufficient information about most native species to enable bioclimatic assessments to provide accurate discrimination between species, especially the lesser known ones. The difficulties of developing species profiles for poorly understood species, and some suggested solutions are discussed in Davidson (1996) and Hackett (1996b).

Experience gained by project members in contributing to bioclimatic assessments for other, related projects confirmed this view. Even when using better-known species the results often lacked credibility, and did not discriminate well between species. It seemed that much investigation and refinement would be needed for each species to produce useful results, ruling this method out for general screening of large numbers of species.

Bioclimatic approaches may be more useful at later stages, after a smaller number of highly prospective species have been identified. Intensive bioclimatic analysis of these species could be useful, in order to identify their site requirements within their current range more precisely, and to investigate their potential for extension beyond their current natural distribution, subject to appropriate weed risk assessment.

In summary, as discussed in Section 3, the quest to assemble a complex decision-making system, combining both biophysical and product information for species, and industrial, commercial and market information for products was abandoned. A less ambitious quest, to assemble a species selection system along the lines described above (without a complex connection to products and markets) met the same fate.

5.1.2 New direction

A more strategic approach was needed to assess the thousands of potentially useful species, and concentrate research efforts on the most prospective ones. The approach adopted in the Search Project was to use simple data that was already available, to eliminate as many species from contention as possible, and then to collect the critical data that was needed to assess the commercial potential of the remaining species.

This approach became possible because the product assessment work identified paper pulp, panel boards and energy as the most prospective large-scale industries. Therefore, it was possible to screen the flora using growth as a criterion, to eliminate all small plants from further consideration at this stage.

Also, both paper pulp and panel boards require wood of low to medium density, so wood density could be used to discriminate further between species. The Australian flora has a wide range of wood densities, with a large number of high-density species in semi-arid areas. Therefore, wood density was a powerful discriminator between species. Colour is a secondary criterion, with both industries preferring pale wood to dark wood. Again, there is wide variation in the colour of Australian woods, so wood colour could be used to further discriminate between species if necessary.

Bioenergy is a relatively undiscriminating use, but also a very low-value use. It is most likely to be successful in conjunction with some other industry, so further screening for bioenergy alone was not required.

5.2 SIFT

5.2.1 Developing a simpler database

To put this species selection method into practice, a process was needed to eliminate as many species from further consideration as efficiently and accurately as possible, based on simple, reliable and relevant data. To achieve this aim, the following work was done:

- A simplified version of the database (known as 'SIFT') was established, using information from WA Herbarium records on all Western Australian species, such as their distribution, conservation status, height, form and natural habitat (described in more detail in Section 5.2 above).
- SIFT was used to identify species of most interest for the target products.
- A panel of botanical experts provided commentary on the species lists generated by SIFT and refined the list (more detail in Section 5.2.2 below).
- Wood cores were collected from most of the species on the refined list, to provide information on wood density and colour (see Section 6.3).

Note: SIFT is the working name given to the Search species selection database to distinguish it from other databases used in the project. It is not an acronym. All database work was performed using Microsoft Access.

The most useful dataset for this task was the comprehensive 'WAHERB' database on Western Australian species maintained by the Western Australian Herbarium. Relevant sections of this information were transformed into a compatible format and provided to the Search Project courtesy of the Herbarium. The tables currently populated in the SIFT database are listed in Table 1. Other tables are partly populated with data for future use when more intensive investigation of fewer species is required, but they are not listed here.

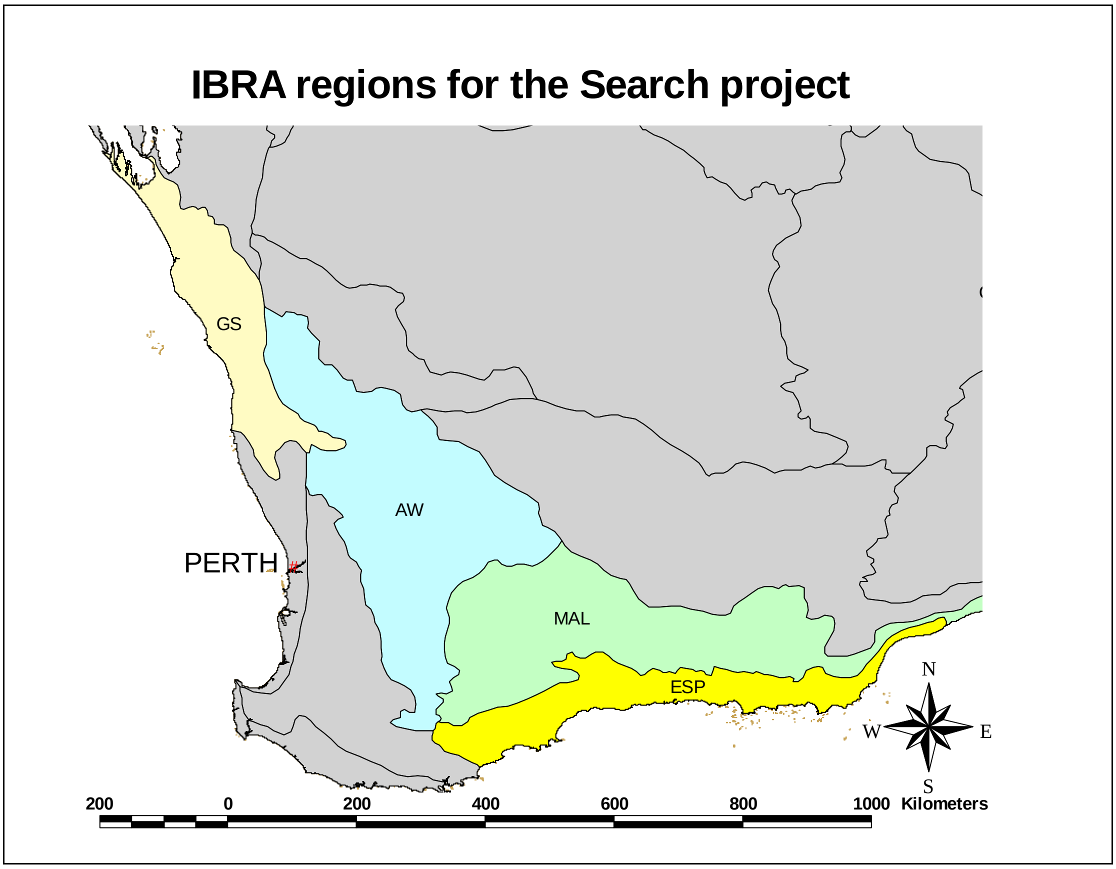
Once the database was set up with WAHERB data, rapid reduction in the number of species of interest was achieved using the following criteria:

- Native to WA - not introduced or recently naturalised.
- Not rare or endangered - since access to these species for material collection would not be possible (discussed in 5.2.2 below).
- Dicotyledon or gymnosperm – removed all non-woody species.
- found in the IBRA regions (Thackway and Cresswell 1995) covering the WA agricultural zone – to restrict the search to species found in the target region for new woody crop development. See Figure 2.
- At least one specimen recorded to 4 metres or taller – using plant height as a surrogate for plant size.

The results of this process are shown in Table 2.

Table 1. Data tables in SIFT.

Table name	Type	WA		
		Prefix	Records	Data
Tables in 2002 02 27 WA SIFT				
Conservation_codes	matrix	W	6	complete
Families	matrix	W	714	complete
Genera	matrix	W	1 777	complete
Groups	matrix	W	9	complete
Infraspecies	matrix	W	17 000	complete
Name_codes	matrix	W	17 000	complete
Species	matrix	W	14 186	complete
Species_Height	matrix	W	14 186	complete
Species_IBRA_matrix	matrix	W	14 186	complete
Taxa_Conservation	matrix	W	17 000	complete
Taxa_Current	matrix	W	17 000	complete
Taxa_Height	matrix	W	17 000	complete
Taxa_IBRA_matrix	matrix	W	17 000	complete



GS: Geraldton Sandplains AW: Avon Wheatbelt
MAL: Mallee ESP: Esperance Plains

Figure 2. Interim Biogeographic Regions of Australia relevant to the Search project.

Table 2. WA Herbarium data – number of species in various categories.

	Location	Species
Individual reductions		
Total (including non-current names)	WA	14 186
Current names	WA	11 038
Native	WA	12 947
Not "Priority" species	WA	12 132
Dicotyledon	WA	11 136
Gymnosperm	WA	32
IBRA - AW, ESP, GS, or MAL	Wheatbelt	6 408
IBRA	"AW"	3 781
IBRA	"ESP"	2 943
IBRA	"GS"	2 878
IBRA	"MAL"	3 199
IBRA - all four IBRA regions	Wheatbelt	765
Taller than 4 metres	WA	1 305
Cumulative reductions		
Total (including non-current names)	WA	14 186
Current names	WA	11 038
Native	WA	9 977
Not "Priority" species	WA	7 965
Woody (Dicotyledon, Gymnosperm)	WA	6 339
IBRA - AW, ESP, GS, or MAL	Wheatbelt	3 664
Taller than 4 metres	Wheatbelt	484
Taller than 4 metres	"AW"	309
Taller than 4 metres	"ESP"	266
Taller than 4 metres	"GS"	219
Taller than 4 metres	"MAL"	293
Taller than 4 metres	All 4 areas	68

From a total of 11,038 current species in Western Australia in 2001, most were native (9,977). Removing “priority taxa” (that is, taxa designated as being either extinct, rare, endangered, requiring special protection, or requiring investigation to determine their conservation status – see 5.2.2 below) reduced the number of species remaining to 7,965. Further steady reductions resulted from restricting the list to woody plants (6,339) and then restricting the search to the four IBRA biogeographic boundaries that approximately coincide with the WA wheatbelt (3,664). However, the largest reduction occurred when the arbitrary height of 4 metres was used to select plants likely to be suitable for the production of bulk biomass (484 species in the wheatbelt, or 582 taxa including subspecies).

Of those 484 species, approximately 200 to 300 occur in each IBRA zone, but only 68 were found in all four zones. The wide distribution of these species increases interest in them as potential crop plants.

Some comment is necessary on the choice of a cut-off height of 4 metres. At first glance it may seem unduly high, and be likely to remove an unnecessary number of prospective species. In practice this seems not to have occurred. Many of the species with a maximum recorded height of 4 metres in fact have average heights little more than half that height. If a lower height cut-off had been used, a large number of extra taxa would have been included in the results, the majority of which are too small for industrial woodchip production. Different heights were tested as potential cut-off points, and it was concluded that 4 metres was a reasonable compromise between including prospective species and excluding those that are too small.

Some caveats are required on this usage of Herbarium data. First, the information is not perfect. It contains only data that has been provided from collected specimens, and therefore may not cover the full range of some plants' location or height. Second, the data is constantly changing. It is subject to revision as new specimens are added, as errors in older data are corrected, and as taxonomic research results in some specimens being re-allocated to different taxa, or new taxa being described. However, despite these minor caveats, the data set used here is believed to be very robust, and well-suited to the purposes of the Search Project. It can also be updated periodically to maintain synchronisation with Herbarium records as they change.

Other information from specimen records for each species was also provided by the WA Herbarium, but was not used at this time. It included information on the plant type and form of each species, and habitat and soil type from locations where it had been collected. The information has been converted into a format that better matches the Search Project's needs, and may be used in subsequent phases of investigation (beyond the Search Project) when more specific information is collected for the most prospective species.

5.2.2 Conservation status

5.2.2.1 Discussion

An important species selection criterion used in SIFT was conservation status. The conservation classifications used in Western Australia are described in 5.2.2.2 below.

Species declared as rare flora ('R') were excluded from further consideration, as they are unlikely to be suited to commercial development. They are likely to have restricted genetic variation, occupy a restricted range, and are unlikely to occur in populations large enough to support extraction of test material or seed collection.

The situation was more complex with other categories of conservation status, the so-called 'Priority Species', P1 to P4.

P1 and P2 priority species were excluded from consideration on the same grounds as rare flora, above. However, P3 and P4 species were considered for selection, as they may be less threatened than higher priority species. Had any of these species been selected for testing, then further investigation would have been required to determine their conservation status more precisely, to allow a decision to be made on whether or not testing for this project was appropriate. At the conclusion of the selection process, five P3 and two P4 species were still in contention for testing, but none were of sufficient interest to justify the effort required to determine whether or not testing would be permissible. Therefore, no samples were collected from these species and they were excluded from further consideration.

5.2.2.2 Descriptions of conservation status

The following conservation categories are used in Western Australia, adapted from FloraBase (Western Australian Herbarium 1998):

R: Declared Rare Flora - Extant Taxa (= Threatened Flora = Endangered + Vulnerable)

Taxa which have been adequately searched for, and are deemed to be in the wild either rare, in danger of extinction, or otherwise in need of special protection, and have been gazetted as such, following approval by the Minister for the Environment, after recommendation by the State's Endangered Flora Consultative Committee.

X: Declared Rare Flora - Presumed Extinct Taxa

Taxa which have not been collected, or otherwise verified, over the past 50 years despite thorough searching, or of which all known wild populations have been destroyed more recently, and have been gazetted as such, following approval by the Minister for the Environment, after recommendation by the State's Endangered Flora Consultative Committee.

P1: Priority One - Poorly Known Taxa

Taxa which are known from one or a few (generally <5) populations which are under threat, either due to small population size, or being on lands under immediate threat, e.g. road verges, urban areas, farmland, active mineral leases, etc., or the plants are under threat, e.g. from disease, grazing by feral animals, etc. May include taxa with threatened populations on protected lands. Such taxa are under consideration for declaration as 'rare flora', but are in urgent need of further survey.

P2: Priority Two - Poorly Known Taxa

Taxa which are known from one or a few (generally <5) populations, at least some of which are not believed to be under immediate threat (i.e. not currently endangered). Such taxa are under consideration for declaration as 'rare flora', but are in urgent need of further survey.

P3: Priority Three - Poorly Known Taxa

Taxa, which are known from several populations, at least some of which are not believed to be under immediate threat (i.e. not currently endangered). Such taxa are under consideration for declaration as 'rare flora', but are in need of further survey.

P4: Priority Four - Rare Taxa

Taxa which are considered to have been adequately surveyed and which, whilst being rare (in Australia), are not currently threatened by any identifiable factors. These taxa require monitoring every 5-10 years.

5.3 Consultation

Following the completion of species selection within the SIFT database, consultations were held with botanical experts to add a subjective element to the process, and to draw on and pool the knowledge held by individuals.

There were a number of aims in consulting experts. The first was to review the list produced from SIFT, to ensure that the species listed were reasonable. As a result of the consultation, some species were added to the list and a few were removed. The experts were able to apply their knowledge of plant form and growth requirements for many of the listed species very quickly and efficiently. This process was far quicker and more effective than trying to define these somewhat nebulous characteristics in ways that can be processed in a database. The experts were also able to check that height (used as a discriminating factor in SIFT) was a reasonable surrogate for biomass. In some cases it wasn't, and some tall spindly plants were excluded.

In the genus *Eucalyptus*, the number of species that satisfied the basic criteria was too large to test. In this case, species were selected strategically, to ensure that as many of the major groups within *Eucalyptus* were represented as possible, based on the assumption that wood characteristics were likely to be similar within related species. If a particular *Eucalyptus* species showed promise in the tests, then related species could be tested in subsequent rounds of testing.

Some species were removed from the list because they are parasitic, and therefore are likely to be too challenging to establish and grow successfully as commodity biomass crops. Other species were removed because they are restricted to environmental niches that are uncommon on agricultural land, or for some other practical reason, such as toxicity to stock.

Another important reason for consulting botanical experts was to set priorities. Since there were still too many species on the list to test them all, a method was needed to refine the list further. This was done by giving each species a subjective 'growth rating', based on the experts' opinions of each species' capability to grow at a reasonable speed in cultivation without major problems, and produce a reasonable amount of harvestable woody biomass. Although there was not a unanimous opinion about every species, there was sufficient agreement for this process to be used successfully.

5.4 Species selection for other products

The process of species selection described above was focussed on selecting species for products such as pulp and paper, and panel boards - the major products chosen by the Search Project for testing. Separate selection processes were used for other potential product types, which were allocated smaller proportions of the feedstock testing budget.

For example, for combustion properties, species were selected that performed well in pulp and paper testing, or panel board testing. Combustion is most likely to be commercially attractive if based on residues from these industries, rather than being a primary use, because of the relatively low value placed on combustion feedstocks. This meant that the final selection of species for combustion testing had to be postponed until test results were available from pulp, paper and panel board testing.

A simple selection process was used for metallurgical charcoal potential. Since testing for ash and mineral content was relatively inexpensive, and the amount of material needed for testing was small, a large number of species could be tested. Most samples were taken from larger collections of material collected for one of the other product testing streams.

Species selection for sawn timber testing followed a different path. In consultation with knowledgeable botanists and foresters, a list was drawn up of species that had potential to fit the size and form requirements of sawn timber. From those, twelve were selected that had not previously been studied, in order that the subsequent testing would generate new knowledge.

5.5 Species lists

The working document listing the results of both the SIFT database work and subsequent consultation with experts is presented in Appendix 15. The species found through this process to be most prospective for pulp, paper and panel boards were then put forward for consideration for feedstock testing (Section 6).

This working document includes the following information for each taxon:

- Scientific name, botanical family.
- Conservation code (X = presumed extinct, R = declared rare flora, P1 to P3 = priority ratings for poorly known taxa, P4 = rare but not currently threatened taxa).
- Height (maximum recorded in WAHERB)
- Presence in relevant IBRA zones.
- Selected by the SIFT process (582 taxa selected).
- Added following expert suggestion (48 taxa added).
- Taxa selected for testing (245 taxa selected for testing, with an additional 31 rated as “maybe”).
- Taxa actually tested by taking wood cores (230 taxa actually tested).
- Growth rating for taxa actually tested (239 taxa were rated – 36 received the top rating [1], 95 received the middle rating [2], and 108 received the lowest rating [3]).

Species tested for their suitability for other products (sawn timber, combustion, charcoal) are listed in the relevant part of Section 6.

5.6 References

Booth, TH (1996). Matching trees and sites. Proceedings of an international workshop held in Bangkok, Thailand 27-30 March 1995, ACIAR Proceedings No. 63. 126p.

Booth, TH (1999). Matching germplasm to geography: Environmental analysis for plant introduction. p63-74 *In* Linking genetic resources and geography: Emerging strategies for conserving and using crop biodiversity. Special publication no. 27. S Greene and L Guarino, Eds. Madison, Wisconsin, Crop Science Society of America.

Davidson, J (1996). Developing Plantgro plant files for forest trees. p93-96 *In* Matching Trees and Sites. Proceedings of an International workshop held in Bangkok, Thailand. 27-30 March 1995. TH Booth, Ed., ACIAR Proceedings No. 63.

Deuter, P (1997). Experience in using Plantgro as a tool in crop and site selection. p177-188 *In* New crops, new products. New opportunities for Australian agriculture. Volume 1 Principles and case studies, Rural Industries Research and Development Corporation.

Hackett, C (1996a). Infer. An expert system for estimating the environmental relationships of plants from the conditions they experience, Plantsoft Services.

Hackett, C (1996b). A study of forest scientists' perceptions of trees' environmental relationships : implications for predicting growth. p77-84 *In* Matching Trees and Sites. Proceedings of an International workshop held in Bangkok, Thailand. 27-30 March 1995. TH Booth, Ed., ACIAR Proceedings No. 63.

Hackett, C (2000). Plantgro: A software package for the prediction of plant growth, Plantsoft Services.

Robin Road Software, Agriculture Western Australia, Department of Conservation and Land Management and Greening Western Australia (1996). REX'96 Revegetation Expert System, PCWARE Australia Pty. Ltd.

Thackway, R and I Cresswell (1995). An interim biogeographic regionalisation for Australia: a framework for establishing the national system of reserves, version 4.0. Australian National Conservation Agency.

Western Australian Herbarium (1998). FloraBase - Information on the Western Australian flora. Accessed: http://www.calm.wa.gov.au/science/florabase.html

Natural Heritage Trust
Helping Communities Helping Australia
An Australian Government Initiative

Search Project Report

Section 6 – Feedstock Testing

Pilot-scale Defibrator for medium density fibreboard manufacture, Ian Wark Laboratories, CSIRO Forestry and Forest Products, Clayton, Victoria

Final report for NHT Project 973849

July 2004

Government of Western Australia
Department of Conservation and Land Management
Conserving the nature of WA

Authors

Graeme Olsen[1]
Don Cooper[2]
Dan Huxtable[2]
Jerome Carslake[2]
John Bartle[2]

This report has been prepared to assist with assessment of potential new commercial opportunities based on woody perennial plants in the wheat-sheep agricultural zone of southern Western Australia. However, the work reported here is of a preliminary nature. While care has been taken in the report's preparation, no responsibility is taken by the authors or publisher for omissions or inaccuracies, or for the use of this information by any other party.

Photographs: Unless stated otherwise, all photographs were taken by Graeme Olsen.

ISBN No: 0 7307 55509

[1] Olsen & Vickery, PO Box 357 Waroona, Western Australia 6215.

[2] Department of Conservation and Land Management, Locked Bag 104, Bentley Delivery Centre, Western Australia 6983.

Sections in this report

Section 1	Summary
Section 2	Background
Section 3	Search Methodology
Section 4	Product Assessment
Section 5	Species Selection
Section 6	Feedstock Testing
Section 7	Economic Analysis
Section 8	Demonstration and Resource Plantings
Section 9	Propagation Project
Section 10	Project Administration
Appendices	

Contents of this Section

Section 6 Feedstock Testing 5

6.1 Feedstock testing strategy..5

6.2 Tenders to test woody material...9

6.3 Wood coring – reconstituted products..9

6.4 Material collection – reconstituted products 20

6.5 Laboratory testing – pulp and paper...22

6.6 Laboratory testing – panel boards 46

6.7 Laboratory testing – sawn timber 72

6.8 Laboratory testing – combustion 112

6.9 Laboratory testing – charcoal reductant 152

6.10 Other products 163

6.11 Conclusions 163

6.12 References 164

Section 6 Feedstock Testing

This section contains a brief description of step three in the Search methodology "Test selected plant material for suitability as feedstock" (Section 3.3). It includes a discussion of the strategy adopted in the Search Project, and the results of testing for a range of potential products, including pulp and paper, panel boards, sawn timber and bioenergy.

6.1 Feedstock testing strategy

6.1.1 General principles

An ideal outcome would be to find native species that combine high growth rate with good feedstock characteristics for the chosen product or products (Figure 1). However, in reality such an ideal situation is unlikely to occur. A more likely outcome is that further development work will be needed to improve either a species' productivity, or its feedstock suitability, or both. The two extremes are listed below (although a combination of both would be required for many species).

- Select species with high feedstock suitability, then improve their productivity to meet commercial requirements (vertical arrow in Figure 1).
- Select the best growing species, then modify their feedstock characteristics, (horizontal arrow in Figure 1), or modify the industrial process.

In both cases, plant modification may be achievable by relatively simple measures such as careful selection of genetic material or development of suitable growing methods, or more sophisticated techniques such as breeding or genetic modification. Improvements in these key characteristics are a common feature of all commercial crop development – most of today's major food and fibre crops display quite different characteristics from their wild progenitors.

6.1.2 Strategy adopted by the Search Project

6.1.2.1 Selection of products

It was not feasible to test every combination of species and product. Selecting the most promising product types (Section 4) and potentially suitable species (Section 5) greatly reduced the number of possible combinations to test, but further decisions had to be made on how to proceed, and how best to allocate the funds available for this part of the project.

The project team decided to base its feedstock testing program on options for the wood fraction of new woody crops, and bioenergy usage of biomass residues. Further work would be needed later to find valuable co-products, such as extractive chemicals, in the species with the best prospects for industrial wood production.

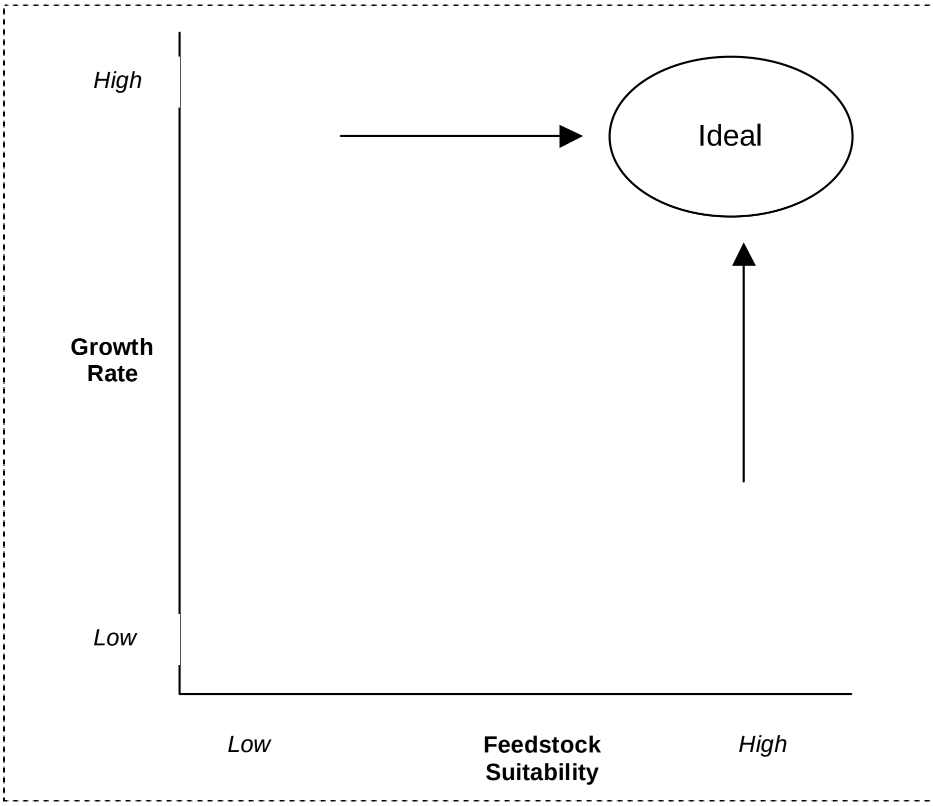


Figure 1. Desirable species attributes.

Three large industrial uses were selected as the most promising targets for short-cycle woody crops:

- chemical pulp and paper,
- panel boards such as medium density fibreboard (MDF) and particleboard,
- solid fuel, for use in combustion processes.

There were many reasons for choosing these three product types, including:

- each product has the potential to use large amounts of material, and could stimulate large-scale planting,
- all are well-established industries in Australia with proven technology,
- small-dimension timber or wood chips are suitable feedstocks for each of these industries,
- pulp and panel board industries pay attractive prices for their woody feedstock,
- the feedstock characteristics required for pulp and paper, and panel board were likely to be very strong discriminators, that should quickly identify a smaller and more manageable number of prospective species,
- any new pulp or panel board industry based on wood from woody crops would be likely to involve bioenergy production, to increase the output of valuable products, and to consume the large volume of material not used in pulp or panel production, especially bark, leaves, twigs and reject wood.

In order to become a profitable crop, any species that proves to be a promising feedstock source for pulp or panel board manufacture may also need to produce other commercial products, such as chemical extractives. However, for this first round of testing, no exploration of chemical extractives was attempted, because:

- there is a wide variety of chemical components in plants that could be tested,
- testing for individual chemical components is expensive,
- species with high levels of commercially valuable chemicals may not necessarily have wood that is suitable for use in pulp or panel board manufacture,
- the project had insufficient time or funds to investigate plant chemistry after completing the wood testing program.

Instead, chemical investigation would be undertaken later (beyond the Search project) for those species that showed themselves to be promising potential feedstocks for pulp or panel boards. This strategy narrows the focus of chemical testing onto species that are already highly prospective for other reasons.

Although the bulk of the wood testing budget was assigned to three product areas (pulp and paper, panel boards, and solid fuel), a small but significant part was allocated to testing long-cycle trees for their timber potential. In addition, some species were tested for their suitability as reductants in smelting processes, such as silicon smelting.

6.1.2.2 Additional notes on selected products

Paper

Chemical pulp was chosen because of its premium position in the market, and its favourable longer term outlook. Mechanical pulp may seem to be more attractive due to its smaller plant size and lower capital requirement, but its market is growing slower than chemical pulp, as recycled fibre makes inroads into this market. There are also technical factors that make mechanical pulp less attractive. For example, mechanical pulping has a very high energy requirement, especially for high density hardwoods. Also, mechanical pulping is less well suited to the short-fibred materials expected from native woody plants, because the pulping action can abrade and break fibres, reducing them to a length below the desirable limit.

Panel boards

Two panel products were chosen – MDF because it is a high quality product, with a rapid rate of expansion of production in Australia, and rapid expansion of exports, and particleboard, which although less suited to some uses than MDF, still provided 57% of the consumption of wood-based panel products in Australia in 2001-02 (ABARE 2003). Because particleboard is cheaper to manufacture than MDF, it is able to compete effectively against it in many markets.

A second reason for testing both types of panels is that they are made by different processes. For MDF, wood is reduced to fibres, then reconstituted with resin into a solid product, so the quality of the finished product is strongly influenced by fibre characteristics. Particleboard is quite different, in that the wood is broken down into small wood particles before being recompressed with resin. As a result, particleboard properties are more likely to be dependent on the wood characteristics. Therefore testing prospective species for both of these products would give two sets of results that could be quite different.

Bioenergy

Combustion was chosen as the form of bioenergy to test, because it employs mature technology, works at many scales, and is able to be implemented immediately, with little further development.

Apart from standard analyses of energy content, important parameters to test are fouling, corrosion, ash content (as it determines the amount of material to be disposed of), and environmental contaminants, such as heavy metals, in the ash.

Sawn timber

Although the economics of long-cycle timber trees are doubtful in lower rainfall areas, many landowners are willing to plant a small percentage of their properties to this type of tree for a range of reasons, including increased water usage, shade and shelter, aesthetic enhancement, and perhaps timber value in the longer term. Therefore there is value in providing more information about timber quality of species not previously tested.

Appearance grade timber was the target product for this part of the project, for uses such as panelling, flooring and joinery, as it attracts a higher price than structural timber, can be based on smaller logs, and is more likely to be a successful enterprise in low to medium rainfall agricultural areas. ‘Wheatbelt timbers’ could widen the range of timbers available in this market, perhaps commanding a higher price based on their appearance, strength, hardness, and durability.

It is unlikely that growers in the wheat-sheep region could compete on a large scale in the lower value, structural timber market, currently dominated by plantation and native forestry in higher rainfall areas, so this use was not assessed.

6.1.2.3 Species testing

The approach to species testing was incremental. Most of the species found to have promising ‘crop’ characteristics in Section 5 were subjected to preliminary testing for pulp and panel, or were considered for sawn timber assessment. The best of those were then selected for more intensive work, through a number of increasingly rigorous and increasingly expensive or time consuming tests. At each stage, only the best performing species from the previous round of tests were carried forward.

It must be stressed that the strategy adopted in the Search project was deliberately focused on finding species close to the ideal feedstock discussed above (Figure 1). Therefore, other species that may have the potential to be developed into commercial crops if sufficient effort is applied to them, may have been overlooked in the first instance because they are too far from the ideal. However, if no species are found sufficiently close to the ideal, then further investigation of species with less initial attraction will be needed, to identify those with the best scope for improvement.

Since the process followed for species testing was different for each product type, the processes are explained separately in each section.

6.2 Tenders to test woody material

A public tender was held by the WA Department of Industry Technology to select organisations to carry out the required test program.

Successful tenderers were:

- WA Forest Products Commission .... Sawn timber testing
- CSIRO Forestry and Forest Products .... Pulp, paper and panels
- CSIRO Energy Technology........................ Advanced combustion

In addition, collaborative work was undertaken with Simcoa Operations Pty. Ltd., to determine ash content and mineral composition of selected species.

6.3 Wood coring – reconstituted products

6.3.1 Introduction

Since the feedstock requirements for wood pulp and panel board are similar, at least at the preliminary level, these product types were considered jointly. The first level of selection was to find species with low density and pale-coloured wood. To do this an extensive wood coring program was undertaken between November 2001 and August 2002. A total of 1706 wood cores were taken from 229 taxonomic entities selected as prospective woody crop species in Section 5. Most of the field work was carried out by Wayne O’Sullivan (Arboressence Consultancy).

To summarise, the species selected for coring were generally tall (4 metres or greater), with good form (erect species with substantial amounts of wood were favoured), and with a natural distribution within the WA wheatbelt. Species not found in the wheatbelt were excluded, as were species classified as rare or potentially rare. In addition, a final selection was made by a group of botanical experts, to exclude species thought to be unlikely for one reason or another to be suitable for large-scale crop development

Note that the term ‘trees’ is used throughout this section to include both trees and woody shrubs.

6.3.2 Overview

Coring was chosen for the first round of field sampling because it is a non-destructive sampling technique suitable for the rapid estimation of wood density and colour.

Sampling was divided into two phases – coring from a single plant population in phase 1, followed by coring from two additional populations of the more prospective species in phase 2, based on the results from phase 1.

A team of two was required – both for safety, and for efficiency. One could do coring while the other collected voucher specimens, took photographs, labelled collecting envelopes, and recorded core colour, length and weight.

6.3.3 Equipment

A Tanaka ProForce 262R drill engine coupled with CSIRO Trecor hollow drill bits was used for coring. This equipment drills a 21mm hole through the tree to produce a 12mm core. Coring bits of two different lengths were used – long (500mm) and short (300mm).

Figure 2. Collecting wood core from *Eucalyptus capillosa.* (Photo: Wayne O'Sullivan)

6.3.4 Selection of populations

Populations of each species to be tested were selected on a number of criteria, in approximate order of importance:

- Easy access (that is – approval easy to obtain, and population accessible by vehicle). Most samples were taken from unallocated crown land. Private property was generally avoided due to the difficulty of finding owners, explaining the project, gaining permission etc. (except where paddock-grown material was sought).
- Large, healthy population.
- Farm-grown material selected where possible, but few of the selected species have been grown in easily identifiable stands on farms.
- Trees of a young age present (3-5 years) where possible.
- Not an outlying population, although for arid zone species, populations along the wetter fringe were chosen, and for wetter zone species, populations along the drier fringe were usually chosen.

In practice, it was not always possible to select populations satisfying all these criteria, so some compromises had to be made.

6.3.5 Phase 1 coring

The procedure followed for phase 1 coring was:

- One population was selected for each species.
- Three trees were selected within each population, preferably some distance apart, say 50 metres.
- GPS location of each 'cored' tree was recorded (trees not tagged in any way).
- One of the three trees was chosen as a voucher specimen.

Cores were drilled horizontally at a practical coring height. This is often low to the ground, as trees of the target age are generally smaller diameter than mature size, and drilling lower (through thicker part of the trunk) left a larger portion of the trunk intact, thus minimising the damage to the tree. Drilling one fork from trees with early multiple forking minimised the risk of coring being destructive to the entire tree (Figure 3). Cores were drilled right through the stem from one side to the other.

Figure 3. Stem of *Gyrostemon ramulosus* six months after coring right hand stem. Note occluded hole. (Photo: Jerome Carslake)

Fresh core samples were immediately returned to the vehicle for measuring and weighing. The core was trimmed at both ends if necessary to remove bark and square up the ends. The core was weighed on an electronic balance (in grams to one decimal place), and its length was measured. Colour was determined by reference to a Standards Australia colour chart (Standards Australia 1996), which can be calibrated to the Methuen Handbook of Colour (Kornerup and Wanscher 1978), Munsell soil colour chart (Anon not dated), or some other standard reference if required. Usually two colours were recorded, to cover the range of colour in the wood, which can be mottled, striped, or vary in a regular way along the core, (commonly heartwood is different to sapwood). Wood colour also changes with time. This data was sued to identify species with lighter coloured wood, rather than to precisely define wood colour.

The core was then stored in a paper bag.

Information recorded on the bag was:
date
location name (eg Merredin, Smith's)
tree GPS location
species name
tree number (usually 1, 2 or 3 – starting at 1 for each population)
fresh weight of core (g)
core length (mm), whether it is a whole core or some fraction of a core (sometimes cores snap into two or more pieces), and how many pieces of core the bag contains
estimated tree height and width
wood colour
for voucher specimens - voucher number. Note: a separate voucher sheet was completed for each voucher specimen, containing details of location, site and plant description (see Appendix 18)

Upon return to the laboratory (usually after four to eight day field trips), cores were dried for 24 hours at 70 degrees Celsius, or until their weights were stable. Twenty-four hours in the drying oven was usually sufficient – longer drying typically reducing core weights by only 1% or so, a small potential error in the overall coring process. Dry cores were weighed (in grams to two decimal places).

Sample details and weights were recorded in a computer file, and basic density and moisture content were calculated.

Phase 1 coring started in November 2001, with some test coring of *Acacia* species, to test and refine the method. Systematic phase 1 coring of target species began in March 2002, and was mostly complete by the end of April 202, although some additional species were cored if the opportunity arose on later field trips.

6.3.6 Phase 2 coring

Species that appeared prospective based on their basic density, colour and other attributes found in phase 1 were selected for further coring, in order to:

- improve the estimate of wood density by increasing the number of samples,
- improve understanding of density variation within each species,
- locate populations from which subsequent wood samples could be collected for further laboratory testing and sample product manufacture.

The target for 'phase 2' species was to collect cores from six trees from each of three different populations. In practice, six samples were nearly always collected from each of two new populations, but sometimes it wasn't possible within the project's time constraints to revisit the first (phase 1) population to collect extra samples.

Occasionally, samples were collected from more than three populations, especially for species of high interest, and especially if new populations were found that were 'better' (that is, younger or more vigorous) than the ones previously sampled.

The sampling protocol was similar to phase 1 (GPS location of all sample trees taken, voucher specimen taken from one tree, etc.)

In addition, one tree in each population was selected for coring at three different heights (roughly shoulder, waist and shin) to provide data on longitudinal variation in wood properties. For trees that were too small or spindly to collect a high core sample, a straight piece of stem was selected instead, cut square on the ends, de-barked (by peeling where possible), weighed and measured (including diameter), then treated as a core. Note that these longitudinal stem sections have different distributions of wood than core samples (a higher ratio of outer wood to inner wood). The diameter measurements were likely to have a higher error than cores, because many of the stems were oval-shaped, so diameter had to be estimated from several measurements.

Phase 2 coring started at the end of April 2002 and continued until early August 2002.

6.3.7 Results of wood coring

Wood density was calculated in accordance with standard formulae (Bootle 1983; Brennan, Gary 1996; Walker 1993).

Green density = Green weight / Green volume (kg/m^3)

Basic density = Dry weight / Green volume (kg/m^3)

Moisture content (green basis) = (Green weight – Dry weight) / Green weight

Basic density is the most "standard" of the various density measures as it combines two reproducible measures – green volume and dry weight. For wood that has dried since being cut, a good approximation of its green volume can be made by soaking it in water to replace any lost moisture, to reverse any consequent shrinkage.

Data from all wood cores is included in Appendix 11 and a summary by species is presented in Appendix12. Green density, basic density and moisture content for each species are shown in Table 1 below.

See also Appendix 22, which includes wood densities for a range of species tested at CALM's Timber Technology Centre at Harvey between 1985 and 1995.

Table 1. Results of wood coring.

Species	Number of cores	Density		Moisture Content
		Green	Basic	
Acacia acuminata subsp. *Acuminata*	1	~	1077	~
Acacia aestivalis	16	1285	935	27%
Acacia aff. *redolens*	5	~	782	~
Acacia aneura subsp. (?)	1	~	952	~
Acacia anthochaera	4	1417	1047	26%
Acacia b (?)	2	~	885	~
Acacia bartleana Maslin (ms)	10	1167	815	35%
Acacia beauverdiana	3	1250	1054	16%
Acacia blakelyi	19	1088	682	37%
Acacia brumalis	10	1169	859	27%

Species	Number of cores	Density		Moisture Content
		Green	Basic	
Acacia burkittii	3	1399	1005	28%
Acacia citrinoviridus	1	~	1094	~
Acacia conniana	3	~	763	~
Acacia coolgardiensis subsp. *coolgardiensis*	1	~	1013	~
Acacia coolgardiensis subsp. *Effusa*	3	1357	1032	24%
Acacia coolgardiensis subsp. *Latior*	3	1390	1150	17%
Acacia cyclops	4	~	802	~
Acacia enervia subsp. *Enervia*	3	1476	1158	22%
Acacia eremaea	3	1395	1089	22%
Acacia fauntleroyi	8	1184	932	21%
Acacia inceana subsp. *Conformis*	3	1463	1157	21%
Acacia jennerae	8	1297	938	28%
Acacia jibberdingensis	8	1154	768	33%
Acacia lasiocalyx	27	1092	762	29%
Acacia microbotrya var. *borealis*	5	1231	873	29%
Acacia microbotrya var. *microbotrya*	30	1233	832	34%
Acacia murrayana	22	1195	692	42%
Acacia neurophylla subsp. *Erugata*	3	1121	944	16%
Acacia obtecta	8	1336	910	32%
Acacia prainii	4	1374	1011	27%
Acacia pruinocarpa	1	~	614	~
Acacia redolens	5	1171	822	30%
Acacia resinimarginea	3	~	1016	~
Acacia rostellifera	13	1272	835	33%
Acacia saligna	38	983	596	42%
Acacia scirpifolia	19	1048	688	34%
Acacia sclerosperma subsp. *sclerosperma*	3	~	976	~
Acacia steedmanii	8	1172	833	29%
Acacia stereophylla var. *stereophylla*	3	1278	1035	19%
Acacia tysonii	8	1364	984	28%
Acacia victoriae	2	~	814	~
Actinostrobus acuminatus	3	1027	661	35%
Actinostrobus arenarius	19	1007	661	34%
Actinostrobus pyramidalis	25	1146	638	44%
Adenanthos cygnorum subsp. *cygnorum*	19	1194	595	50%
Adenanthos sericeus subsp. *sericeus*	19	1264	572	55%
Adenanthos stictus	20	1249	599	52%
Agonis flexuosa var. *flexuosa*	3	1220	786	36%
Alectryon oleifolius subsp. *Oleifolius*	3	1382	1010	27%
Allocasuarina acutivalvis subsp. acutivalvis	6	1275	981	23%
Allocasuarina campestris	3	1220	975	20%
Allocasuarina dielsiana	3	1343	953	29%
Allocasuarina huegeliana	4	1076	748	30%
Alyogyne hakeifolia	3	1200	779	35%
Alyogyne huegelii var. *huegelii*	11	1225	720	41%
Alyogyne sp.	8	1232	668	46%
Anthocercis littorea	19	926	473	49%
Astartea heteranthera	3	1265	815	36%
Banksia attenuata	19	1273	696	45%
Banksia grandis	19	1254	672	46%
Banksia prionotes	19	1195	636	47%

Species	Number of cores	Density		Moisture Content
		Green	Basic	
Brachychiton gregorii	11	1179	461	61%
Bursaria occidentalis	12	1250	706	43%
Callistachys lanceolata	19	1082	593	45%
Callistemon phoeniceus	6	1298	916	29%
Callitris canescens	3	1125	774	31%
Callitris glaucophylla	9	1108	786	29%
Callitris tuberculata	3	1129	739	35%
Calothamnus asper	3	1230	779	37%
Calothamnus tuberosus	3	1301	803	38%
Calycopeplus paucifolius	3	1035	843	19%
Casuarina obesa	30	1244	711	43%
Chamelaucium uncinatum	1	1198	709	41%
Codonocarpus cotinifolius	32	1162	397	67%
Conospermum triplinervium	14	1214	530	56%
Corymbia calophylla	3	1170	725	38%
Dodonaea (?) sp.	4	1396	1079	23%
Dodonaea inaequifolia	3	1384	1085	22%
Dodonaea ptarmicaefolia	3	1406	1064	24%
Dodonaea viscosa subsp. *angustissima* (?)	3	1342	1011	25%
Dryandra arborea	3	1280	851	34%
Dryandra nobilis subsp. *nobilis*	3	1194	765	36%
Dryandra sessilis var. *sessilis*	19	1245	735	41%
Duboisia hopwoodii	6	919	479	48%
Eremophila alternifolia (?)	6	1267	1044	18%
Eremophila caperata (?)	3	1193	874	27%
Eremophila deserti	3	1166	835	28%
Eremophila interstans subsp. *interstans*	3	1251	921	26%
Eremophila longifolia	6	1151	875	24%
Eremophila miniata	6	1094	783	28%
Eremophila oldfieldii subsp. *oldfieldii*	6	1188	919	23%
Eremophila oppositifolia subsp. *angustifolia*	3	1155	885	23%
Eremophila psilocalyx (?)	3	1239	924	25%
Eremophila scoparia	3	1356	1038	23%
Eremophila serrulata (?)	3	1178	944	20%
Eucalyptus accedens	3	1267	889	30%
Eucalyptus alipes	3	1289	1022	21%
Eucalyptus angustissima subsp. *angustissima*	3	1234	878	29%
Eucalyptus annulata	6	1231	920	25%
Eucalyptus argyphea	3	1215	906	25%
Eucalyptus aspratilis	3	1305	1031	21%
Eucalyptus astringens subsp. *astringens*	3	1157	801	31%
Eucalyptus astringens subsp. *redacta*	3	1221	902	26%
Eucalyptus balladoniensis subsp. *balladon.*	3	1271	910	28%
Eucalyptus brachycorys	3	1321	991	25%
Eucalyptus burracoppinensis	3	1273	969	24%
Eucalyptus camaldulensis var. *obtusa (?)*	17	1206	636	47%
Eucalyptus capillosa subsp. *capillosa*	3	1273	984	23%
Eucalyptus capillosa subsp. *polyclada*	3	1264	967	24%
Eucalyptus celastroides subsp. *celastroides*	3	1282	1034	19%
Eucalyptus clivicola	3	1291	977	24%
Eucalyptus conferruminata	3	1193	860	28%

Species	Number of cores	Density		Moisture Content
		Green	Basic	
Eucalyptus cornuta	3	1237	802	35%
Eucalyptus dundasii	3	1217	979	20%
Eucalyptus eremophila subsp. *eremophila*	3	1275	999	22%
Eucalyptus erythrocorys	11	1260	731	42%
Eucalyptus erythronema var. *erythronema*	3	1229	967	21%
Eucalyptus erythronema var. *marginata*	3	1332	1014	24%
Eucalyptus ewartiana	3	1314	1016	23%
Eucalyptus gomphocephala	3	1237	756	39%
Eucalyptus gratiae	3	1163	760	35%
Eucalyptus halophila	3	1346	1045	22%
Eucalyptus hypochlamydea subsp. *hypochl.*	3	1336	889	33%
Eucalyptus incrassata	3	1296	1014	22%
Eucalyptus indurata	3	1311	942	28%
Eucalyptus kochii subsp. *horistes*	3	1223	848	31%
Eucalyptus kochii subsp. *kochii*	3	1200	849	29%
Eucalyptus kochii subsp. *plenissima*	3	1195	835	30%
Eucalyptus kondininensis	3	1223	879	28%
Eucalyptus leptopoda subsp. *arctata*	3	1276	973	24%
Eucalyptus leptopoda subsp. *leptopoda*	3	1312	972	26%
Eucalyptus leptopoda subsp. *subluta*	3	1317	949	28%
Eucalyptus lesouefii	3	1195	959	20%
Eucalyptus longicornis	3	1241	858	31%
Eucalyptus loxophleba subsp. *lissophloia*	19	1230	801	35%
Eucalyptus loxophleba subsp. *loxophleba*	3	1182	771	35%
Eucalyptus loxophleba subsp. *supralaevis*	3	1245	821	34%
Eucalyptus melanoxylon	3	1283	998	22%
Eucalyptus myriadena subsp. *myriadena*	3	1258	874	31%
Eucalyptus occidentalis	6	1158	802	31%
Eucalyptus platypus subsp. *platypus (?)*	6	1250	861	31%
Eucalyptus pleurocarpa	11	1276	820	36%
Eucalyptus polybractea	3	1231	851	31%
Eucalyptus rudis subsp. *rudis*	19	1196	553	54%
Eucalyptus salmonophloia	3	1262	946	25%
Eucalyptus salubris	3	1228	959	22%
Eucalyptus sargentii subsp. *sargentii*	3	1145	883	23%
Eucalyptus semivestita	3	1325	940	29%
Eucalyptus spathulata	3	1146	846	26%
Eucalyptus todtiana	19	1238	644	48%
Eucalyptus uncinata	3	1325	1015	23%
Eucalyptus urna	3	1202	923	23%
Eucalyptus utilis	3	1197	889	26%
Eucalyptus valens	3	1295	875	32%
Eucalyptus vegrandis subsp. *vegrandis*	3	1187	877	26%
Eucalyptus wandoo subsp. *wandoo*	3	1255	911	27%
Exocarpos aphyllus	3	1315	1037	21%
Exocarpos sparteus	19	1205	703	42%
Grevillea argyrophylla	3	1220	794	35%
Grevillea cagiana	3	1241	822	34%
Grevillea candelabroides	19	1204	642	47%
Grevillea excelsior	19	1212	747	38%
Grevillea insignis subsp. *insignis*	3	1291	835	35%

Species	Number of cores	Density		Moisture Content
		Green	Basic	
Grevillea leucopteris	19	1162	554	52%
Grevillea nematophylla subsp. *nematoph. (?)*	3	1183	720	39%
Grevillea obliquistigma subsp. *obliquistigma*	3	1258	969	23%
Grevillea pterosperma	3	1144	845	26%
Grevillea vestita subsp. *vestita*	3	1293	766	41%
Gyrostemon racemiger	16	1122	352	69%
Gyrostemon ramulosus	13	1171	416	65%
Gyrostemon sp.	6	1109	352	68%
Hakea bucculenta	3	1344	986	27%
Hakea francisiana	3	1275	821	36%
Hakea invaginata	3	1237	931	25%
Hakea laurina	3	1271	877	31%
Hakea minyma	3	1381	939	32%
Hakea multilineata	3	1327	884	33%
Hakea oleifolia	19	1239	662	47%
Hakea petiolaris subsp. *trichophylla*	3	1200	825	31%
Hakea preissii	3	1368	890	35%
Hakea prostrata	19	1184	667	43%
Hakea recurva subsp. *recurva*	3	1338	957	29%
Hakea stenophylla subsp. *notialis* (?)	3	1284	908	29%
Jacksonia furcellata	19	1272	661	48%
Jacksonia sternbergiana	19	1180	626	47%
Kunzea ericifolia subsp. *ericifolia*	3	1233	768	38%
Kunzea glabrescens	19	1232	699	43%
Lamarchea hakeifolia var. *brevifolia*	3	1268	807	36%
Lambertia inermis var. *inermis*	19	1260	687	46%
Leptomeria pauciflora	3	1290	876	32%
Leptospermum nitens	3	1242	926	25%
Melaleuca acuminata subsp. *acuminata*	3	1342	886	34%
Melaleuca cuticularis	3	1262	832	34%
Melaleuca eleuterostachya	3	1342	1013	25%
Melaleuca fulgens subsp. *fulgens*	3	1276	956	25%
Melaleuca globifera	6	1243	768	38%
Melaleuca halmaturorum	3	1311	951	27%
Melaleuca hamata	3	1257	919	27%
Melaleuca hamulosa	3	1233	875	29%
Melaleuca hamulosa (?)	3	1268	751	41%
Melaleuca hnatiukii	3	1339	957	29%
Melaleuca huegelii subsp. *huegelii*	3	1272	850	33%
Melaleuca incana subsp. *incana*	8	1243	655	47%
Melaleuca lanceolata	6	1275	894	30%
Melaleuca lateriflora subsp. *lateriflora*	3	1263	953	25%
Melaleuca linguiformis	3	1284	857	33%
Melaleuca pauperiflora subsp. *pauperiflora*	6	1314	940	28%
Melaleuca preissiana	19	1253	574	54%
Melaleuca quadrifaria	3	1280	863	33%
Melaleuca rhaphiophylla	19	1223	581	52%
Melaleuca sp.	3	1299	893	31%
Melaleuca stereophloia	3	1260	897	29%
Melaleuca strobophylla	3	1199	722	40%
Melaleuca uncinata form "ligno spicate"	3	1203	823	32%

Species	Number of cores	Density		Moisture Content
		Green	Basic	
Melaleuca uncinata form "non-ligno. spicate"	6	1261	914	27%
Melaleuca uncinata form "uncinata"	3	1271	918	28%
Melaleuca viminea subsp*. viminea*	3	1272	624	51%
Myoporum platycarpum subsp*. platycarpum*	4	1246	952	24%
Nuytsia floribunda	19	1197	499	58%
Oxylobium lineare	3	1025	667	35%
Paraserianthes lophantha subsp*. lophantha*	3	922	397	57%
Persoonia elliptica	19	1226	599	51%
Persoonia saundersiana	3	1233	847	31%
Persoonia stricta	3	1225	901	26%
Pimelea clavata	3	845	449	47%
Pinus pinaster	3	1114	458	59%
Pittosporum angustifolium	6	1286	871	32%
Pittosporum phylliraeoides	4	1280	836	32%
Santalum acuminatum	6	1148	775	32%
Santalum murrayanum	19	1202	720	40%
Senna (?) sp.	3	1221	710	42%
Senna glutinosa subsp*. chatelainiana*	19	1110	624	43%
Senna pleurocarpa subsp. (?)	8	982	588	40%
Senna sp. Austin	8	1455	1146	21%
Spyridium globulosum	3	1245	849	32%
Taxandria juniperina	19	1205	569	53%
Templetonia retusa	3	1414	1014	28%
Trymalium floribundum subsp*. floribundum*	22	1092	692	37%
Viminaria juncea	22	957	478	50%
Xylomelum angustifolium	19	1243	601	52%

Taxa marked (?) are taxa not yet formally identified from the vouchered specimens.
Green density is green weight / green volume (kg/m3).
Basic density is oven dry weight / green volume (kg/m3).
Moisture content is expressed on a green basis, that is, weight of water / green weight.

6.3.8 Sources of error

The method used to estimate wood density in this project was chosen because it is quick and simple. Because the aim was to quickly separate low density woods from high density woods, small errors due to the method were irrelevant. If the aim were to detect small differences in density between provenances of a single species, or between individuals in a population, then a more accurate method would be needed.

Potential sources of inaccuracy in density and moisture content calculated in this project included the following:

- Error in length measurement - most cores were quite small (12mm diameter, and about 50 mm in length).
- Differences in diameter – it was assumed that all cores were 12mm in diameter (the diameter of the drill bit bore), but variations may have been caused by different temperature of the bit (expanding when hot), or different compressibility of different woods (some cores were very tight in the drill bit)
- Over representation of wood in the centre of the stem – because the cores are cylindrical, they include a greater percentage of inner wood than outer wood.

- Loss of moisture (weight) during coring – sometimes the drill bit became very hot, especially in denser woods, which may have vaporised some of the moisture in the wood.
- Because coring started at the end of summer (dry season) and extended into winter (wet season), it is possible that some of the observed variation in wood density and moisture content between individuals of the same species was due to seasonal fluctuations rather than inherent differences between plants.

6.3.9 Other methods for calculating wood density

Other methods for calculating wood density can be used if greater accuracy is required. Some of these are discussed in Balodis et al. (1980) and Washusen et al. (2001).

For example, liquid displacement can be used for measuring volume. The wood is usually soaked to re-hydrate it to its green volume, although this is not without its own inherent problems, especially for hardwood species that may contain significant amounts of water soluble extractives. If possible the wood's volume should be measured as soon as possible after cutting or coring, to minimise volume loss, or after oven drying and weighing, so that loss of extractives does not affect the dry weight.

The method endorsed by Standards Australia in AS 1301 (Standards Association of Australia 1979) involves drying a sample of woodchips to determine its oven dry weight, and determining the volume of a known weight of woodchips (sampled from the same source used for the dry-weight determination) by a water displacement method. Woodchips are soaked for 7 days, then weighed in air, and weighed again suspended in water, to determine the volume of water displaced by the chips.

Another method, that does not involve measuring the material's volume, is the 'maximum moisture content' method (Balodis *et al.* 1980), which requires oven drying the material to find its dry weight, then soaking it for at least 16 days until the wood is fully saturated, to find its saturated weight. Boiling water is used initially to speed up the process, as well as occasional partial vacuum to help remove air from the wood. Basic density can be calculated from the two weights if it is assumed that the density of wood substance is constant at 1530 kg/m3, as found by Stamm (1929), cited in Balodis et al. (1980). Basic density is then calculated using the following formula:

$D = Wd / (d (W_s - W) + W)$

where D = basic density, W = oven dry weight, W_s = saturated weight and d is the density of wood substance (1530 kg/m^3).

Since the material's dry weight is found before it is soaked, losses of soluble material during soaking do not affect the calculation. One disadvantage of these more accurate methods is the length of time taken to soak the wood to reach a stable volume. There is also some experimental evidence that soaked wood volume is 1 to 2 per cent higher than green volume (Dadswell 1931) cited in (Balodis *et al.* 1980).

Accuracy can also be increased by using larger quantities of wood, such as horizontal discs cut from tree trunks, or woodchips produced from stem material. However, unlike using single wood cores, these methods require the tree to be felled.

6.4 Material collection – reconstituted products

6.4.1 Wood collections for reconstituted products

Based on wood cores and growth characteristics, fifty-one species were selected for more intensive laboratory testing. The amount of wood needed for this next stage of laboratory testing was 10kg (dry weight), for various tests including chipping, wet chemistry and fibre characterisation. A further 10kg (dry weight) was added, to ensure sufficient material was provided for each species to also undergo chemical pulping, and if warranted, pulp bleaching and paper making.

At the completion of initial laboratory testing (wet chemistry and fibre characterisation) and analysis of the results, the most promising species were selected for laboratory scale manufacture of MDF and particleboard panels. Nineteen species were used to make MDF and twenty species were used to make particleboard. These tests required 150kg dry weight of wood.

Procedures followed for the 20kg and 150kg wood collections are described below.

6.4.1.1 20 kg collections

Where possible wood samples were collected from the populations that had previously been cored. There were several reasons for re-visiting the same populations:

- Time saved in not having to locate new populations.
- For many species, the populations chosen for coring had been selected from a number of different populations, on the basis of their desirable features.
- It was logical to select material for further investigation from the populations that had provided cores with attractive properties.
- Plants cored earlier could be inspected for wound recovery.

Wood collections followed similar protocols to those used for wood coring (Section 6.3) with the following modifications:

- Material was obtained as a bulk collection from a minimum of six plants.
- Plants were sawn off close to ground level and stem wood greater than 20mm in diameter under bark was collected.
- The collection amount was 20 kg on a dry weight basis, calculated using the moisture contents of the cores, plus a safety buffer.
- In many cases, trees that had previously been cored were included as part of the sample collection.
- Because voucher specimens had been collected during the coring phase, new voucher specimens were collected only where new populations had to be used.

All wood was debarked in the field and species that were difficult to debark or which had a high ratio of bark to wood were noted. In the field, one person usually collected the samples and information, while the second person debarked the wood. After delivery to CALM Kensington, the wood was oven dried at 70 degrees Celsius to approximately air-dry moisture content, to minimise biological activity in the wood before it reached CSIRO's laboratory at Clayton in Victoria. This was particularly important for some of the species with high moisture contents, such as *Gyrostemon ramulosus* and *Codonocarpus cotinifolius*.

Finally, wood collected within the green snail quarantine zone was inspected by quarantine inspectors in Western Australia before shipping. All material was packed into large cardboard boxes (pallet sized) and sent by road freight to Clayton, with the exception of the first seven species, which were delivered by air by members of the project team while on a visit to CSIRO's laboratories.

Figure 4. Debarked sticks ready for packing and shipping to laboratory.

6.4.1.2 150 kg collections

The procedure followed for these larger wood collections was similar to the collection procedure for 20kg samples, with the following exceptions:

Due to the larger collection size, new populations had to be found for some species, to enable this larger quantity of wood to be collected without putting pressure on some of the smaller populations previously used for coring and 20 kg wood collections.

Wood was collected in long lengths to facilitate chipping at CSIRO Clayton. A length of 1.1 metres was chosen – the maximum length that could be packed into the pallet-sized cartons used for transport.

All wood was debarked at CALM, Kensington to allow a large debarking crew to be employed, and to hasten field collection.

It was not necessary to oven dry the wood, because this second collection was made in mid-summer. Before shipping, the wood was left in the open for approximately two weeks. However, despite this "field drying", some species began to develop mildew after chipping at CSIRO Clayton, and were subsequently dried and kept in refrigerated storage until processed into panels.

6.5 Laboratory testing – pulp and paper

6.5.1 Introduction

Testing of WA native species for their suitability in pulp and fine paper manufacture was performed by CSIRO Forestry and Forest Products at the Ian Wark Laboratories in Clayton, Victoria.

The information presented below is drawn from a report on this work by CSIRO Forestry and Forest Products (Appendix 02).

A useful description of the technical aspects of pulping, paper manufacture and paper testing is found in Uprichard and Walker (1993).

The selected species were tested for their suitability for chemical pulping, rather than mechanical pulping, for a number of reasons. The main reason was the belief that the short fibres likely to be produced by short-cycle hardwood species would be best suited to chemical pulping, in which fibres are delignified by chemical means, rather than mechanical pulping which relies on energy to break the wood into small-fibred material suitable for paper making. Although the yield is lower for chemical pulp (because the lignin component is removed), chemical pulp has a higher value and a growing market. Also, the short fibres of Search Project species are most likely to suit high grade paper manufacture, which favour chemical pulp, rather than newsprint or packaging materials. Finally, feedstock for mechanical pulp now faces increasing competition from both recycled materials and non-wood materials, which could limit the market volumes or price available to new feedstocks.

6.5.2 Species selection

Wood cores from approximately 130 species that had been rated as highly or moderately prospective for commercial development (based on their botanical attributes, especially growth and form) were delivered to CSIRO's Clayton Laboratory for further assessment. The earlier stages of species selection are described in Section 5, while details of the wood coring program are presented in Section 6.3.

Based on the wood density of these species, and physical examination of the cores, a total of fifty-one species were selected for laboratory testing, to assess their suitability for panel board and pulp and paper manufacture. These species are listed in Table 2.

Forty-seven species were selected early in the program, as described above, and tested as a batch. A further four species (*Acacia rostellifera*, *Eucalyptus astringens*, *Eucalyptus kochii* ssp. *plenissima* and *Eucalyptus occidentalis*) were tested later, after a second round of species selection. In most tables below, data for laboratory tests is presented for all 51 species. However, the second batch of four species was not tested for fibre length and width, so Table 3 contains data for the original 47 species only.

Table 2: Species investigated for pulp and paper properties in this study.

Species tested for pulp and paper	
Acacia aff. redolens	*Eucalyptus erythrocorys*
Acacia bartleana Maslin (ms)	*Eucalyptus kochii* ssp *plenissima*
Acacia cyclops	*Eucalyptus loxophleba* ssp *lissophloia*
Acacia lasiocalyx	*Eucalyptus occidentalis*
Acacia microbotrya	*Eucalyptus rudis*
Acacia murrayana	*Eucalyptus todtiana*
Acacia rostellifera	*Exocarpus sparteus*
Acacia saligna	*Grevillea candelabroides*
Actinostrobus arenarius	*Grevillea leucopteris*
Adenanthos stictus	*Gyrostemon ramulosus*
Agonis flexuosa	*Hakea oleifolia*
Allocasuarina huegeliana	*Hakea prostrata*
Alyogyne hakeifolia	*Jacksonia sternbergiana*
Alyogyne huegelii	*Kunzea glabrescens*
Anthocercis littorea	*Lambertia inermis*
Banksia prionotes	*Melaleuca preissiana*
Bursaria occidentalis	*Melaleuca rhaphiophylla*
Callitris glaucophylla	*Paraserianthes lophantha*
Casuarina obesa	*Persoonia elliptica*
Codonocarpus cotinifolius	*Pittosporum angustifolium*
Corymbia calophylla	*Pittosporum phylliraeoides*
Dryandra arborea	*Senna pleurocarpa*
Dryandra sessilis	*Taxandria juniperina*
Duboisia hopwoodii	*Trymalium floribundum*
Eucalyptus astringens	*Viminaria juncea*
Eucalyptus camaldulensis	

6.5.3 Methods and results

6.5.3.1 Fibre length and width

Fibre length and width were determined on fibres prepared by the Kraft cooking process in the pulping program using a Galai CIS-100 image analysis system. Dilute suspensions of fibres were passed in front of an optical lens and video camera allowing digital still frames to be analysed by computer. Fibre length and widths are given for all species assayed in Table 3, and are displayed in Figure 5 and Figure 6.

As expected, the fibre lengths of the hardwood species tested here were much shorter than those found in softwoods such as *Pinus radiata* (2mm). Almost all species had fibre lengths in the range 0.4-0.8 mm, similar to the *Eucalyptus nitens* control (0.56 mm). The two softwoods tested, *Actinostrobus arenarius* and *Callitris glaucophylla*, also had fibre lengths less than half that found for *Pinus radiata*.

The fibre widths of most species fell between the values for the two controls of 0.018 and 0.030 mm. In general, the species tested here had fibres with lower length to width ratios than the two commercial species included as controls.

Table 3: Mean weighted wood fibre length and width, determined on samples taken from pulp yield trials (pooled 95% confidence interval in brackets).

Species	Fibre Length (um)	Fibre Width (um)
Grevillea candelabroides	843 (11)	22.0 (0.18)
Actinostrobus arenarius	826 (10)	23.6 (0.17)
Persoonia elliptica	821 (9)	30.1 (0.17)
Taxandria juniperina	786 (11)	22.7 (0.18)
Agonis flexuosa	745 (11)	21.9 (0.18)
Callitris glaucophylla	727 (7)	22.1 (0.12)
Lambertia inermis	689 (10)	22.9 (0.17)
Grevillea leucopteris	686 (14)	20.7 (0.18)
Hakea oleifolia	667 (11)	22.7 (0.17)
Corymbia calophylla	661 (13)	20.0 (0.19)
Trymalium floribundum	634 (11)	23.0 (0.18)
Dryandra sessilis	633 (10)	23.4 (0.16)
Melaleuca rhaphiophylla	633 (11)	23.1 (0.17)
Pittosporum phylliraeoides	623 (10)	23.3 (0.17)
Dryandra arborea	621 (12)	21.1 (0.17)
Melaleuca preissiana	611 (9)	20.3 (0.13)
Gyrostemon ramulosus	597 (16)	20.5 (0.20)
Banksia prionotes	596 (11)	21.5 (0.18)
Hakea prostrata	591 (14)	20.5 (0.18)
Kunzea glabrescens	588 (11)	21.3 (0.18)
Adenanthos stictus	577 (12)	21.8 (0.18)
Viminaria juncea	575 (14)	19.8 (0.20)
Eucalyptus erythrocorys	566 (12)	20.6 (0.18)
Jacksonia sternbergiana	563 (15)	19.4 (0.19)
Alyogyne huegelii	561 (13)	18.1 (0.20)
Eucalyptus nitens (control)	556 (13)	18.1 (0.19)
Acacia cyclops	553 (11)	20.2 (0.17)
Pittosporum angustifolium	532 (9)	24.4 (0.16)
Allocasuarina huegeliana	531 (13)	19.3 (0.19)
Exocarpus sparteus	529 (11)	19.6 (0.17)
Eucalyptus todtiana	529 (11)	20.1 (0.18)
Anthocercis littorea	526 (10)	20.7 (0.18)
Alyogyne hakeifolia	523 (12)	19.7 (0.18)
Acacia bartleana Maslin (ms)	513 (12)	18.8 (0.19)
Codonocarpus cotinifolius	506 (12)	19.9 (0.20)
Eucalyptus camaldulensis	486 (14)	18.7 (0.19)
Acacia aff. redolens	477 (14)	18.0 (0.19)
Paraserianthes lophantha	474 (9)	19.8 (0.12)
Duboisia hopwoodii	465 (12)	20.1 (0.18)
Senna pleurocarpa	465 (12)	18.9 (0.18)
Eucalyptus rudis	460 (14)	19.1 (0.20)
Casuarina obesa	454 (16)	17.7 (0.20)
Acacia microbotrya	449 (10)	19.4 (0.19)
Acacia murrayana	447 (12)	18.5 (0.21)
Bursaria occidentalis	447 (12)	20.2 (0.18)
Acacia saligna	430 (10)	18.8 (0.19)
Acacia lasiocalyx	411 (10)	18.1 (0.19)
Eucalyptus loxophleba ssp. lissophloia	383 (13)	16.6 (0.18)
Pinus radiata (control) [1]	2000	30

[1] (Kininmonth and Whitehouse 1991)

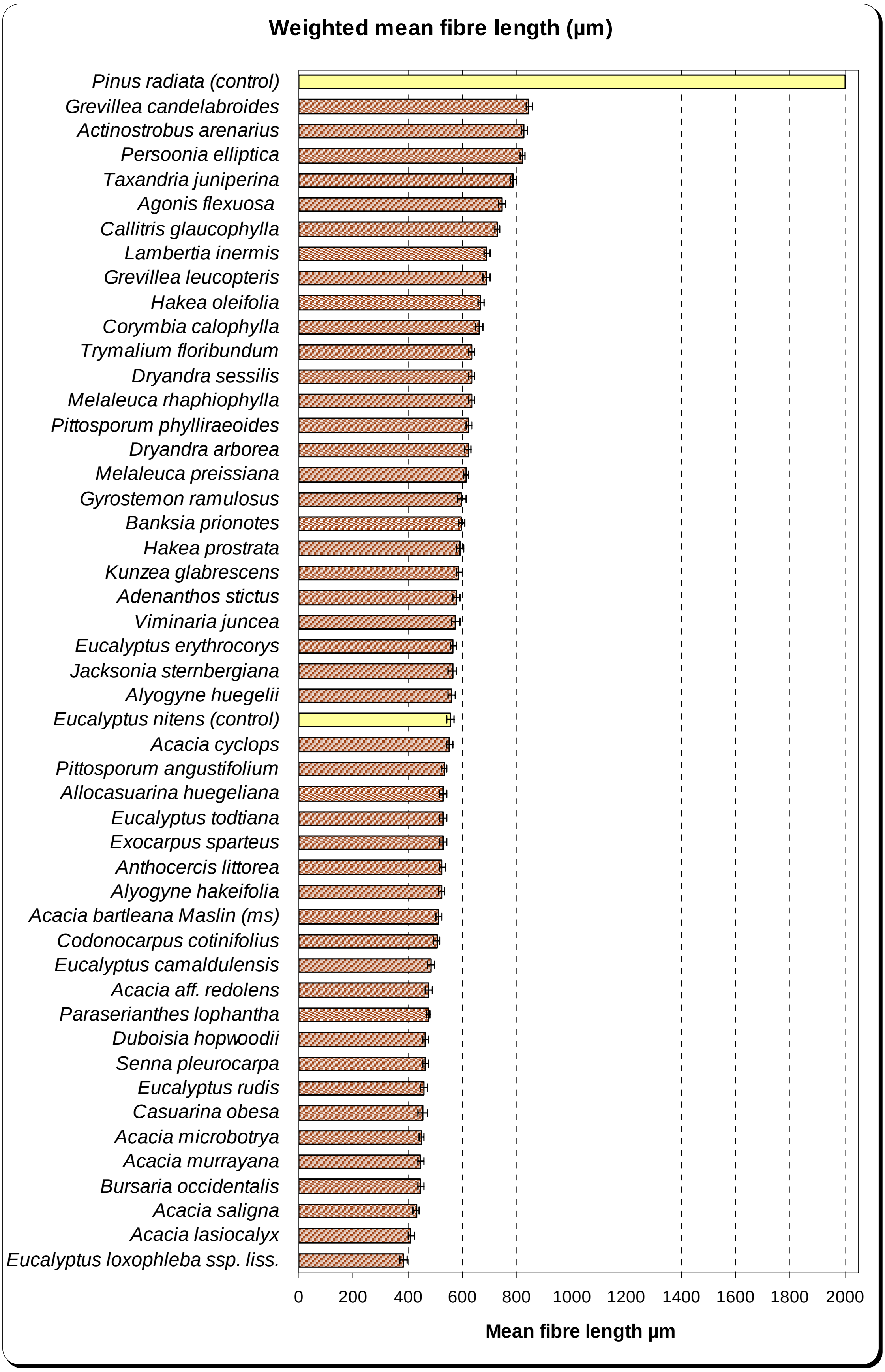


Figure 5. Mean weighted wood fibre length of selected Western Australian species.

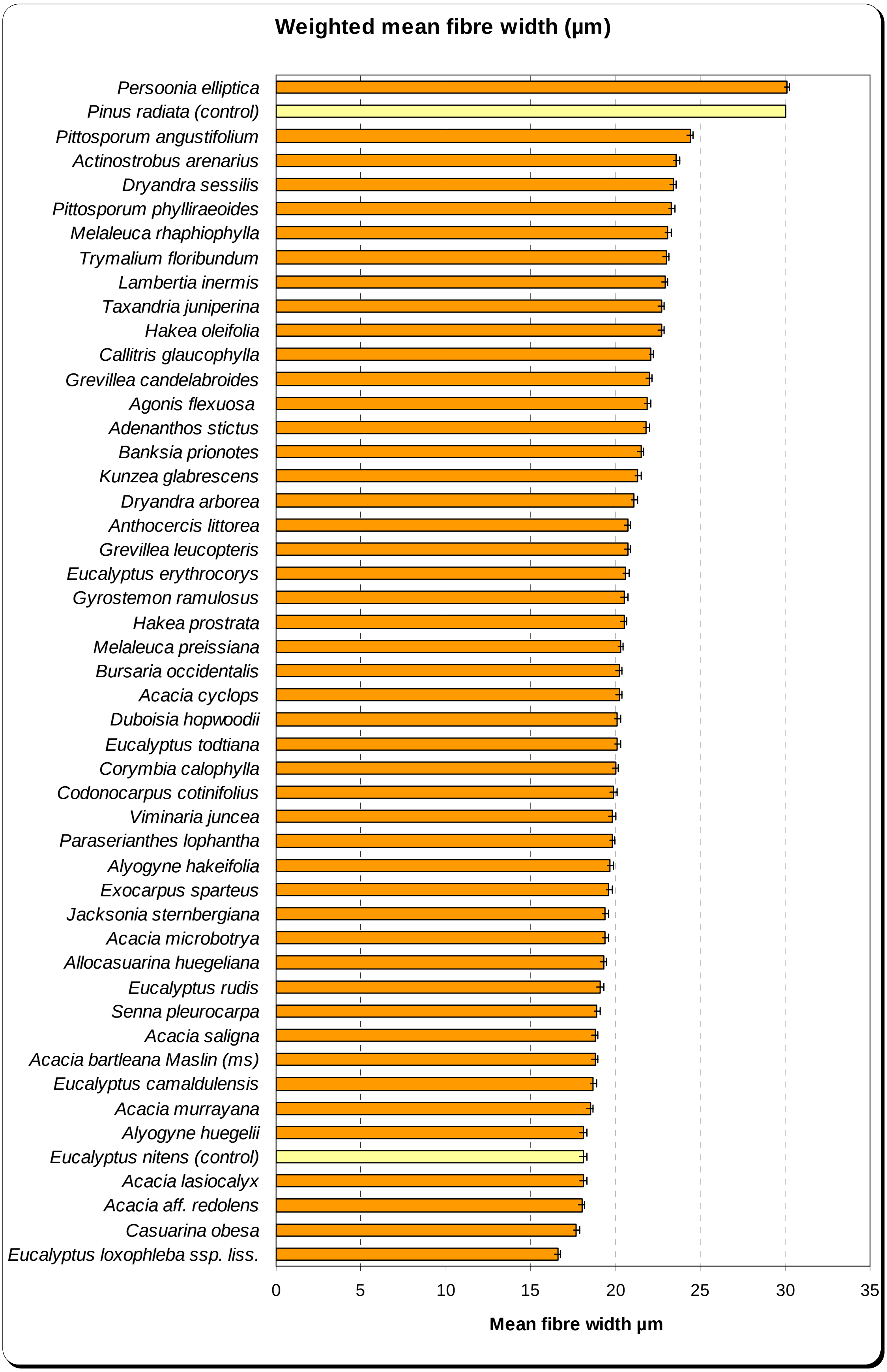


Figure 6. **Mean weighted wood fibre width of selected Western Australian species.**

6.5.3.2 Cellulose Content

Wet Chemistry

Cellulose determinations were carried out on wood meals prepared from random samples of wood chips, which were air dried to approximately 5% moisture content, then milled in a Wiley Mill through a 1 mm screen.

Diglyme (10 mL) and hydrochloric acid (2 mL) were added to milled wood (1 g) in a reaction vial, sealed with a PTFE lined septum and placed in a shaking water bath at 90°C. After one hour the sample was removed and filtered through a tared, porous alundum crucible. The residue was washed with methanol (50 mL) and then boiling water (500 mL) and the crucible dried overnight at 105°C. Cellulose was calculated as a percentage of oven dry wood. Results are a mean of duplicate determinations (Table 4).

Near Infra-Red (NIR) Analysis

Wood meal was used to generate NIR spectra for each of the species using an FIR Systems 5000 bench top analyser. Spectra from the wood samples were used to establish base-line controls against the results from the wet chemistry results. Estimates of cellulose content for other species were obtained from their NIR spectra (Table 4).

A good correlation was found between the two data sets (Figure 7), which could be used as a rapid and cheap method for cellulose determination by NIR alone. However, this method was not pursued further, since the primary objective of measuring cellulose content was to find a cheaper screening method for pulp yield. However, for the species examined here, the correlation between cellulose content and pulp yield was poor.

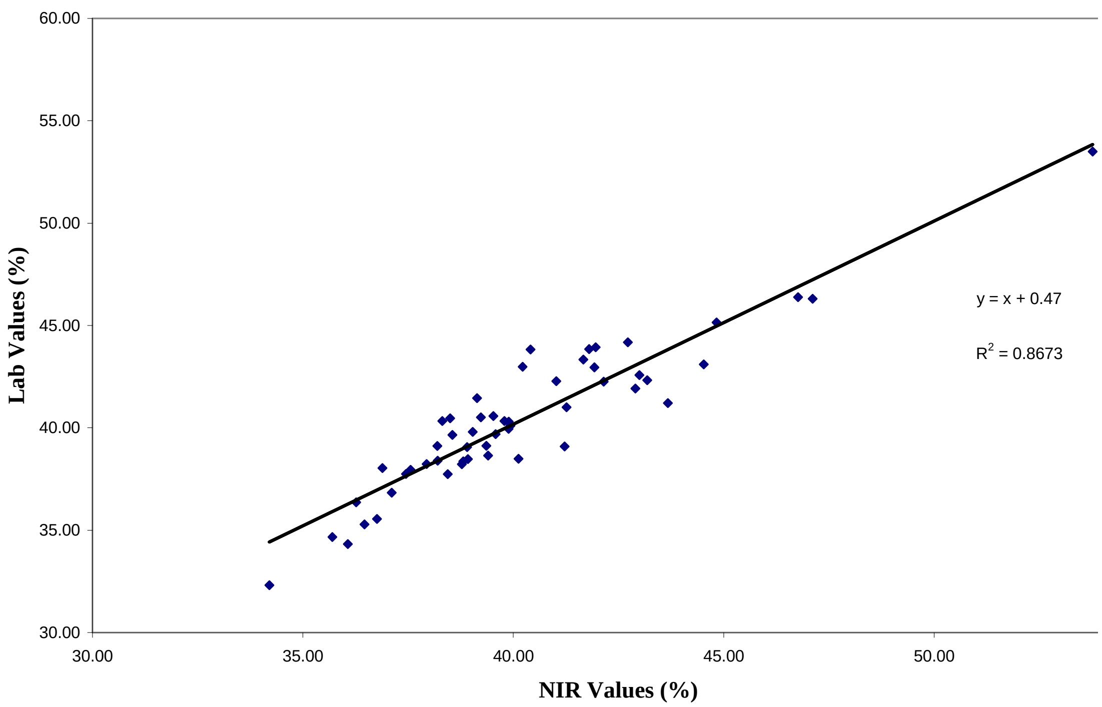


Figure 7: Wet chemistry determination of cellulose content plotted against results of NIR analysis.

Table 4. Cellulose content by NIR and by wet chemistry.

Species	NIR	Lab
Pinus radiata (control)	53.77	53.49
Eucalyptus nitens (control)	42.15	42.26
Acacia aff. redolens	39.36	39.12
Acacia bartleana Maslin (ms)	39.40	38.65
Acacia cyclops	39.89	40.30
Acacia lasiocalyx	42.72	44.18
Acacia microbotrya	39.89	39.95
Acacia murrayana	38.92	38.47
Acacia rostellifera	40.41	43.83
Acacia saligna	38.31	40.33
Actinostrobus arenarius	46.77	46.38
Adenanthos stictus	41.22	39.99
Agonis flexuosa	41.93	42.96
Allocasuarina huegeliana	39.94	40.11
Alyogyne hakeifolia	38.78	38.22
Alyogyne huegelii	39.58	39.69
Anthocercis littorea	42.90	41.92
Banksia prionotes	37.11	36.84
Bursaria occidentalis	36.46	35.29
Callitris glaucophylla	47.11	46.31
Casuarina obesa	39.04	39.80
Codonocarpus cotinifolius	43.67	41.21
Corymbia calophylla	37.56	37.95
Dryandra arborea	39.23	40.52
Dryandra sessilis	38.90	39.06
Duboisia hopwoodii	41.96	43.93
Eucalyptus astringens	38.55	39.65
Eucalyptus camaldulensis	35.70	34.67
Eucalyptus erythrocorys	39.53	40.57
Eucalyptus kochii ssp. plenissima	40.22	42.99
Eucalyptus loxophleba ssp. *lissophloia*	38.20	39.11
Eucalyptus occidentalis	38.50	40.47
Eucalyptus rudis	38.44	37.74
Eucalyptus todtiana	40.12	38.49
Exocarpus sparteus	36.07	34.33
Grevillea candelabroides	36.89	38.04
Grevillea leucopteris	39.79	40.33
Gyrostemon ramulosus	44.52	43.10
Hakea oleifolia	36.27	36.36
Hakea prostrata	37.45	37.75
Jacksonia sternbergiana	41.02	42.28
Kunzea glabrescens	41.67	43.33
Lambertia inermis	39.14	41.46
Melaleuca preissiana	37.94	38.23
Melaleuca rhaphiophylla	38.20	38.40
Paraserianthes lophantha	41.27	41.01
Persoonia elliptica	38.81	38.37
Pittosporum angustifolium	34.20	32.31
Pittosporum phylliraeoides	36.76	35.55
Senna pleurocarpa	43.19	42.33
Taxandria juniperina	44.83	45.15
Trymalium floribundum	43.00	42.58
Viminaria juncea	41.80	43.85

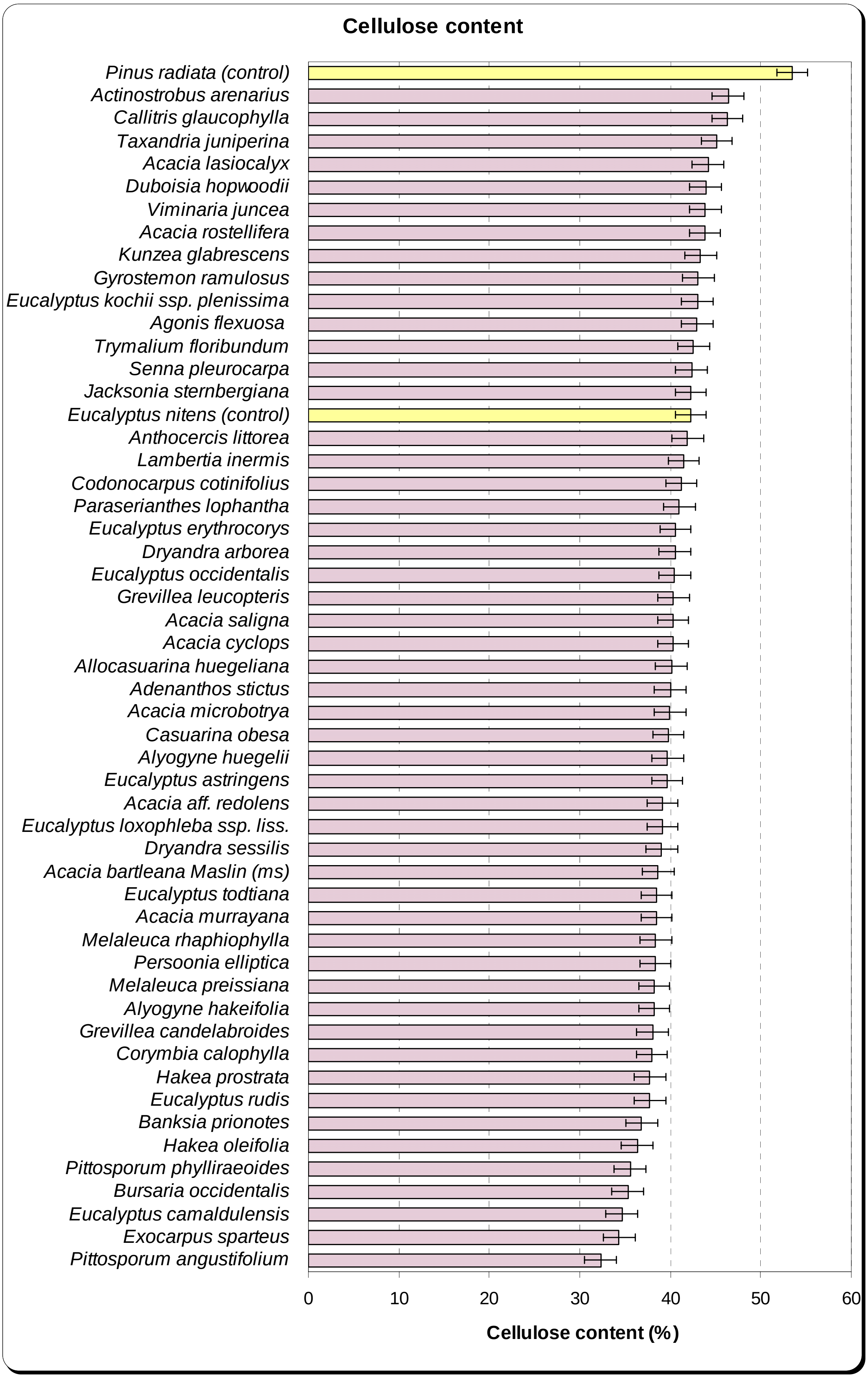


Figure 8. Cellulose content of selected Western Australian species.

Most of the species tested had a cellulose content in the range 40±4% (Figure 8). The error bars shown in the figure represent 95% confidence intervals, based on a pooled estimate of the error. *Pinus radiata* had a significantly higher cellulose content than all other species tested, including the two other softwood species tested (*Actinostrobus arenarius* and *Callitris glaucophylla*). Most of the hardwood species had similar cellulose content to the commercial pulp species *Eucalyptus nitens*. Since these results were poorly correlated with pulp yield (for example *Actinostrobus arenarius* and *Duboisia hopwoodii*), they were not used for further species selection. However, they may be useful; in future should any of these species be targeted for bioenergy uses such as fermentation to ethanol.

6.5.3.3 Wood Basic Density

Wood density was obtained by boiling wood chip samples to fully saturate the chips with water prior to using the displacement technique to obtain chip volume. The wood chips were then oven dried to obtain their dry weight. Basic density was calculated as oven dry weight divided by saturated volume. Results are contained in Table 5 and Figure 9.

Most species had relatively low density, as expected, since approximate wood density, derived from stem coring, was a key criterion used to select species for laboratory investigation. Of the species at the higher end of the density range, most were selected because of their good growth or form despite their slightly high density, on the grounds that the disadvantage of higher density might be outweighed by superior growth performance. Other reasons for including some species outside the target density range were:

- the coring program could not cover the full range of each species, so lower density populations or individuals may occur, and
- density is known to be affected by silvicultural practices, so it is difficult to estimate the likely density of farm-grown plants from the density of plants growing in the wild.

In summary, the density results confirmed that most of the species selected for testing had the potential to produce woodchips of acceptable density for pulp and paper manufacture, especially after factoring in potential changes due to plant breeding and silviculture.

6.5.3.4 Pulp yield

Accurate screening of species for desirable pulp and paper properties proved not to be possible using the basic assaying methods described above. The most effective method to determine species suitability was to carry out laboratory scale pulping, and to test hand sheets made from the pulps of those species with the most promising yields. Therefore, chemical pulping tests were performed for all 51 species.

Pulp yields were determined by laboratory scale Kraft cooking of wood chips in a multiple digester (triplicate runs per species in 3 litre steel ‘bombs’). Conditions were: 400g oven dry charge; Liquor:Wood ratio of 4:1; percentage active alkali required, 25% sulfidity; 1.75hrs to 165°C; approximately 2 hours at temperature; H factor 1300 (an index of ‘area under the curve’ of a time/temperature chart above 100°C).

On completion of the cook, bombs were immersed in water and rapidly cooled to room temperature. The cooked chips were mechanically disintegrated, then the pulp was screened over a 0.25mm Packer screen before being collected in a 50 mesh bag. Finally, the pulp was dewatered, crumbed in a planetary Hobart mixer and sealed in plastic bags prior to evaluation of pulp properties.

Pulp yield was calculated as the ratio between the oven dry equivalent of pulp produced and the oven dry equivalent of wood used. The pulp was delignified to Kappa number 18 (an indicator of residual lignin). The Kappa number of each pulp was determined as described in AS/NZS 1301.201s:2002 (Standards Australia 2002). Pulp yield at Kappa number 18 was inferred from two or three separate digestions of each species, to give a single pulp yield per species. Note that in the pulping industry, hardwoods are generally pulped to a Kappa number of 15-20 (2.5-3.5% lignin) before bleaching (Uprichard and Walker 1993).

Pulping results, with species ranked by pulp yield, are presented in Table 5. Note that some species were tested twice, on separate occasions using different collections of wood. The results are also presented graphically in Figure 10. Where a species was pulped more than once, the average value is used in the graph.

The most prospective species are those with a high pulp yield and a low requirement for alkali to reach Kappa number 18. From the figure it can be seen that the two requirements usually occur together. In general terms, species with high pulp yields have lower alkali demand than species with low pulp yields. In particular, none of the species with pulp yields greater than 45% had alkali requirements greater than 20.

In the figure, red bars indicate ‘less than’ or ‘more than’, where the results were too far from normal pulping behaviour for a pulp yield at Kappa number 18 to be extrapolated (or for active alkali, where the amount of alkali required to reach Kappa number 18 could not be extrapolated). In one case (*Adenanthos stictus*), the amount of alkali needed was *less* than could be determined reliably by the tests, so in this case the red bar is favourable.

Following these pulping tests, thirty species with the highest pulp yields were selected for evaluation of their pulp bleaching performance (to remove residual lignin and increase brightness). From pulp of these thirty species, paper handsheets were prepared and tested for a range of paper properties.

Table 5: Basic density, and alkali usage and pulp yield at 18 Kappa number.

Species	Basic density (kg/m^3)	*AA Na_2O (%)	Pulp yield (%)	Tested for paper?
Taxandria juniperina	501	13	54.3	Yes
Senna pleurocarpa	557	13	53.2	Yes
Paraserianthes lophantha	501	14.5	52.9	Yes
Grevillea leucopteris	544	17.8	52.4	Yes
Acacia lasiocalyx	648	17	51.6	Yes
Anthocercis littorea	418	14	49.7	Yes
Trymalium floribundum	582	19	49.7	Yes
Eucalyptus occidentalis	581	14	49.4	Yes
Adenanthos stictus	543	<15	49.2	Yes
Eucalyptus astringens	718	14	48.9	Yes

Species	**Basic density (kg/m^3)**	***AA Na_2O (%)**	**Pulp yield (%)**	**Tested for paper?**
Acacia cyclops	657	17.5	48.8	Yes
Acacia murrayana (2)	580	16	48.7	Yes
Acacia murrayana (1)	627	19	43.4	
Eucalyptus loxophleba spp *liss.*	707	13	48.7	Yes
Lambertia inermis	604	14	48.6	Yes
Eucalyptus rudis (2)	494	17	48.4	Yes
Eucalyptus rudis (1)	468	15	43.5	
Alyogyne huegelii	617	15.5	47.8	Yes
Jacksonia sternbergiana	577	16	47.6	Yes
Acacia aff. redolens	734	17	47.3	Yes
Eucalyptus kochii ssp. plenissima	758	16	47.3	Yes
Acacia microbotrya	742	16	47.1	Yes
Codonocarpus cotinifolius	378	14.5	46.5	Yes
Eucalyptus erythrocorys (2)	627	16.5	46.2	Yes
Eucalyptus erythrocorys (1)	669	15.5	44.0	
Allocasuarina huegeliana	606	17	45.6	Yes
Acacia saligna	585	16.5	45.2	Yes
Grevillea candelabroides	608	17.5	45.1	Yes
Dryandra sessilis	656	16	44.9	Yes
***Acacia bartleana* Maslin (ms) (2)**	709	20.3	44.8	Yes
***Acacia bartleana* Maslin (ms) (1)**	735	17	43.9	
Viminaria juncea	436	15	44.7	Yes
Agonis flexuosa	620	16	44.6	Yes
Gyrostemon ramulosus (2)	384	20.5	44.5	Yes
Gyrostemon ramulosus (1)	384	20	44.3	
Persoonia elliptica	505	15	44.1	
Corymbia calophylla	612	17	43.6	
Exocarpus sparteus	593	17.5	43.0	
Dryandra arborea	720	16.5	42.7	
Banksia prionotes	594	14.5	42.5	
Hakea oleifolia	565	22	42.1	
Casuarina obesa	613	22	41.8	
Melaleuca rhaphiophylla	547	16.5	39.0	
Bursaria occidentalis	629	18	38.6	
Eucalyptus camaldulensis	576	17	38.3	
Eucalyptus todtiana	611	21.8	38.1	
Kunzea glabrescens	633	24	37.3	
Duboisia hopwoodii	446	25	36.5	
Hakea prostrata	552	>22	<43	
Acacia rostellifera	697	>24	<42	
Alyogyne hakeifolia	600	>25	<39	
Pittosporum phylliraeoides	719	>22	<39	
Melaleuca preissiana	514	20.5	<37	
Actinostrobus arenarius	571	>25	<36	
Pittosporum angustifolium	719	>22	<36	
Callitris glaucophylla	601	>25	<35	

Species ranked in order of pulp yield (species pulped twice are ranked according to the higher yield)
(*) Active Alkali calculated as Na_2O
(<) Resultant pulp yield would be less than value shown due to high fines content.

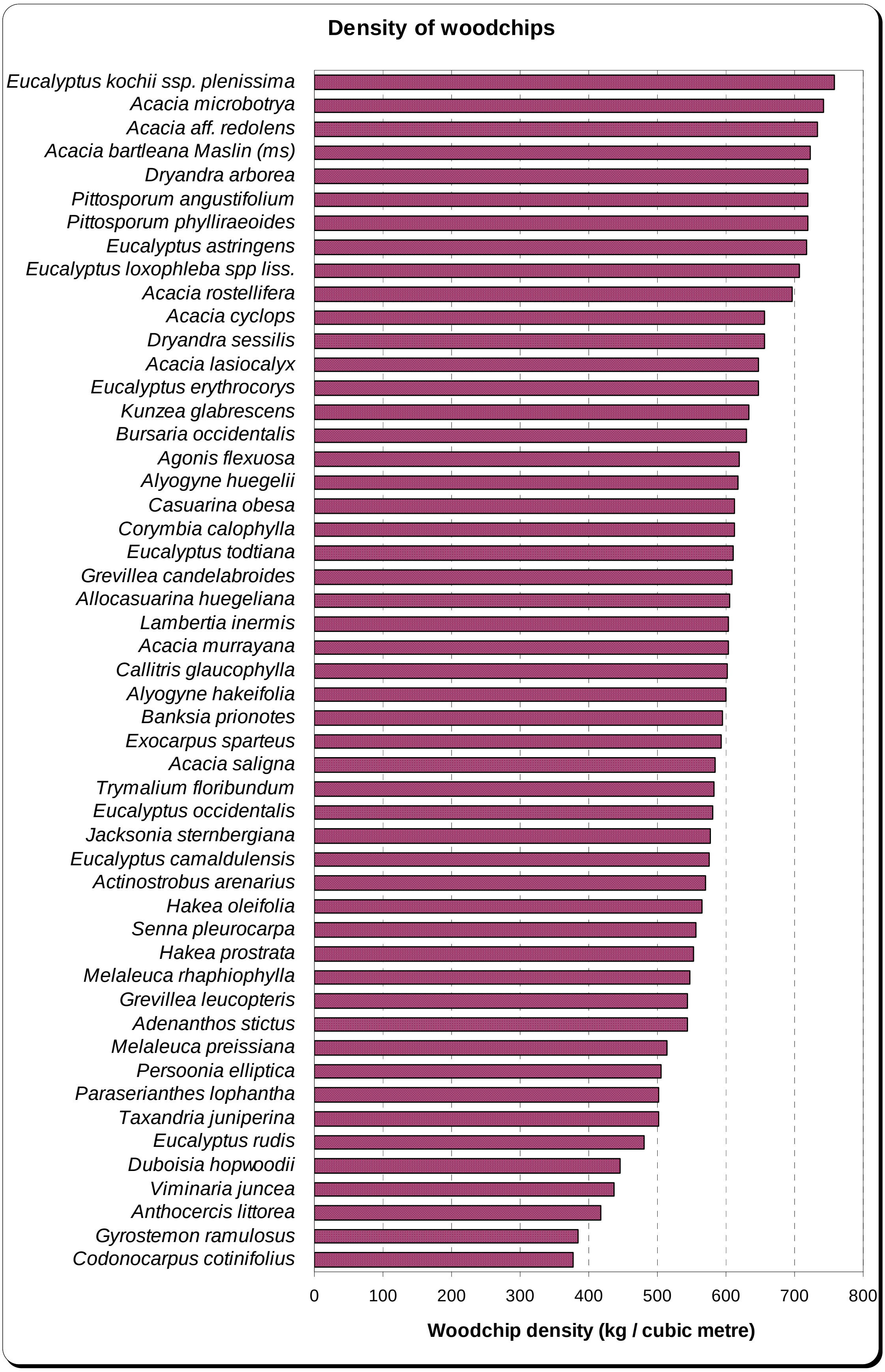
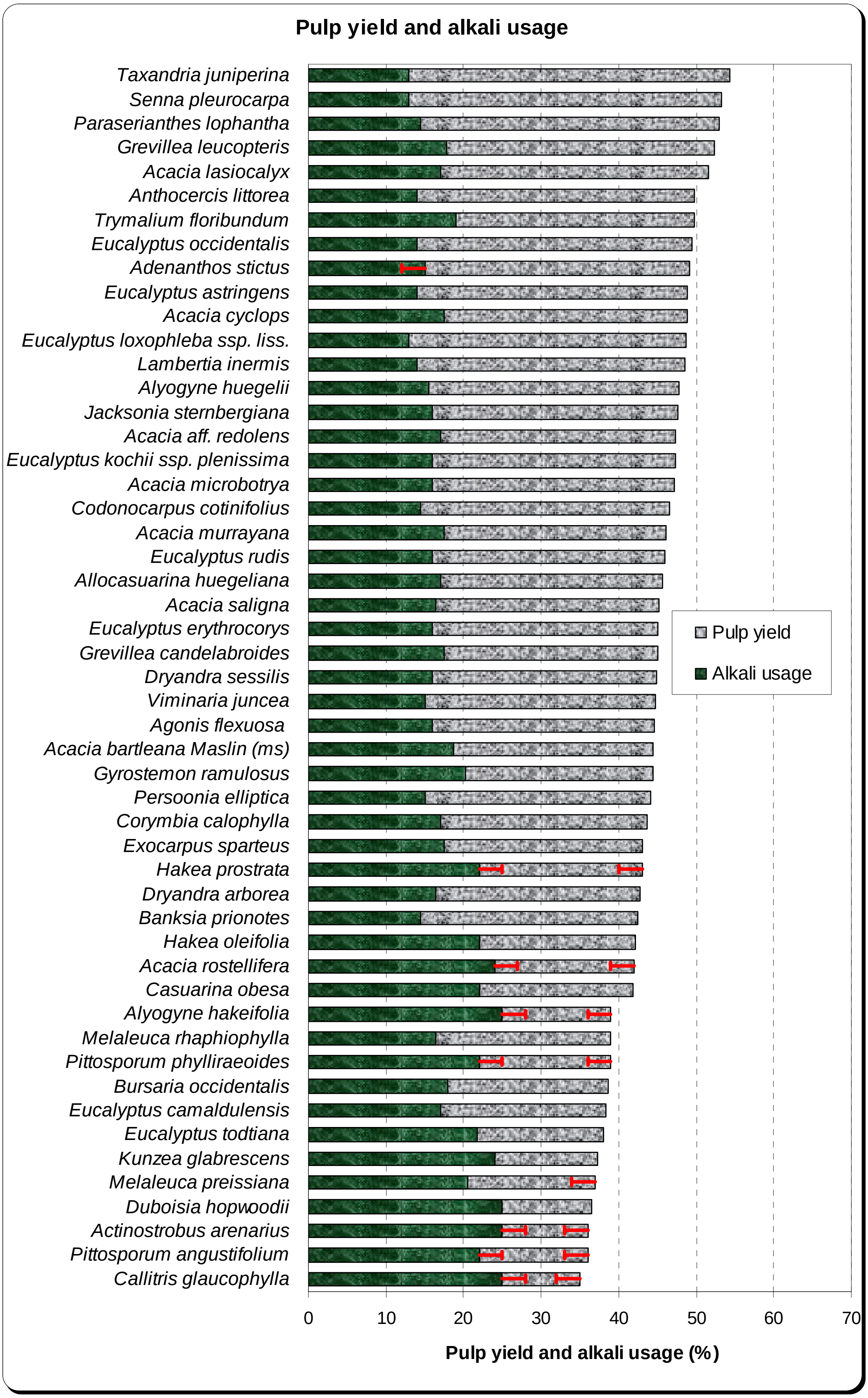


Figure 9. Woodchip density of species selected for laboratory investigation.



Note: Red bars have been used to show “less than” or “more than”.

Figure 10. Pulp yield and alkali usage for selected species.

6.5.3.5 Pulp bleaching

Bleaching trials, to remove residual lignin from the pulp, were carried out on the species selected for paper testing. A three-stage bleach sequence was used – D (EP) D. Although not a typical commercial bleaching sequence, it gives the same results and is a relatively quick and cost-effective method for screening purposes.

D: Chlorine dioxide charge ca 1.8%+(kappa-15)*0.3/2.63; small amount of sulphuric acid added so that the end pH is 2-2.5; 6% consistency; 1 hour at 60°C.

EP: 10% consistency; 1.2 - 0.5% NaOH; 1.5 hours at 75°C with a final pH of ~11.

D: 10% consistency; 3 hours at 70°C using 0.3% chlorine dioxide and small amount of sulphuric acid added so that the end pH is 3.8-4.5.

Bleaching results are presented in Table 6 and Figure 12. The reflectance (or ‘brightness’ of bleached pulp is tested against a known standard. Brightness is measured again after the bleached pulp has been heated to 105^{o}C for one hour, a treatment that accelerates the discoloration of any residual lignin.

Many species performed well under the test bleaching conditions, reaching satisfactory levels of brightness. However, some of the species tested here achieved only low brightness levels, and would require extra chemical use to achieve satisfactory brightness levels, while the poorest performing species may not achieve satisfactory brightness levels even with higher chemical use.

The ratings given for bleaching performance (Table 8) were based on the brightness after one hour at 105^{o}C (Table 6, Figure 12). For comparison, some bleached Kraft pulps can achieve brightness levels up to 92% (Uprichard and Walker 1993).

6.5.3.6 Paper properties

Of the fifty-one species pulped, thirty were chosen for paper handsheet manufacture and testing (Table 5, Figure 11), based on their pulp yield. A lower cut-off of 44.5% pulp yield was used, although this is lower than currently considered commercially desirable (for example, pulp yields of individual *Eucalyptus globulus* trees vary between about 47% and 57%). However, a lower cut-off was used in this trial, because the material collected for each species came from a small number of individual plants, from only one or two populations. It is likely that the pulp yield of these species could be improved by selection, breeding and silvicultural management.

Paper hand-sheets were made from pulp from the same batches of wood chips as those tested for pulp yield. The paper was preconditioned / conditioned in accordance with Australian Standard AS 1301.P414m – 86 (Standards Australia 1986). Temperature and relatively humidity were controlled within limits described in AS/NZS 1301.415s:1998 (Standards Australia 1998b): Temperature 23 ±1°C; Relative humidity: 50 ±2% RH

Ratings for each species for the major pulp and paper tests are presented in Table 8, based on categories defined in Table 7. Test results on which these ratings are based are contained in Table 5, Table 6 and Table 9.

Figure 11. Paper handsheet manufacture and testing at CSIRO Forestry and Forest Products.
Top row: Pulp beater; Canadian freeness tester.
Second row: Handsheet manufacture; Handsheet drying racks.
Third row: Tensile strength; Burst strength.
Bottom row: Tearing resistance; Air resistance.

Table 6. Brightness values after pulp bleaching

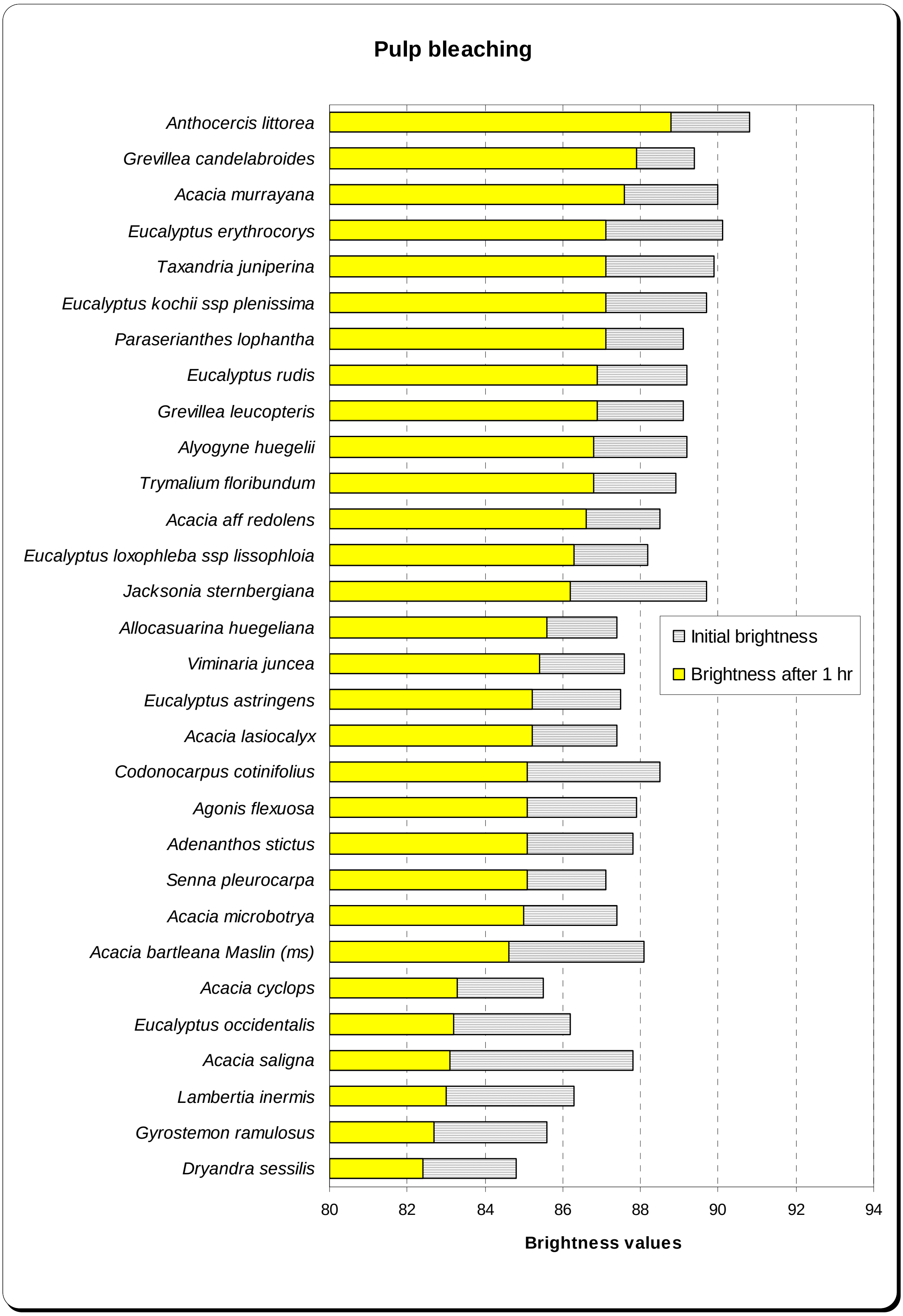
Species	Initial Brightness	Brightness after 1 hour at 105°C	Comment
Acacia aff *redolens*	88.5	86.6	v. good
Acacia bartleana Maslin (ms)	88.1	84.6	poor
Acacia cyclops	*85.5	83.3	v. poor
Acacia lasiocalyx	87.4	85.2	good
Acacia microbotrya	87.4	85.0	good
Acacia murrayana	90.0	87.6	excellent
Acacia saligna	*87.8	83.1	poor
Adenanthos stictus	87.8	85.1	good
Agonis flexuosa	87.9	85.1	good
Allocasuarina huegeliana	87.4	85.6	good
Alyogyne huegelii	89.2	86.8	v. good
Anthocercis littorea	90.8	88.8	excellent
Codonocarpus cotinifolius	88.5	85.1	good
Dryandra sessilis	*84.8	82.4	v. poor
Eucalyptus astringens	87.5	85.2	good
Eucalyptus erythrocorys	90.1	87.1	excellent
Eucalyptus kochii ssp *plenissima*	89.7	87.1	excellent
Eucalyptus loxophleba ssp *lissophloia*	88.2	86.3	v. good
Eucalyptus occidentalis	86.2	83.2	v. poor
Eucalyptus rudis	89.2	86.9	v. good
Grevillea candelabroides	89.4	87.9	excellent
Grevillea leucopteris	89.1	86.9	v. good
Gyrostemon ramulosus	85.6	82.7	v. poor
Jacksonia sternbergiana	89.7	86.2	v. good
Lambertia inermis	86.3	83.0	v. poor
Paraserianthes lophantha	89.1	87.1	excellent
Senna pleurocarpa	87.1	85.1	good
Taxandria juniperina	89.9	87.1	excellent
Trymalium floribundum	88.9	86.8	v. good
Viminaria juncea	87.6	85.4	good

Those marked with an asterisk will require more chemicals for bleaching than others.

Table 7. Ratings categories for pulp and paper tests.

Rating	Pulp yield at Kappa no 18	Bleaching (unbeaten)	Freeness (unbeaten)	Density (unbeaten)	Tear index at 70 tensile	Tensile index at 350 Freeness
excellent	> 50	> 87	> 500	< 620	> 9.0	> 90
v. good	48 – 50	86 – 87	450 – 500	620 – 650	8.5 – 9.0	80 – 90
good	45 – 48	85 – 86	400 – 450	650 – 680	8.0 – 8.5	70 – 80
poor	41 – 45	< 85*	350 – 400	680 – 710	7.5 – 8.0	60 – 70
v. poor	< 41	< 85	< 350	> 710	< 7.5	< 60

* If initial brightness > 87.



Note: Species were ranked by their brightness after 1 hour at 105^{0}C.

Figure 12. Bleaching performance of selected species.

Table 8. Ratings for pulp yield, bleaching and paper properties for selected species.

Species	Pulp yield	Bleaching	Freeness	Density	Tear index	Tensile index
Acacia aff. *redolens*	good	v. good	good	excellent	v. poor	v. poor
Acacia bartleana Maslin (ms)	poor	poor	excellent	excellent	v. poor	poor
Acacia cyclops	v. good	v. poor	v. good	v. good	v. poor	poor
Acacia lasiocalyx	excellent	good	excellent	excellent	v. poor	poor
Acacia microbotrya	good	good	v. good	excellent	v. poor	v. poor
Acacia murrayana	v. good	excellent	v. good	excellent	v. poor	v. poor
Acacia saligna	good	poor	excellent	excellent	v. poor	poor
Adenanthos stictus	v. good	good	v. good	v. good	v. poor	v. poor
Agonis flexuosa	poor	good	excellent	excellent	poor	good
Allocasuarina huegeliana	good	good	poor	excellent	v. poor	v. poor
Alyogyne huegelii	good	v. good	excellent	excellent	v. good	good
Anthocercis littorea	v. good	excellent	good	v. poor	v. poor	v. good
Codonocarpus cotinifolius	good	good	v. good	v. poor	v. poor	poor
Dryandra sessilis	poor	v. poor	v. good	excellent	v. poor	v. poor
Eucalyptus astringens	v. good	good	excellent	excellent	v. poor	poor
Eucalyptus erythrocorys	good	excellent	excellent	v. good	v. poor	v. poor
Eucalyptus kochii ssp *plenissima*	good	excellent	v. good	excellent	v. poor	v. poor
Eucalyptus loxophleba ssp. *lissophloia*	v. good	v. good	poor	v. good	v. poor	v. poor
Eucalyptus occidentalis	v. good	v. poor	good	poor	v. poor	poor
Eucalyptus rudis	v. good	v. good	v. good	poor	v. poor	poor
Grevillea candelabroides	good	excellent	excellent	excellent	excellent	good
Grevillea leucopteris	excellent	v. good	excellent	excellent	good	good
Gyrostemon ramulosus	poor	v. poor	v. good	poor	v. poor	v. poor
Jacksonia sternbergiana	good	v. good	excellent	excellent	v. poor	v. poor
Lambertia inermis	v. good	v. poor	excellent	excellent	v. poor	poor
Paraserianthes lophantha	excellent	excellent	v. good	poor	v. poor	poor
Senna pleurocarpa	excellent	good	v. good	poor	v. poor	good
Taxandria juniperina	excellent	excellent	excellent	excellent	v. good	v. good
Trymalium floribundum	v. good	v. good	v. good	v. good	v. poor	good
Viminaria juncea	poor	good	excellent	poor	v. poor	poor

Table 9. Paper properties of selected species.

Species	Cook No.	Kappa No.	Ref. No.	Beating (revs)	Freeness (csf)	Density (kg/m3)	Tear Index (mNm2/g)	Tensile Index (Nm/g)	Stretch (%)	Tensile Stiffness (kNm/g)	TEA[1] (J/g)	Burst Index (kPam2/g)	Air Resistance (sec)
Acacia aff. *redolens*	29b	16.7	2003-038	**0**	402	613	3.6	37	1.5	5.6	0.4	1.7	2.4
				250	370	630	4.3	45	2.1	6.0	0.7	2.4	3.0
				400	**350**	645	4.8	50	2.4	6.1	0.9	2.6	4.0
				1750	250	720	6.5	**70**	3.3	7.0	1.6	4.4	12
Acacia bartleana Maslin (ms)	82c	19.9	2003-078	**0**	524	585	3.5	35	1.3	5.6	0.3	1.5	1.2
				250	480	630	5.6	44	1.8	6.2	0.6	2.0	2.4
				1350	**350**	710	6.9	67	3.0	7.2	1.4	4.1	4.0
				1600	330	720	7.1	**70**	3.3	7.3	1.6	4.4	5.0
Acacia cyclops	23e	17	2003-002	**0**	471	631	3.9	39	1.4	6.0	0.4	1.7	1.8
				250	440	670	4.8	48	1.9	6.3	0.7	2.4	2.5
				900	**350**	730	5.6	63	2.7	7.2	1.3	3.7	7.9
				1450	300	750	5.9	**70**	2.8	7.8	1.4	4.3	14
Acacia lasiocalyx	02c21a	16.4	2003-072	**0**	513	553	3.1	30	1.1	5.1	0.2	1.2	1.0
				250	490	582	4.5	37	1.5	5.3	0.3	1.8	1.2
				1700	**350**	700	7.1	61	3.5	6.2	1.5	4.0	3.9
				3000	238	738	7.3	**70**	4.1	6.5	2.0	4.9	8.5
Acacia microbotrya	14e	17.6	2003-040	**0**	498	573	2.6	31	1.2	4.8	0.2	1.2	0.9
				250	460	600	3.8	39	1.6	5.2	0.4	1.7	1.0
				1150	**350**	670	5.7	52	2.6	6.0	1.0	3.0	3.8
				2650	240	740	6.6	**70**	3.8	6.7	1.8	4.6	15
Acacia murrayana	83e	19.6	2003-082	**0**	492	608	3.3	32	1.4	4.8	0.3	1.4	2.0
				250	430	635	4.2	39	2.0	5.2	0.5	2.0	3.5
				625	**350**	675	5.3	49	2.6	5.6	0.9	2.8	6.0
				2200	180	748	7.1	**70**	3.9	6.2	1.9	4.8	37

Species	Cook No.	Kappa No.	Ref. No.	Beating (revs)	Freeness (csf)	Density (kg/m3)	Tear Index (mNm2/g)	Tensile Index (Nm/g)	Stretch (%)	Tensile Stiffness (kNm/g)	TEA (J/g)	Burst Index (kPam2/g)	Air Resistance (sec)
Acacia saligna	14f	14.9	2003-041	**0**	506	616	4.1	36	1.5	5.1	0.4	1.6	3.2
				250	450	690	5.6	45	2.4	6.1	0.8	2.5	8.5
				350	**350**	755	6.9	63	3.4	7.0	1.6	3.9	18
				650	310	785	7.2	**70**	3.9	7.1	2.1	4.7	28
Adenanthos stictus	5e	16.4	2003-005	**0**	475	631	2.4	32	0.9	5.5	0.2	1.1	2.6
				250	405	650	3.0	38	1.3	6.1	0.3	1.6	6.0
				450	**350**	670	3.4	43	1.4	6.3	0.4	1.9	9.9
				2650	95	800	5.8	**70**	2.8	7.7	1.3	3.9	430
Agonis flexuosa	5f	17.7	2003-020	**0**	543	571	3.4	36	1.1	5.8	0.2	1.3	1.4
				250	495	615	4.8	43	1.5	6.1	0.8	2.0	2.5
				1850	**350**	715	7.9	70	3.3	7.3	1.7	4.3	10
				1850	350	715	7.9	**70**	3.3	7.3	1.7	4.3	10
Allocasuarina huegeliana	29d	16.5	2003-039	**0**	385	590	3.5	39	1.3	6.1	0.3	1.7	2.0
				250	350	610	4.2	45	1.5	6.1	0.4	2.0	2.5
				250	**350**	610	4.2	45	1.5	6.1	0.4	2.0	2.5
				2050	170	710	6.6	**70**	2.9	7.2	1.4	4.0	23
Alyogyne huegelii	21f	20.3	2003-043	**0**	528	603	3.1	41	1.5	6.4	0.4	1.8	1.7
				250	460	635	7.6	50	2.0	6.8	0.8	2.5	4.0
				900	**350**	695	8.7	72	3.0	7.4	1.5	4.2	11
				800	365	690	8.6	**70**	2.9	7.3	1.4	4.0	9.5
Anthocercis littorea	02c23b	16.6	2003-001	**0**	443	797	6.1	54	2.2	7.0	0.9	2.7	15
				250	405	840	6.3	67	2.6	7.4	1.1	4.5	25
				650	**350**	890	6.7	80	3.4	7.8	1.2	4.9	100
				350	390	855	6.4	**70**	2.9	7.5	1.9	3.9	50

Species	Cook No.	Kappa No.	Ref. No.	Beating (revs)	Freeness (csf)	Density (kg/m3)	Tear Index (mNm2/g)	Tensile Index (Nm/g)	Stretch (%)	Tensile Stiffness (kNm/g)	TEA (J/g)	Burst Index (kPam2/g)	Air Resistance (sec)
Codonocarpus cotinifolius	17f	20	2003-044	**0**	460	744	4.9	42	1.5	6.5	0.4	1.9	14
				250	380	785	6.2	55	2.2	7.0	1.0	3.0	51
				350	**350**	805	6.5	60	2.5	7.2	1.1	3.2	70
				650	275	840	6.8	**70**	3.0	7.7	1.5	4.4	125
Dryandra sessilis	15b	18.2	2003-021	**0**	471	564	2.8	33	1.0	5.8	0.2	1.1	1.7
				250	420	595	3.6	39	1.2	6.0	0.4	1.5	4.0
				500	**350**	625	4.3	45	1.5	6.4	0.5	1.8	6.0
				2650	95	735	6.9	**70**	2.7	7.7	1.2	3.9	45
Eucalyptus astringens	83a	16.2	2003-083	**0**	514	609	3.1	37	1.3	5.5	0.3	1.6	1.1
				250	460	630	3.9	46	1.7	5.9	0.6	2.2	1.5
				850	**350**	690	5.1	62	2.7	6.7	1.2	3.6	3.9
				1300	290	710	7.0	**70**	3.4	7.1	1.6	4.5	8.0
Eucalyptus erythrocorys	80e	18.9	2003-073	**0**	504	626	3.1	38	1.3	5.9	0.3	1.6	1.9
				250	425	645	4.3	45	1.8	6.2	0.6	2.5	3.0
				550	**350**	670	5.6	53	2.3	6.5	0.9	3.1	5.0
				1800	225	725	7.2	**70**	3.4	7.2	1.7	4.1	17
Eucalyptus kochii ssp *plenissima*	83b	17.8	2003-081	**0**	453	534	1.8	32	0.9	5.8	0.2	1.0	0.8
				250	420	550	2.2	35	1.1	5.9	0.3	1.3	1.1
				825	**350**	585	3.0	43	1.7	6.1	0.5	2.0	1.7
				2750	250	645	4.9	**(60)**	2.7	6.9	1.2	3.4	5.7
Eucalyptus occidentalis	83c	16.2	2003-084	**0**	420	702	3.4	40	1.5	5.7	0.4	1.8	4.3
				250	385	735	4.4	49	2.3	6.2	0.8	2.3	8.0
				600	**350**	780	5.3	60	3.0	6.6	1.3	3.5	14
				1150	300	820	5.8	**70**	3.7	7.1	1.8	4.6	30

Species	Cook No.	Kappa No.	Ref. No.	Beating (revs)	Freeness (csf)	Density (kg/m3)	Tear Index (mNm2/g)	Tensile Index (Nm/g)	Stretch (%)	Tensile Stiffness (kNm/g)	TEA (J/g)	Burst Index (kPam2/g)	Air Resistance (sec)
Eucalyptus rudis	80f	19.2	2003-076	**0**	471	709	4.9	50	1.7	6.9	0.6	2.3	6.4
				250	410	725	5.6	58	2.1	7.3	0.9	3.2	11
				450	**350**	738	6.2	65	2.5	7.6	1.2	3.9	16
				650	310	748	6.6	**70**	2.7	7.8	1.4	4.3	20
Eucalyptus loxophleba ssp *lissophloia*	02c16e	16.7	2002-070	**0**	388	629	3.4	39	1.8		0.5	1.9	2.4
				250	370	650	3.6	43	1.9		0.6	2.3	3.0
				740	**350**	670	4.0	50	2.6		0.9	3.0	4.5
				2750	305	745	5.2	**70**	4.2	6.8	2.0	4.8	19
Grevillea candelabroides	15c	21.3	2003-037	**0**	600	575	6.9	36	1.5	3.5	0.4	1.6	1.3
				250	550	620	8.9	48	2.0	5.9	0.7	2.2	2.0
				1800	**350**	710	8.9	75	3.4	7.4	1.8	4.9	12
				1350	400	690	9.1	**70**	3.2	7.1	1.5	4.4	7.0
Grevillea leucopteris	31e	17.6	2003-004	**0**	558	606	6.1	36	2.0	4.8	0.5	2.0	2.2
				250	530	660	7.0	45	2.3	5.4	0.7	2.8	3.5
				2650	**350**	760	8.1	70	3.7	6.8	1.8	4.8	28
				2650	350	760	8.1	**70**	3.7	6.8	1.8	4.8	28
Gyrostemon ramulosus	80d	18.7	2003-071	**0**	496	701	4.0	34	1.4	5.5	0.3	1.5	10
				250	400	755	5.1	53	1.9	7.1	0.6	2.5	30
				450	**350**	795	5.8	46	2.8	7.4	0.9	3.1	50
				1500	220	871	6.8	**70**	3.5	7.6	1.8	4.4	208
Jacksonia sternbergiana	16a	17	2003-042	**0**	526	588	3.8	31	1.1	5.3	0.2	1.2	1.6
				250	445	615	4.5	38	1.5	5.8	0.3	2.0	3.5
				650	**350**	660	5.4	47	1.9	6.3	0.7	2.7	7.0
				2650	175	765	6.7	**70**	3.5	7.5	1.8	4.4	63

Species	Cook No.	Kappa No.	Ref. No.	Beating (revs)	Freeness (csf)	Density (kg/m3)	Tear Index (mNm2/g)	Tensile Index (Nm/g)	Stretch (%)	Tensile Stiffness (kNm/g)	TEA (J/g)	Burst Index (kPam2/g)	Air Resistance (sec)
Lambertia inermis	10f	17.3	2003-022	**0**	609	574	3.1	27	0.9	5.0	0.1	0.9	0.9
				250	535	610	3.5	35	1.3	5.8	0.4	1.6	2.1
				1250	**350**	780	6.3	63	2.7	7.2	1.1	3.4	10
				1700	285	808	6.8	**70**	3.1	7.6	1.4	4.0	18
Paraserianthes lophantha	7a	19.9	2003-018	**0**	494	703	3.6	39	1.7	5.2	0.5	1.8	5.8
				250	440	752	4.1	54	2.4	6.1	1.1	2.8	15
				745	**350**	820	5.0	65	3.2	6.9	1.6	3.8	35
				1350	290	860	5.6	**70**	3.6	7.3	1.9	4.6	92
Senna pleurocarpa	02c18a	16.4	2002-071	**0**	498	694	4.3	46	1.7	6.2	0.5	2.5	4.3
				250	450	740	5.7	56	2.3	6.6	0.9	3.2	8.5
				1100	**350**	862	6.6	77	3.7	7.5	2.0	5.4	25
				700	385	794	6.6	**70**	3.1	7.2	1.7	4.4	14
Taxandria juniperina	6a	16.3	2003-006	**0**	583	619	6.0	50	1.3	7.5	0.4	1.9	1.5
				250	540	645	7.7	59	1.8	7.6	0.7	2.8	2.2
				1900	**350**	760	8.8	87	3.2	8.4	1.9	5.6	24
				600	500	685	8.7	**70**	2.4	7.9	1.2	4.1	4.0
Trymalium floribundum	24e	20.8	2003-003	**0**	485	629	4.1	45	1.3	6.8	0.4	1.9	1.8
				250	455	660	4.6	53	1.7	7.2	0.6	2.6	3.0
				1125	**350**	700	6.0	71	2.5	8.1	1.3	4.2	12
				1050	355	700	6.1	**70**	2.5	8.0	1.2	4.1	10
Viminaria juncea	15e	18.7	2003-019	**0**	505	706	5.2	44	1.8	5.9	0.5	1.9	8.2
				250	420	735	6.0	52	2.4	6.4	0.9	3.0	22
				560	**350**	770	6.6	60	3.0	7.0	1.2	3.9	38
				1100	295	820	6.9	**70**	3.6	7.4	1.8	4.6	70

[1] TEA = Total Energy Absorption on tensile testing.

6.5.4 Conclusions and recommendations

These pulp and paper tests produced a wide range of results. The best performing species, were *Taxandria juniperina, Grevillea leucopteris, Alyogyne huegelii* and *Grevillea candelabroides.* These species all demonstrated sufficient potential to justify further investigation.

A second group, including *Senna pleurocarpa, Acacia lasiocalyx, Anthocercis littorea, Trymalium floribundum, Viminaria juncea* and *Agonis flexuosa,* produced less favourable test results, but are also worthy of further consideration. *Anthocercis littorea*, in particular, is likely to perform better if older material is used.

Wood age is a particularly important consideration for paper quality. Most species currently used in commercial paper production are grown to an older age than the material used in these trials, which assists in raising pulp yield, and improving the characteristics of their fibres. Young material was used deliberately in this project to simulate the type of material that could be produced by very short-cycle woody crops. It is notable that the greatest defect of many of the species tested here was the poor strength characteristics of the paper made from them, a characteristic that is likely to have been exacerbated by the young age of the material. Despite this potential handicap, some species performed surprisingly well. Future trials of the more promising species should include material from a range of ages, to better determine each species' suitability, and optimum harvest age.

In conclusion, these results must be treated with caution. They provide a single snapshot of each species' potential based on the fibre characteristics of a very limited collection of (mostly) young material from wild populations. Large variation in productivity, density, pulp yield and fibre characteristics could be found when different aspects of these species are examined. In particular, the following variables, and the interactions between them, deserve further exploration, to ascertain their effect on the paper-making qualities of the more promising species:

- genetic variability
- effect of site conditions
- response to cultivation
- growth rate
- age of harvest

6.6 Laboratory testing – panel boards

6.6.1 Introduction

Testing of WA native species for their suitability in panel board manufacture was performed by CSIRO Forestry and Forest Products at the Ian Wark Laboratories in Clayton, Victoria.

The information presented below is drawn from a report on this work by CSIRO Forestry and Forest Products. The full report is contained in Appendix 02.

6.6.2 Basis of statistical analysis

Testing was carried out at two levels – preliminary exploration of chemical and fibre characteristics, followed by selection of the most promising species for laboratory-scale panel manufacture and testing.

For panel testing, statistical treatment of the data was effected by first applying single-factor analysis of variance (ANOVA) to each test result for each species for between panel variance to allow the pooling of data for reporting. In many cases the null hypotheses (H_o: all means are equal) was rejected – the data being significant at the 0.05 level. To present the data in a useful format, the results for each test (per panel) for each species were treated as a subset of an infinite population to obtain an estimate of the mean test value and an estimate of the reliability of that mean by generating a 95% confidence interval.

The estimate of the mean (μ) was taken to be the grand mean ($\bar{y}$) plus a confidence interval, $\pm ts_P$; where t is the value obtained from t-distribution tables (eg for 6 panels and a 95% confidence interval, t = 2.571) and s_P is an estimate of the standard error (subscript 'p' is for panel). The estimate of standard error was obtained from the ANOVA table using the 'between-panel mean squares' – (MSB) and calculating s_P using the following equation:

$$s_P = \sqrt{MSB/mn}$$

where m = the number of panels and n = the number of test coupons per panel.

6.6.3 Species selection

The same suite of species that were selected for initial screening for their suitability for pulp and paper were also tested for their suitability for panel board manufacture (Table 2). In both cases, species with relatively low wood density were sought. See Section 6.5.2 for more details. The earlier stages of species selection are described in Section 5, while details of the wood coring program are presented in Section 6.3.

6.6.4 Methods and results – preliminary tests

6.6.4.1 Introduction

Some of the preliminary tests used for selecting panel board species were also used to select pulp and paper species. Other preliminary tests specific for panel board assessment included pH, buffering capacity, and extractives content. These chemical assays were carried out on wood meals prepared from random samples of wood chips, air dried to approximately 5% moisture content and milled in a Wiley Mill through a 1 mm screen.

6.6.4.2 Buffering capacity and pH

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

Using a modified method described by Johns and Niazi (1980), buffering capacities and pH were determined for air-dried wood meals prepared from milled composite samples of wood chips. The wood meal (1 g) was steeped in 100 mL of distilled water until a steady pH was reached, at which point the suspension was titrated against 0.01 N NaOH or H_2SO_4 until a pH of 7 or 3 was reach respectively. Titrating with the base to pH 7 yields the Acid Buffering Capacity (ABC in mmol/g) and titrating with the acid to pH 3 gives the Base Buffering Capacity (BBC in mmol/g). The Wood Buffering Capacity (WBC) is the sum of the two buffering capacities. The initial pH of the suspended wood meal prior to titration was taken to represent the pH of the wood.

Results are presented numerically (Table 10) and graphically (Figure 13 and Figure 14). All of the species had pH values within an approximate range of 4.5 and 6, and less than one third of the species tested had pH values that were significantly different (at the 5% level) from at least one of the control species. Buffering capacities appeared to be more variable, but due to the large error bars(pooled 95% confidence interval), almost no species differed significantly from at least one of the control species.

6.6.4.3 Hot Water Soluble Extractives

Hot water soluble extractives include tannins, sugars and free acids. High levels of extractives in the wood represent a reduction of fibre available for processing, and may have positive or negative effects on resin curing and wood bonding.

The analysis method used in this test was based on the Australian standard: Solubility of wood in boiling water, AS/NZS 1301.004s:1998 (Standards Australia 1998a). Briefly, wood meal was boiled for one hour under reflux conditions with the weight difference before and after boiling being the water soluble content.

Results are presented in Table 10 and Figure 15. Extractive content varied considerably, and all species tested had higher extractive contents than the two control species.

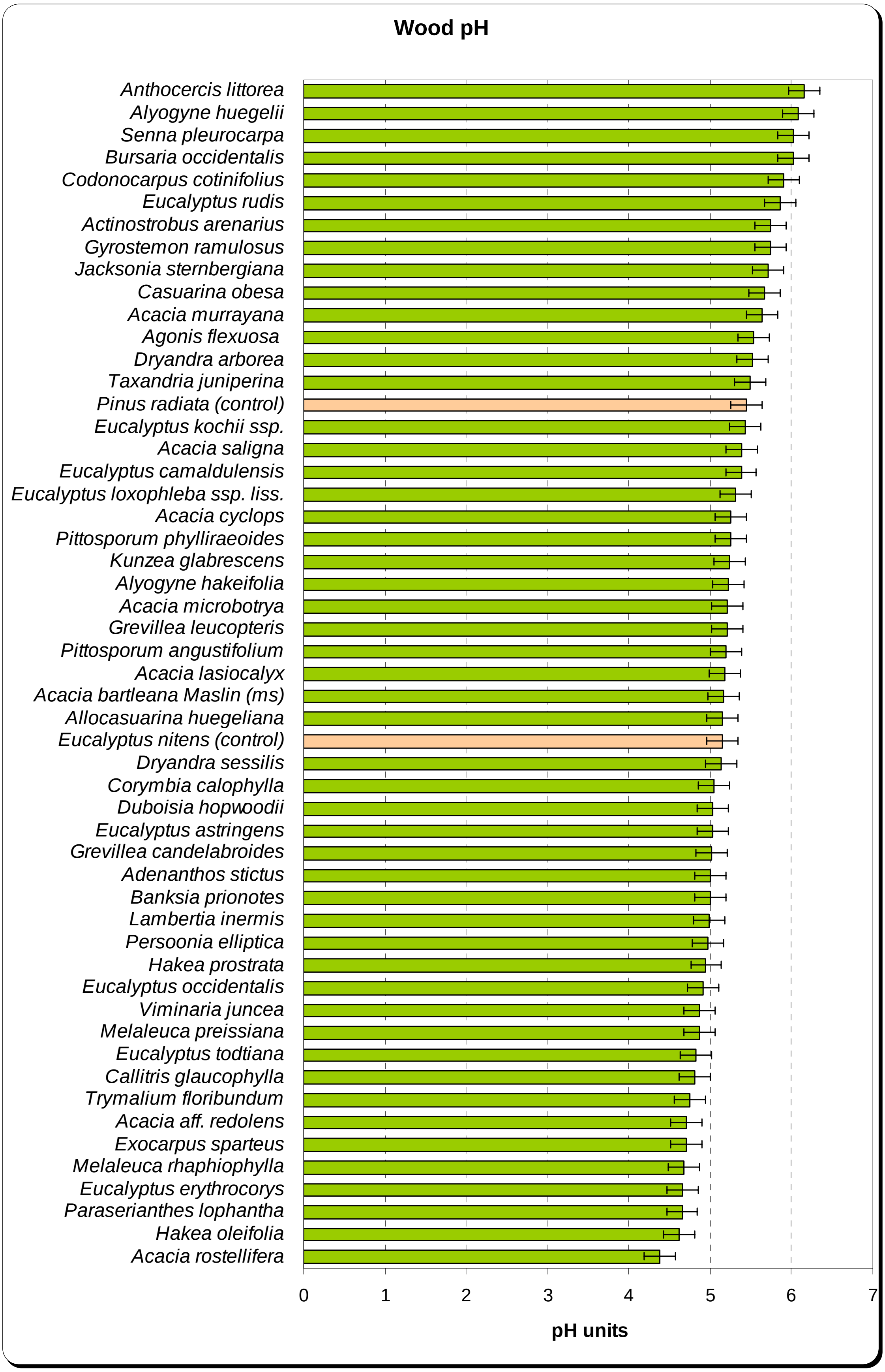


Figure 13. pH values for wood samples (with pooled 95% confidence intervals).

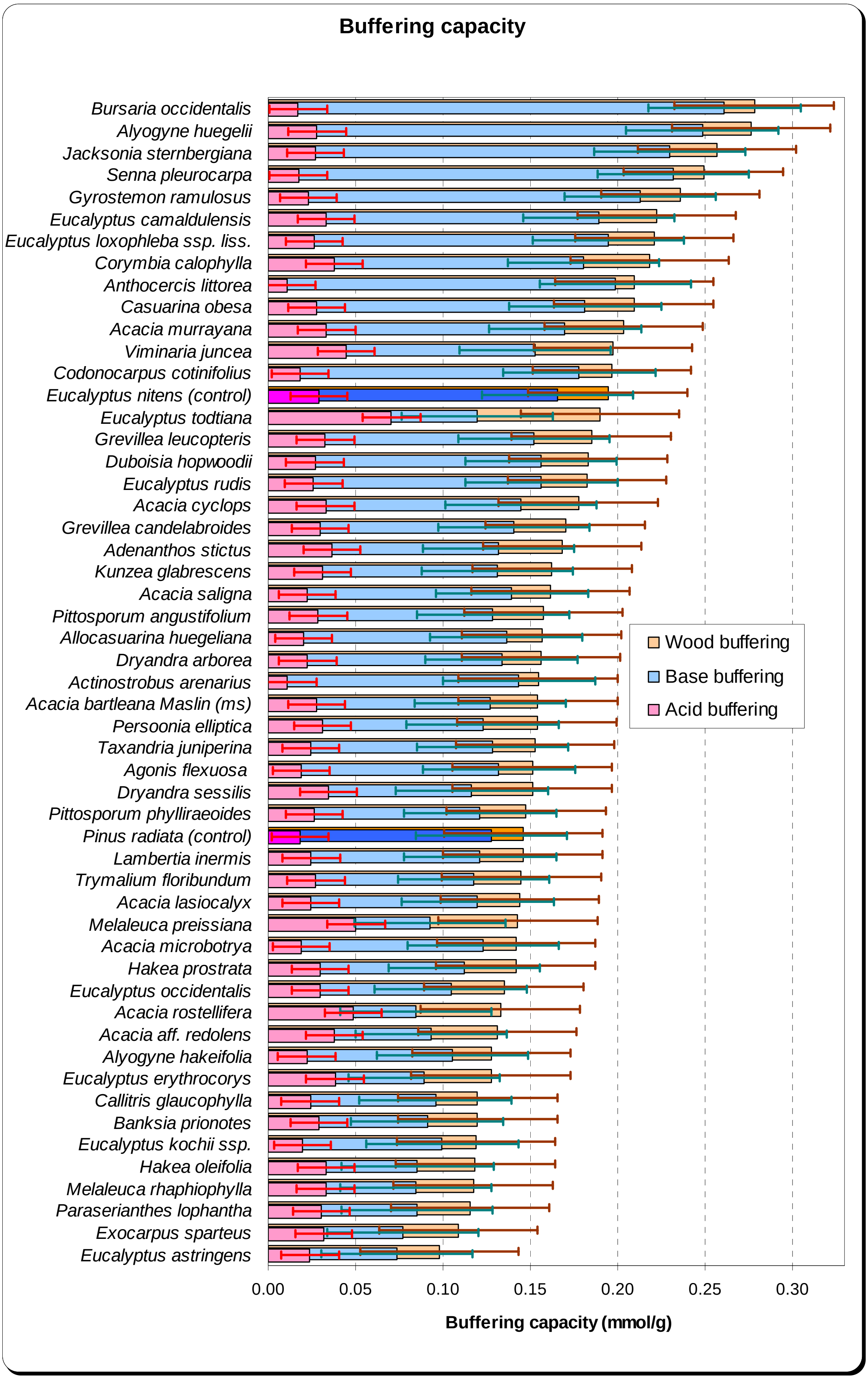


Figure 14. Buffering capacity of wood samples, including acid buffering capacity, base buffering capacity and 'wood' (or, total) buffering capacity.

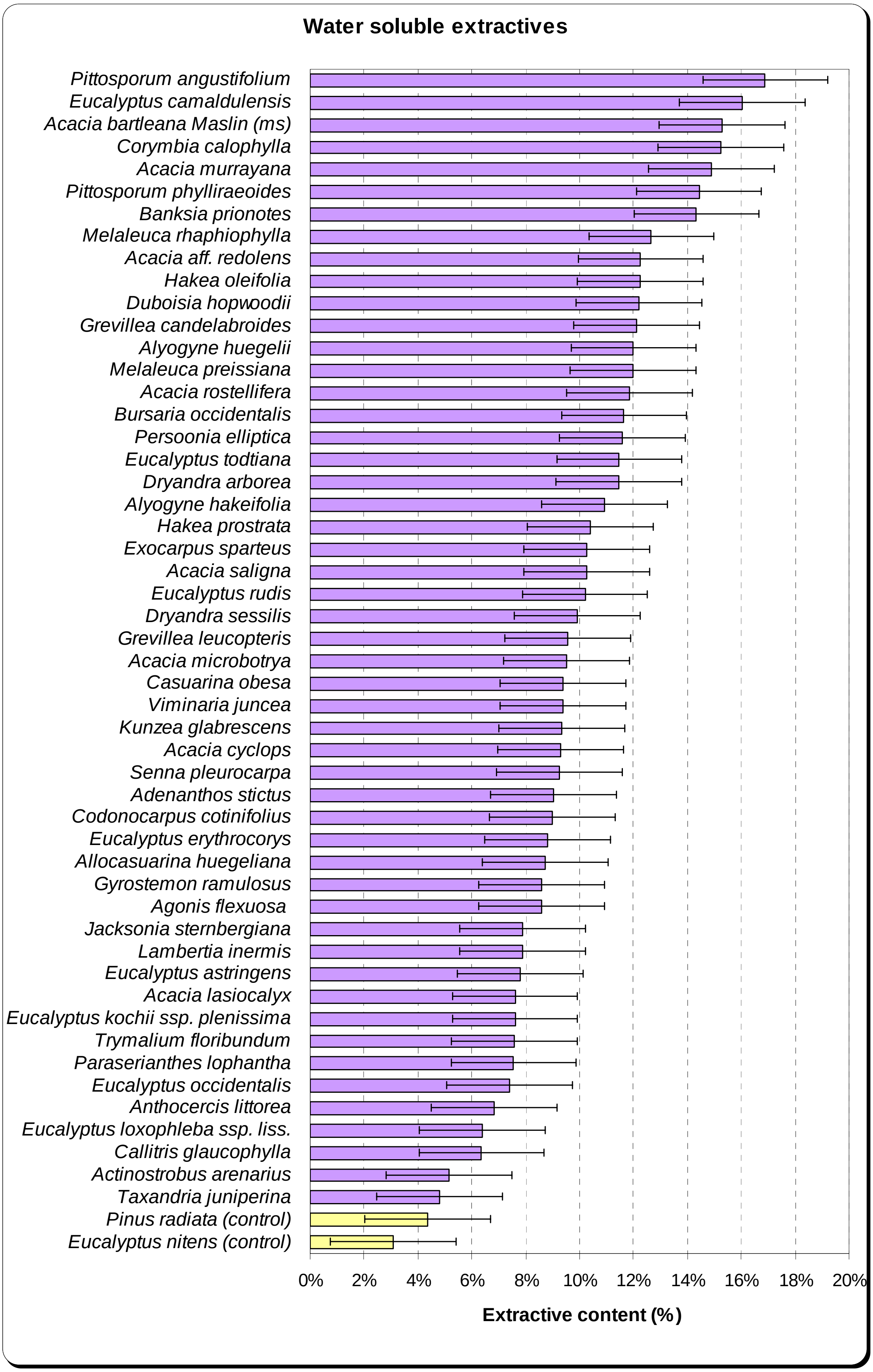


Figure 15. Water soluble extractives from selected Western Australian species (with pooled 95% confidence limits).

Table 10. Alphabetical list of species with their pH, buffering capacities and extractive contents (hot water soluble).

Species	pH	ABC mmol/g	BBC mmol/g	WBC mmol/g	Water soluble extracts
Acacia aff. redolens	4.7	0.038	0.093	0.131	12.3
Acacia bartleana Maslin (ms)	5.2	0.028	0.127	0.154	15.3
Acacia cyclops	5.3	0.033	0.145	0.178	9.3
Acacia lasiocalyx	5.2	0.024	0.120	0.144	7.6
Acacia microbotrya	5.2	0.019	0.123	0.142	9.5
Acacia murrayana	5.6	0.033	0.170	0.203	14.9
Acacia rostellifera	4.4	0.049	0.085	0.133	11.8
Acacia saligna	5.4	0.022	0.140	0.162	10.3
Actinostrobus arenarius	5.7	0.011	0.144	0.155	5.1
Adenanthos stictus	5.0	0.036	0.132	0.168	9.0
Agonis flexuosa	5.5	0.019	0.132	0.151	8.6
Allocasuarina huegeliana	5.2	0.020	0.136	0.157	8.7
Alyogyne hakeifolia	5.2	0.022	0.106	0.128	10.9
Alyogyne huegelii	6.1	0.028	0.249	0.277	12.0
Anthocercis littorea	6.2	0.011	0.199	0.210	6.8
Banksia prionotes	5.0	0.029	0.091	0.120	14.3
Bursaria occidentalis	6.0	0.017	0.261	0.278	11.7
Callitris glaucophylla	4.8	0.024	0.096	0.120	6.4
Casuarina obesa	5.7	0.028	0.182	0.209	9.4
Codonocarpus cotinifolius	5.9	0.018	0.178	0.197	9.0
Corymbia calophylla	5.1	0.038	0.181	0.219	15.2
Dryandra arborea	5.5	0.023	0.134	0.156	11.4
Dryandra sessilis	5.1	0.035	0.117	0.151	9.9
Duboisia hopwoodii	5.0	0.027	0.156	0.183	12.3
Eucalyptus astringens	5.0	0.024	0.074	0.098	7.8
Eucalyptus camaldulensis	5.4	0.033	0.189	0.222	16.0
Eucalyptus erythrocorys	4.7	0.038	0.089	0.128	8.8
Eucalyptus kochii ssp. plenissima	5.4	0.020	0.100	0.119	7.6
Eucalyptus loxophleba ssp. *lissophloia*	5.3	0.026	0.195	0.221	6.4
Eucalyptus nitens (control)	5.1	0.029	0.166	0.195	3.1
Eucalyptus nitens (control)	5.2	0.030	0.112	0.142	5.0
Eucalyptus occidentalis	4.9	0.030	0.105	0.134	7.4
Eucalyptus rudis	5.9	0.026	0.156	0.182	10.2
Eucalyptus todtiana	4.8	0.071	0.120	0.190	11.5
Exocarpus sparteus	4.7	0.032	0.077	0.109	10.3
Grevillea candelabroides	5.0	0.030	0.141	0.170	12.1
Grevillea leucopteris	5.2	0.033	0.152	0.185	9.5
Gyrostemon ramulosus	5.7	0.023	0.213	0.236	8.6
Hakea oleifolia	4.6	0.033	0.085	0.119	12.3
Hakea prostrata	5.0	0.030	0.112	0.142	10.4
Jacksonia sternbergiana	5.7	0.027	0.230	0.257	7.9
Kunzea glabrescens	5.2	0.031	0.131	0.163	9.4
Lambertia inermis	5.0	0.025	0.121	0.146	7.9
Melaleuca preissiana	4.9	0.050	0.093	0.143	12.0
Melaleuca rhaphiophylla	4.7	0.033	0.085	0.118	12.7
Paraserianthes lophantha	4.7	0.030	0.085	0.116	7.6
Persoonia elliptica	5.0	0.031	0.123	0.154	11.6
Pinus radiata (control)	5.7	0.018	0.175	0.193	6.2

Species	pH	ABC mmol/g	BBC mmol/g	WBC mmol/g	Water soluble extracts
Pinus radiata (control)	5.4	0.018	0.128	0.146	4.4
Pittosporum angustifolium	5.2	0.029	0.129	0.158	16.9
Pittosporum phylliraeoides	5.3	0.026	0.121	0.148	14.4
Senna pleurocarpa	6.0	0.017	0.232	0.249	9.3
Taxandria juniperina	5.5	0.024	0.128	0.153	4.8
Trymalium floribundum	4.8	0.027	0.118	0.145	7.6
Viminaria juncea	4.9	0.045	0.153	0.198	9.4

ABC= Acid Buffering Capacity
BBC= Base Buffering Capacity
WBC= Wood Buffering Capacity

6.6.5 Methods and results - MDF

6.6.5.1 Species selection

Nineteen species were selected for further evaluation for MDF suitability, based on their wood density, colour and the results of the preliminary tests described above. For each of these species, laboratory-scale panels were made and subjected to a range of tests.

The species selected for MDF panel manufacture are listed in Table 11. Note that *Pinus radiata* was included in the trial as an 'industry standard' control.

6.6.5.2 MDF panel manufacturing method

A pilot scale Sunds Defibrator CD300 was used to refine the wood chip material into MDF fibre furnish. The unit is a single disc refiner driven by a 105 kW motor running at 3000 rpm. It consists of a PREX screw-feeder, which compresses the feed material (to aid fibre separation) and moves the feed material on a continuous basis into a higher pressure environment. The compression ratio is 1:4. After compression, the material is introduced into the lower part of the impregnation vessel housed within the preheater. Twin screws lift the macerated feed material to the top of the impregnation vessel and into the preheater. The refiner has both disc (300 mm diameter) and conical (100 mm diameter) elements for refining which can be independently adjusted for gap width. The plate pattern used was R3847 (stator and rotor). A schematic of the refiner is shown in Figure 16.

After exiting the refiner housing the fibres are mixed with a predetermined weight of resin[2] and forced into the 'blow-line dryer' which reduces the moisture content of the fibres to approximately 10% (by wt). A wax emulsion[3] is applied to the fibre furnish in a separate operation whereby the water emulsified wax is injected at the front of the refiner housing as the softened wood chips are fed into the refiner disks. In this series of trials, 12% resin and 0.6% wax were used (solids on OD wt. of fibre).

[2] Urea-Formaldehyde, Cascoresin MBP 1285 from Borden Chemical Australia Pty Ltd

[3] Technimul and Vivashield 9363 from BP Global Special Products (Aust.) Pty Ltd

Resinated fibre was then pre-pressed (cold pressing to reduce fibre mattress height to fit into the heated platen press) and hot pressed to a target of 13 mm thickness on panel areas of 90×90 cm for a target panel density of 750 kg/m^3. The pressing schedule, using position control, consisted of a temperature of 160°C for a total time of 210 seconds. Once cooled, each panel was trimmed (~100 mm all around) and a 50 mm wide strip was taken from the middle of the panel for the entire length. A 50 x 50 mm sample was removed from the middle of the strip and a density profile was generated, to assist in quality control and determining sanding thickness. Approximately 0.5-0.7 mm thickness of material was sanded from each face using a 600 mm wide belt sander.

Some photographs illustrating the production and testing of test MDF panels are displayed in Figure 17.

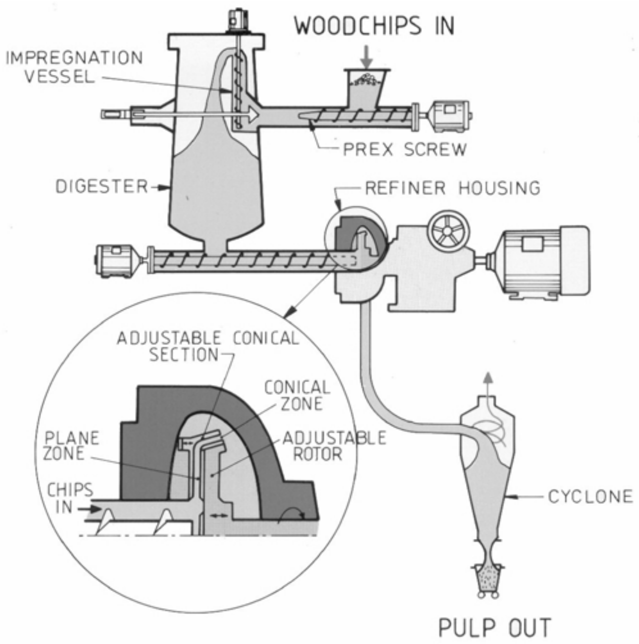


Figure 16: Schematic of high pressure refiner used for the production of MDF furnish.

6.6.5.3 Testing MDF panels

The mechanical and physical properties of medium density fibreboard (MDF) panels were tested in accordance with the following standards:

- AS/NZS 4266: Method 5 – Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) in bending (Standards Australia 2001a). Five test coupons per panel.
- AS/NZS 4266: Method 6 – Internal bond strength (IBS) (Standards Australia 2001b). Six test coupons per panel.
- AS/NZS 4266: Method 7 – Thickness swell (TS) (Standards Australia 2001c). 24 hours in water at 20°C. Six test coupons per panel.

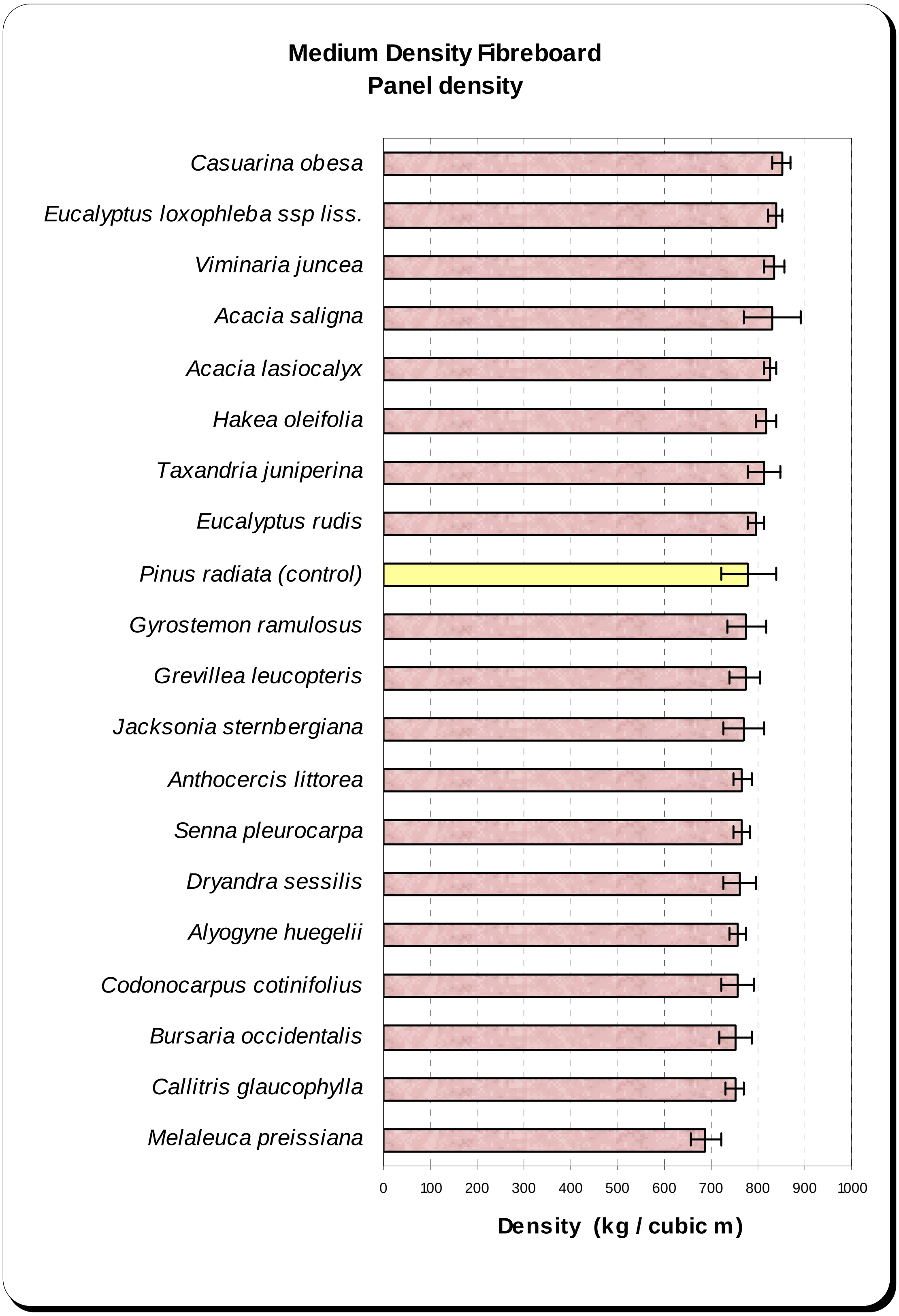
A summary of results is contained in Table 11 and the following figures (Figure 18 to Figure 22). The data are based on replicate panels prepared from each species. Attempts to produce six replicate panels for each species were not always successful due to the time needed to stabilise the pilot plant for successful panel production, and the limited amount of material provided for testing.

Figure 17. MDF manufacture and testing, CSIRO Forestry and Forest Products.
Top row: Wood chip feedstock; high pressure refiner.
Second row: Refiner disk; Refined, resinated and dried fibres.
Third row: Pre-press; Hot press.
Bottom row: Test panels 900 x 900; Test blocks.

Table 11. Summary of MDF properties.

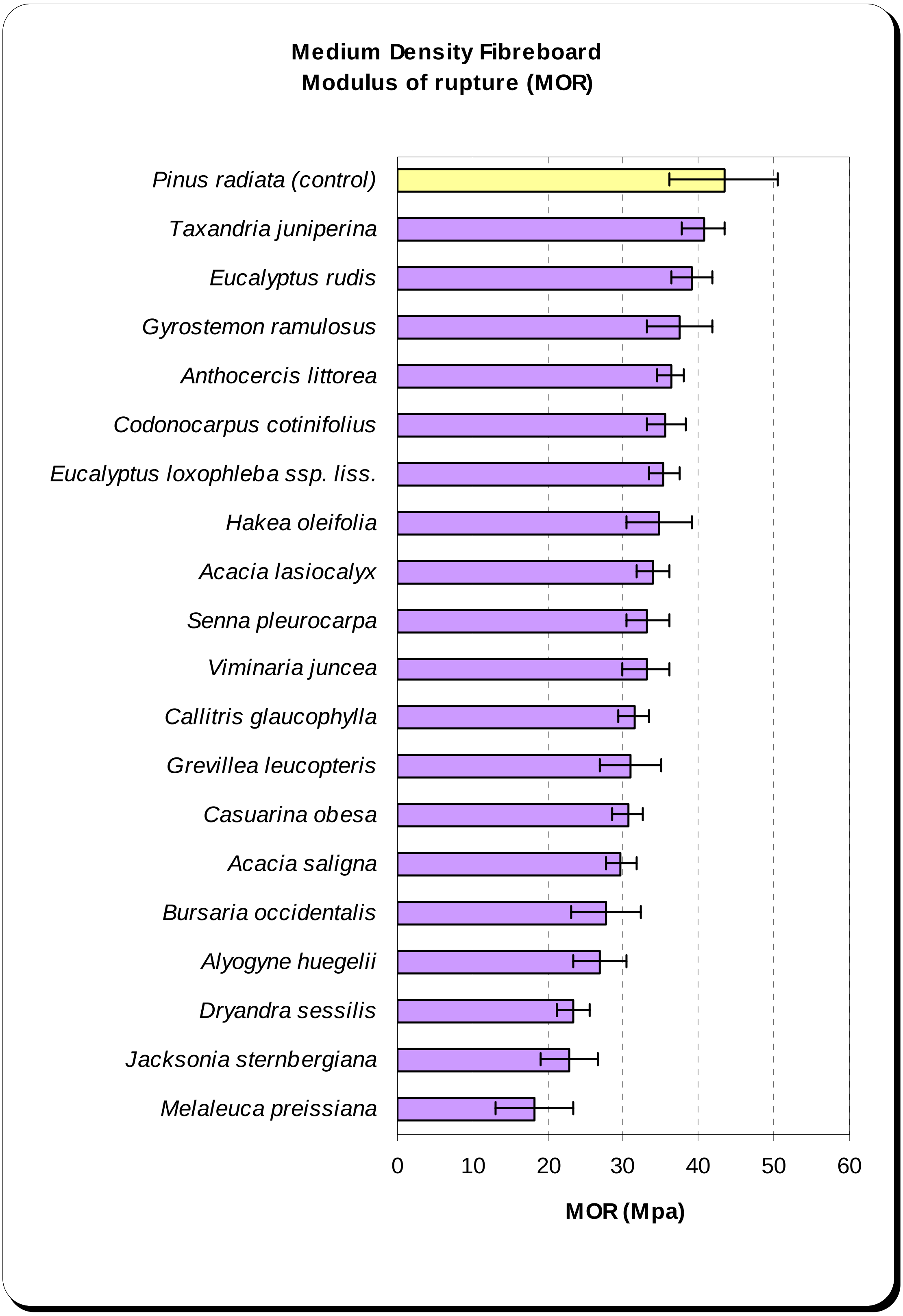
Species	Number of panels	Whole Panel Density (kg/m^3)	Flexural Strength - MOR (MPa)	Flexural Modulus - MOE (MPa)	Internal Bond Strength (kPa)	Thickness Swell (%)
Acacia lasiocalyx	6	827 (12)	34.03 (2.24)	3396 (181)	1340 (176)	10.1 (1.3)
Acacia saligna	5	830 (62)	29.66 (2.07)	3298 (190)	953 (121)	13.7 (2.2)
Alyogyne huegelii	4	756 (18)	26.94 (3.47)	3218 (355)	989 (236)	17.9 (2.4)
Anthocercis littorea	6	766 (19)	36.30 (1.82)	3429 (147)	1582 (83)	11.0 (2.6)
Bursaria occidentalis	6	752 (34)	27.75 (4.55)	2804 (345)	1523 (191)	9.0 (0.6)
Callitris glaucophylla	6	751 (20)	31.36 (2.00)	3135 (184)	1124 (170)	6.5 (0.4)
Casuarina obesa	6	850 (21)	30.64 (2.09)	3513 (195)	1563 (124)	21.3 (2.5)
Codonocarpus cotinifolius	6	756 (34)	35.63 (2.63)	3017 (156)	1608 (179)	11.4 (1.7)
Dryandra sessilis	6	762 (34)	23.32 (2.13)	2564 (182)	997 (91)	14.5-23.4
Eucalyptus loxophleba ssp *lissophloia*	6	837 (14)	35.42 (2.09)	3167 (163)	2040 (222)	11.1 (1.7)
Eucalyptus rudis	6	795 (16)	39.06 (2.78)	3750 (242)	1758 (204)	8.6 (0.5)
Grevillea leucopteris	5	772 (34)	30.91 (4.09)	3171 (409)	547-1133	10.3 (0.9)
Gyrostemon ramulosus	6	775 (41)	37.35 (4.28)	3337 (298)	1938 (222)	8.0 (2.2)
Hakea oleifolia	6	817 (20)	34.80 (4.35)	3422 (330)	2124 (235)	11.0 (1.7)
Jacksonia sternbergiana	6	770 (43)	22.76 (3.89)	3262 (339)	1093 (211)	11.2 (3.1)
Melaleuca preissiana	3	689 (32)	18.24 (5.05)	2072 (453)	746 (312)	7.0 (0.6)
Pinus radiata	6	780 (59)	43.40 (7.16)	3525 (481)	1334 (150)	7.6 (0.3)
Senna pleurocarpa	6	765 (18)	33.23 (2.80)	3295 (206)	1188 (54)	19.7 (0.6)
Taxandria juniperina	6	813 (35)	40.64 (2.91)	3659 (252)	2022 (239)	7.7 (0.7)
Viminaria juncea	5	835 (22)	33.03 (3.06)	2894 (185)	1946 (153)	9.7-25.6

Note: Figures in brackets are 95% confidence intervals, e.g. 827 +/- 12 for *Acacia lasiocalyx* whole panel density.
Result of IBS for *Grevillea leucopteris* is given as a range of two distinct groups of 3 and 2 panels. Results of thickness swell for *Viminaria juncea* and *Dryandra sessilis* are given as ranges of grand means.



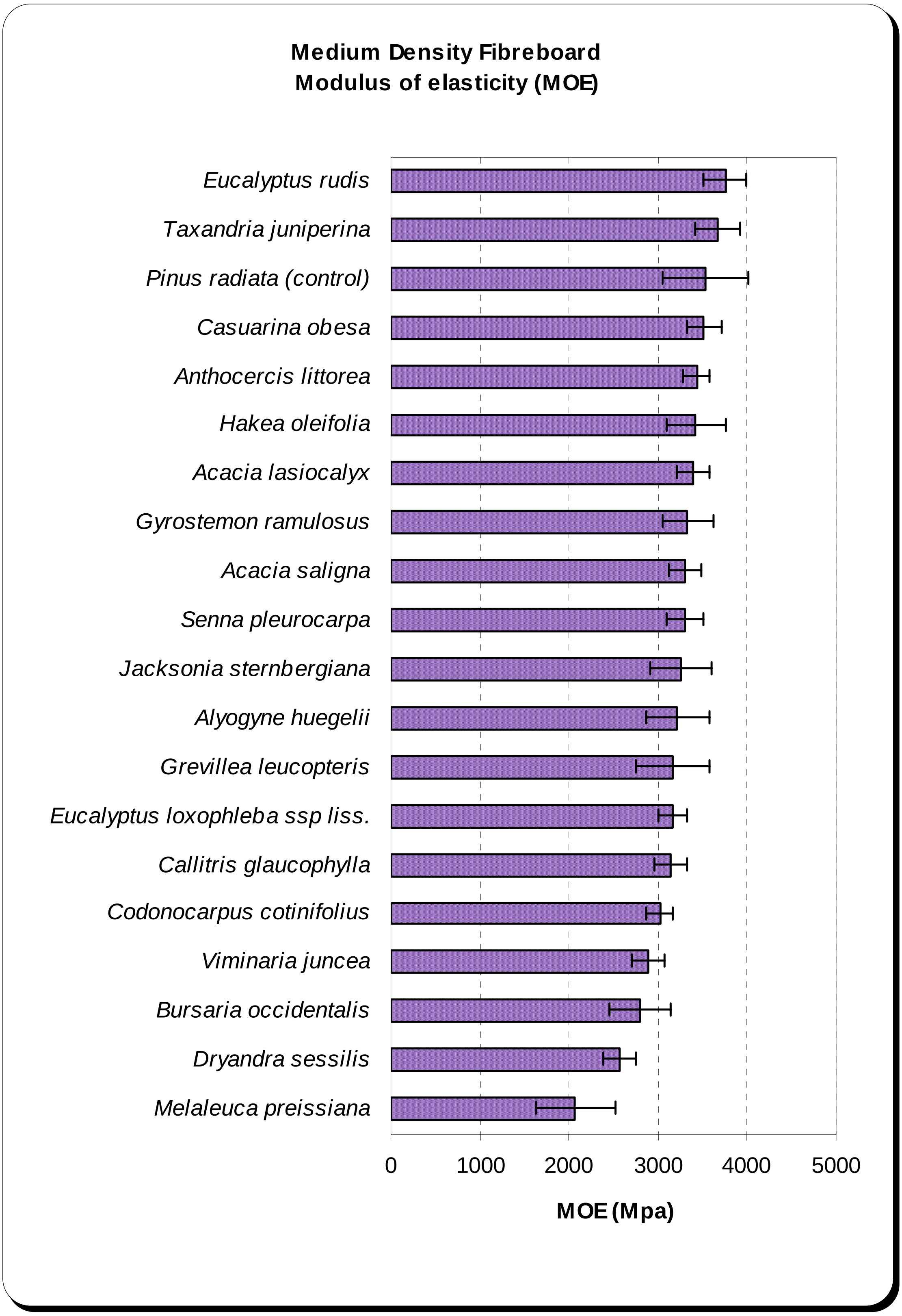
Note: Error bars show 95% confidence intervals.

Figure 18. MDF panel density for tested species.



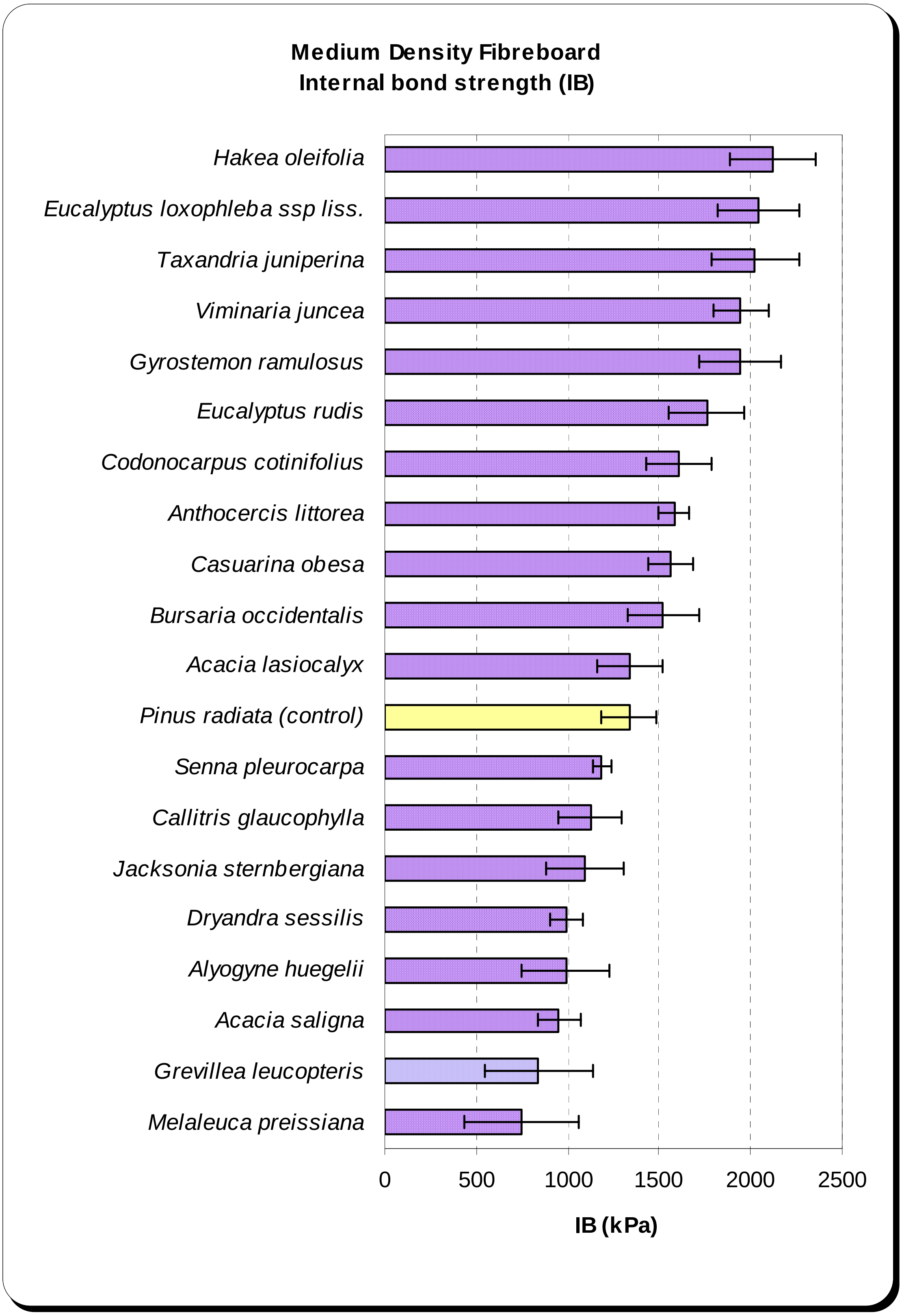
Note: Error bars show 95% confidence intervals.

Figure 19: MDF modulus of rupture (MOR) from three point flexural testing.



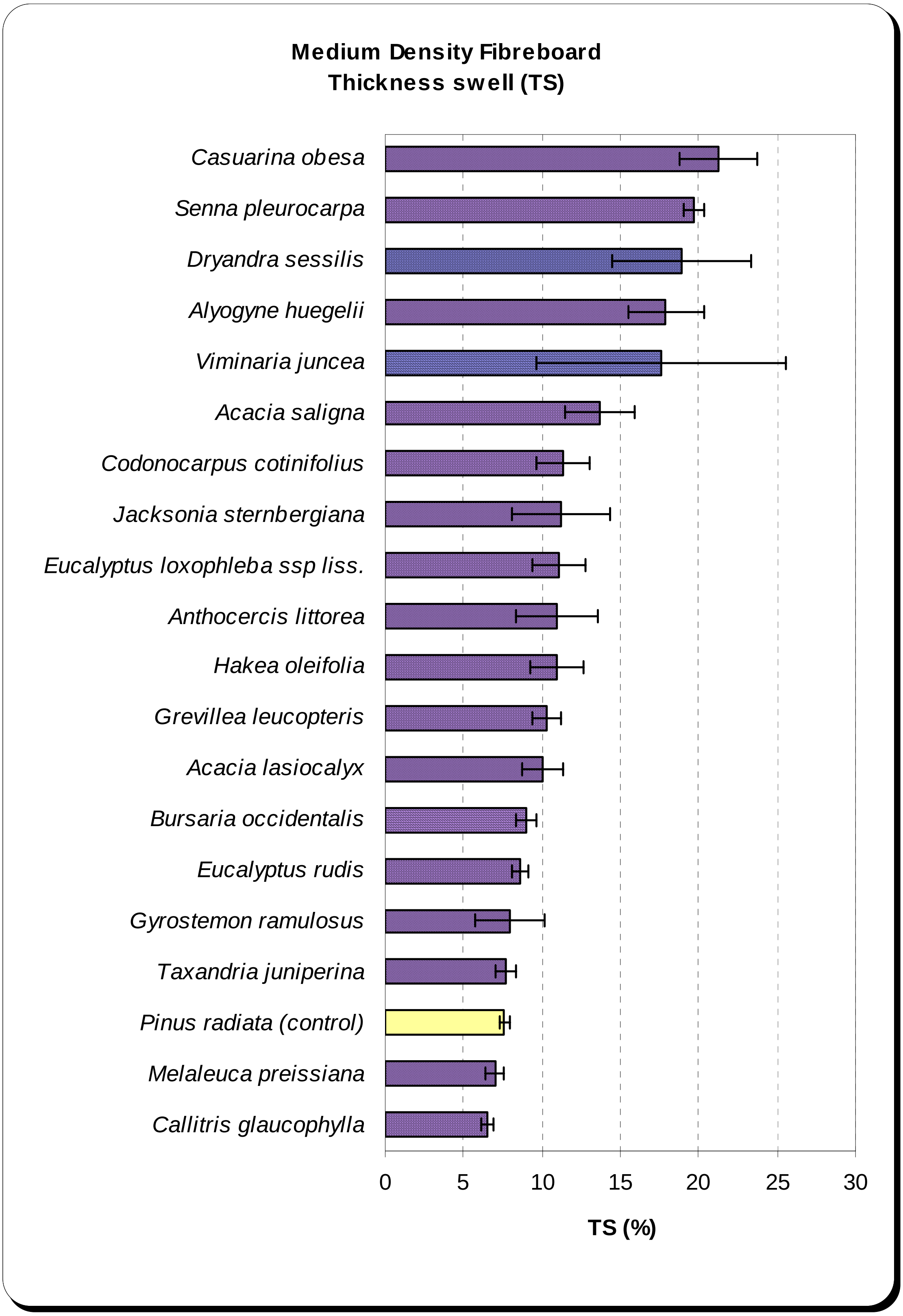
Note: Error bars show 95% confidence intervals.

Figure 20: MDF modulus of elasticity from three point flexural testing.



Note: Error bars show 95% confidence intervals. For *Grevillea leucopteris*, the result is given as a range of two distinct groups of 3 and 2 panels – the value is a grand mean (840 kPa) and the error bars (±293 kPa) show the range.

Figure 21: MDF internal bond strength.



Note: Error bars show 95% confidence intervals. For *Viminaria juncea* and *Dryandra sessilis*, values are mid points of grand means. Ranges have been substituted for error bars *V. juncea* – 17.5 ±7.95 and *D. sessilis* – 19.0 ±4.5

Figure 22: MDF thickness swell.

6.6.6 Discussion - MDF

The wood of many of the species tested was successfully converted to MDF panels with acceptable mechanical and physical properties. Although the target panel density was 750 kg/m^3 this work program generated a considerable spread of whole-panel densities (Table 11). Due to the limited body of work able to be carried out with respect to process variables, this work is very much a screening process. Nonetheless, the flexural properties of many species compared well with those of the pine control. Strength and stiffness dropped away for hardwood species when the panel density fell below 750 kg/m^3. This would be expected for MDF prepared from hardwood species having relatively high basic density.

It should be noted that high pressure refining of hardwoods produces a high ‘fines’ content in the fibrous mass. High fines content would have an effect on compaction and resin distribution leading to high internal bond strengths. Eight species were between 1500 and 2000 kPa whereas 1000 kPa would be considered more typical for a commercial panel. The poorest performing species, *Melaleuca preissiana* also possessed the lowest panel density, which suggests that this species could warrant re-investigation.

Thickness swell after 24 hour water immersion was acceptable for all species tested, for this ‘standard’ grade of MDF panel. Although a thickness swell of ~20% represents an upper limit for commercial acceptability, the majority of species were at ~10%. In Figure 22, two distinct groupings within species were found (notwithstanding the spread of data for *Dryandra sessilis* and *Viminaria juncea*). Species above *Acacia saligna* had relatively high thickness swells compared to those below this level.

The results show that at the pilot scale, a wide variety of native woody species can be successfully processed by high-pressure refining and converted to a panel product. Further consideration could be made to blending these hardwood species (*Callitris* was the only native softwood studied) with *Pinus radiata* during production.

The species under study here did not greatly outperform the benchmark *Pinus radiata* species in mechanical or physical performance. Pine panels were at or near the top of flexural strength and stiffness, possessed low thickness swell and were in the mid-range of the internal bond strengths. This would suggest more work is needed to optimise the preparation of panels using hardwood species, especially the high pressure refining operation and the need to reduce fines. Further studies to benchmark against (high rainfall) plantation hardwoods would also be useful to better estimate the potential of the species studied here.

6.6.7 Method and results - particleboard

6.6.7.1 Species selection

Twenty species were selected for further evaluation of their suitability as raw materials for particleboard manufacture, based on their wood density, colour and the results of the preliminary tests described above. For each species, laboratory-scale panels were made and subjected to a range of tests.

The species selected for particleboard panel manufacture are listed in Table 12. *Pinus radiata* was included as an 'industry standard' control.

6.6.7.2 Particleboard panel manufacturing method

Wood chips were dried overnight at ~105°C and passed through a Bauer refiner fitted with 'breaker' plates. This reduced their size sufficiently to be used as 'core' material, as well as allowing the furnish to be screened through 12 mm mesh to supply material for the 'faces' of the particleboard, that is, a three layered board with 50% of the weight being core and each face having 25% of the total weight. Some species required further milling to produce sufficient face material. This was done by passing processed chips through a Wiley Mill fitted with a 6.3 mm screen.

Sufficient particleboard furnish for three panels (core and face being treated separately) was sprayed with resin/wax/water suspension, with the woody furnish tumbled in a rotating drum. Resin was applied at 10% (on wt. of wood) and wax at 0.6% (on wt. of wood) for a panel target density of 700 kg/m^3. Resinated particles were hand-laid in a 45x45 cm forming box and transferred to the hot press sandwiched between 2.5 mm aluminium caul plates and Teflon release film (0.2 mm thick). Hot pressing was carried out at 160°C for 210 seconds.

After cooling, panels were trimmed to 32x32 cm and sanded, removing ~0.5-0.7 mm thickness of material from each face.

Photographs of some test particleboard panels are shown in Figure 23.

6.6.7.3 Testing particleboard panels

The mechanical and physical properties of particleboard panels prepared from selected species are presented over the following pages. The data are based on replicate panels prepared from each of the species listed in Table 12. An attempt to produce six replicate panels was not always successful due to material and processing constraints.

Particleboard panels were tested for the following mechanical and physical properties:

- AS/NZS 4266: Method 5 – Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) in bending (Standards Australia 2001a). Three test coupons per panel.
- AS/NZS 4266: Method 6 – Internal bond strength (IB) (Standards Australia 2001b). Six test coupons per panel.

- AS/NZS 4266: Method 7 – Thickness swell (TS) (Standards Australia 2001c). 1 hour in water at 20°C. Six test coupons per panel.

Figure 23. Particleboard manufacture and testing at CSIRO Forestry and Forest Products.
Top row: 32 cm square panels after manufacture; Panels of *Callitris glaucophylla* showing poor conformation (packing) of particles within board.
Bottom row: Test panels of *Gyrostemon ramulosus* (left) and *Codonocarpus cotinifolius* (right) showing good conformation of wood particles within the board.

6.6.7.4 Results of particleboard testing

Results for each type of test are presented numerically (Table 12) and graphically (Figure 24 to Figure 28).

Table 12. Summary of particleboard properties.

Species	Panel No.	Whole Panel Density (kg/m^3)	Flexural Strength MOR (MPa)	Flexural Modulus MOE (MPa)	Internal Bond Strength (kPa)	Thickness Swell (%)
Acacia lasiocalyx	6	711 (23)	9.93 (1.98)	2119 (354)	147 (73)	4.5 (0.9)
Acacia saligna	6	714 (33)	17.71 (1.66)	2825 (293)	619 (170)	4.8 (0.8)
Alyogyne huegelii	5	687 (7)	11.85 (1.59)	2268 (205)	461 (59)	8.6 (0.5)
Anthocercis littorea	5	690 (39)	14.59 (2.03)	2415 (254)	607 (198)	7.6 (0.6)
Bursaria occidentalis	6	710 (9)	10.25 (0.77)	2166 (37)	235 (40)	4.3 (0.6)
Callitris glaucophylla	6	741 (8)	9.25 (1.36)	2306 (99)	527 (96)	5.6 (0.5)
Casuarina obesa	6	739 (31)	13.35 (2.77)	2460 (112)	354 (88)	6.3 (0.4)
Codonocarpus cotinifolius	6	680 (29)	15.18 (0.95)	2586 (105)	645 (203)	4.1 (0.7)
Dryandra sessilis	6	668 (20)	9.20 (1.76)	1813 (201)	227 (73)	6.6 (1.3)
Eucalyptus loxophleba ssp *lissophloia*	5	794 (38)	11.79 (2.04)	2209 (210)	902 (315)	6.3 (0.5)
Eucalyptus occidentalis	6	692 (44)	9.11 (1.63)	1846 (220)	552 (167)	5.2 (0.6)
Eucalyptus rudis	6	727 (31)	15.66 (0.48)	2680 (140)	668 (95)	6.3 (1.0)
Grevillea leucopteris	5	750 (28)	11.67 (1.96)	2368 (325)	408 (133)	4.5 (0.3)
Gyrostemon ramulosus	6	689 (30)	16.66 (1.90)	2460 (244)	1296 (170)	7.6 (0.7)
Hakea oleifolia	6	743 (50)	14.27 (2.83)	2216 (345)	1138 (307)	5.3 (0.7)
Jacksonia sternbergiana	3	696 (14)	6.79 (1.09)	1634 (460)	115 (67)	6.1 (1.5)
Melaleuca preissiana	6	744 (26)	13.55 (2.15)	1990 (226)	1642 (225)	6.2 (0.8)
Pinus radiata	6	733 (11)	16.89 (1.37)	2816 (332)	950 (35)	4.6 (0.3)
Senna pleurocarpa	5	737 (15)	16.32 (1.79)	2794 (211)	398 (91)	4.8 (0.2)
Taxandria juniperina	6	733 (15)	17.37 (1.69)	2806 (219)	884 (144)	5.0 (0.9)
Viminaria juncea	6	713 (14)	16.05 (0.82)	2314 (67)	720 (96)	4.2 (0.5)

Note: Figures in brackets are 95% confidence intervals, e.g. 711 +/- 23 for *Acacia lasiocalyx* whole panel density.
Eucalyptus rudis MOR and MOE and IBS based on 5 panels.

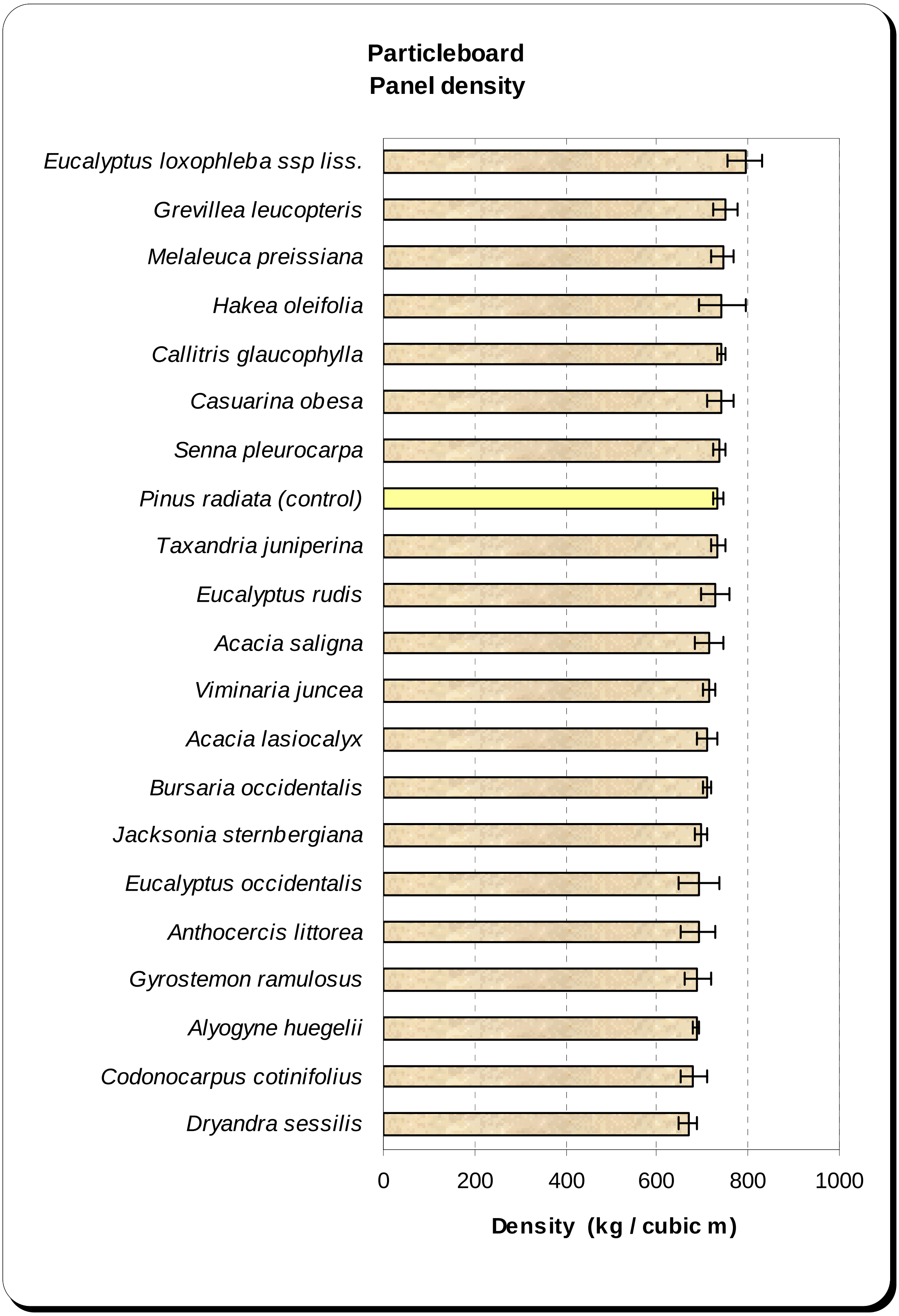
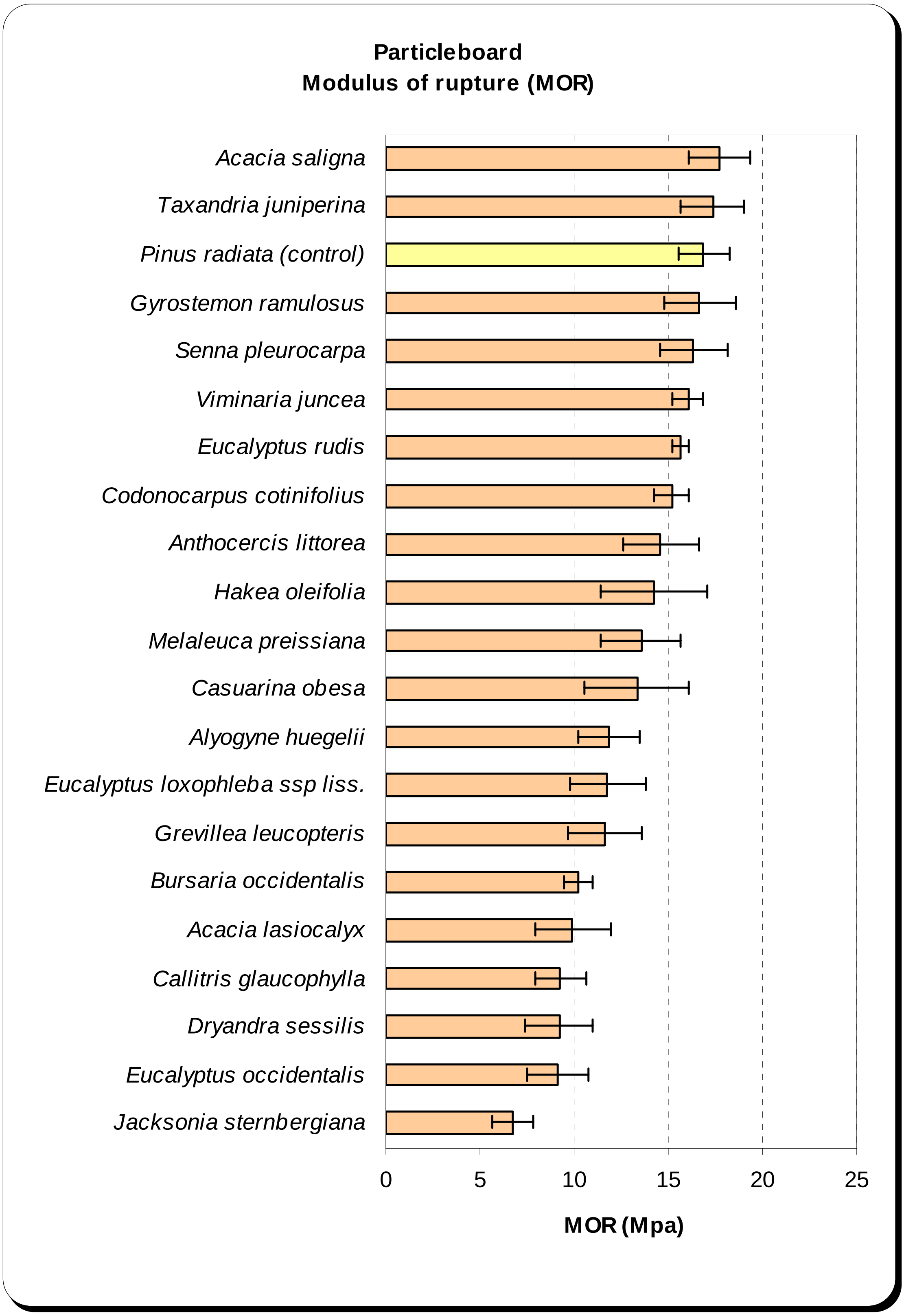
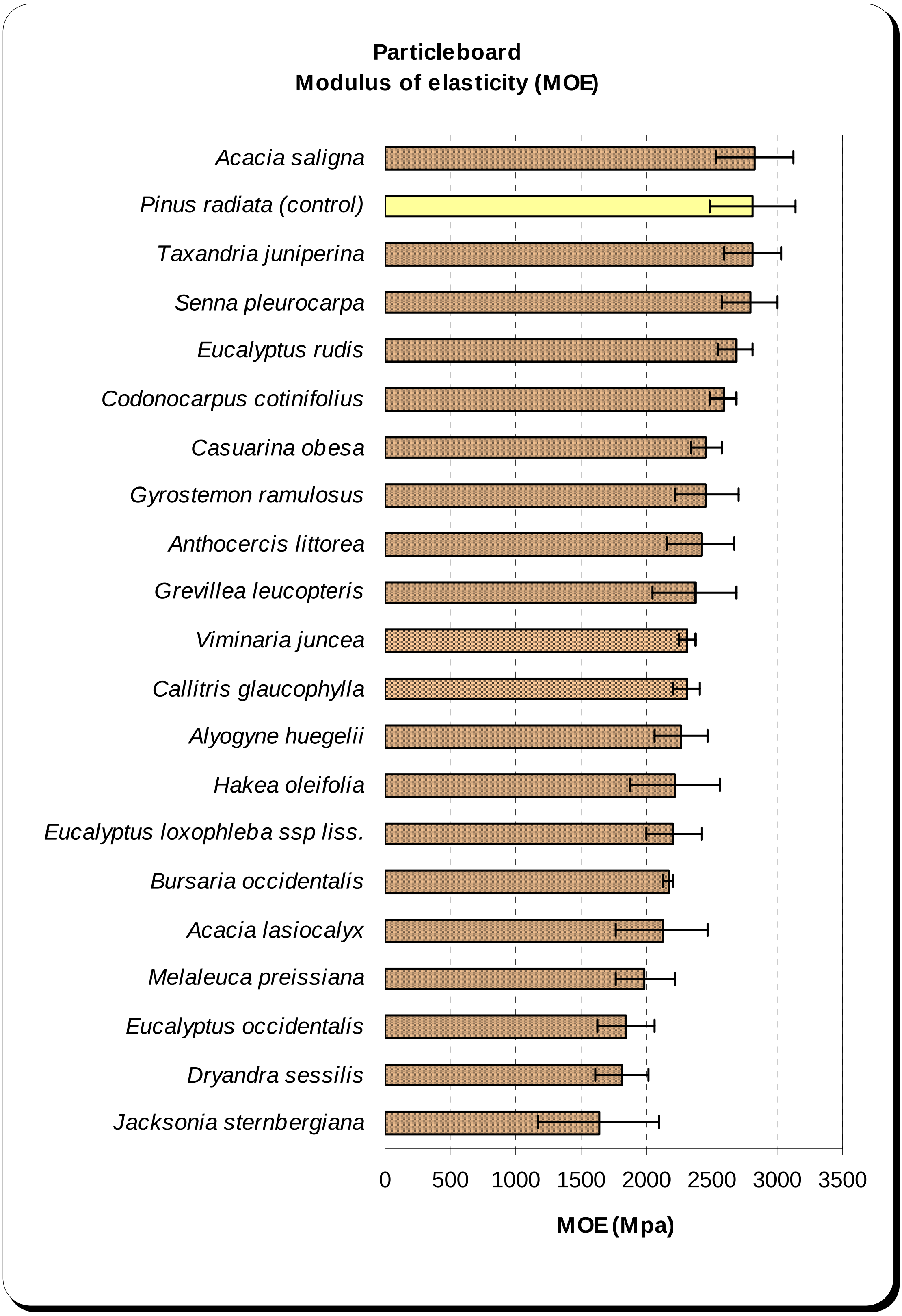


Figure 24. **Panel density of particleboard panels.**



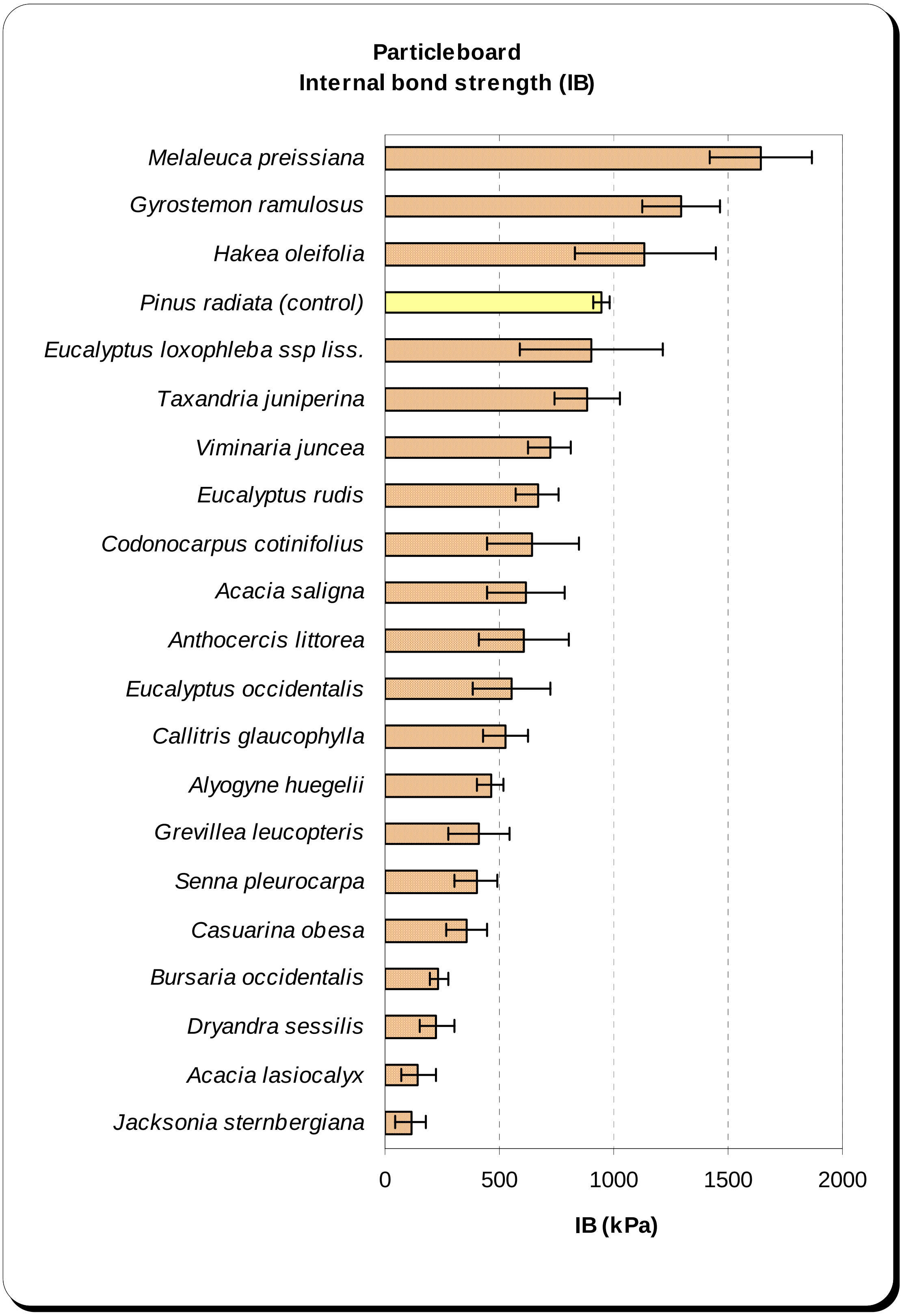
Note: Error bars show 95% confidence intervals. *Eucalyptus rudis* data is based on only 5 panels.

Figure 25: Particleboard modulus of rupture from three point flexural testing.



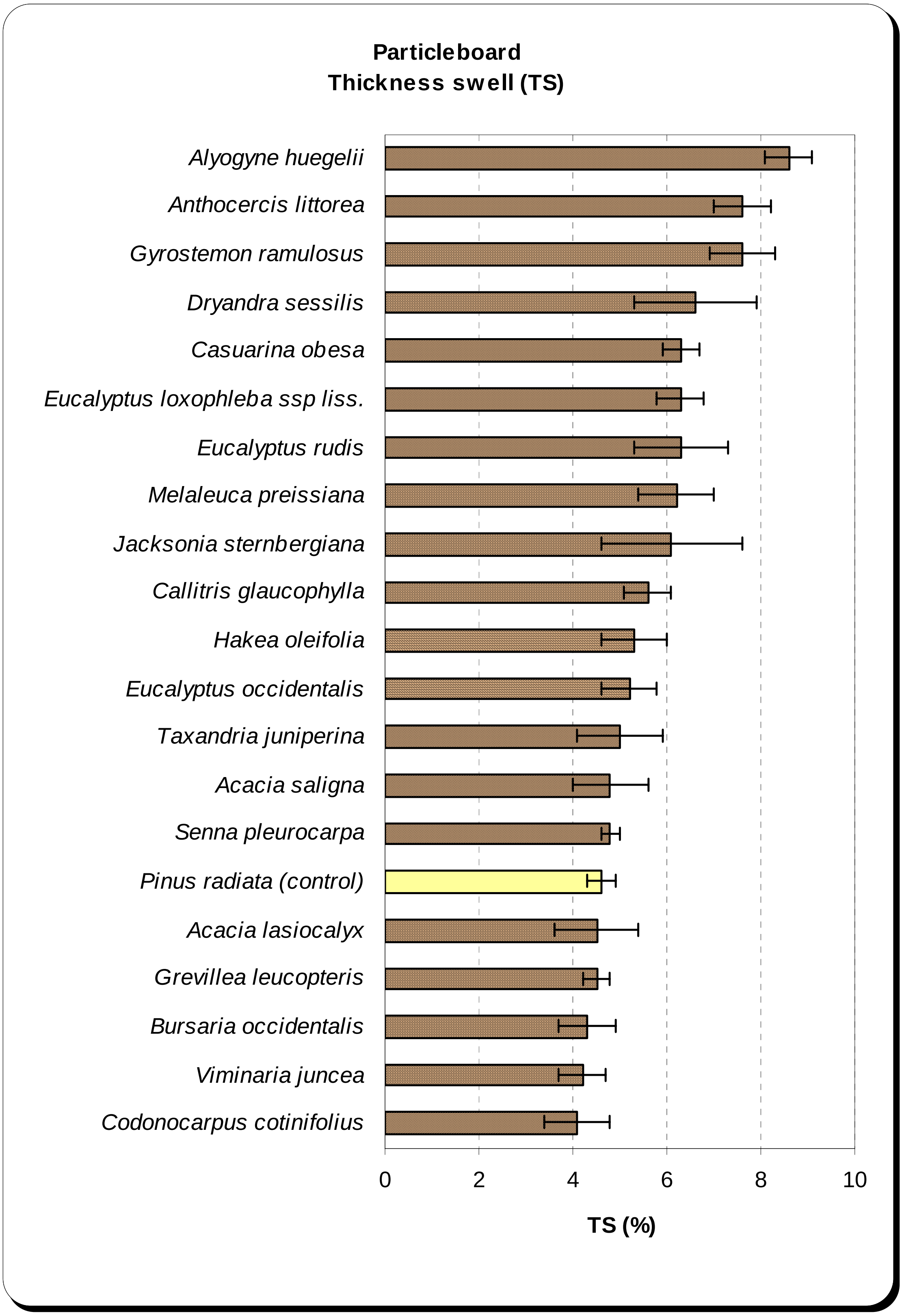
Note: Error bars show 95% confidence intervals. *Eucalyptus rudis* data is based on only 5 panels.

Figure 26: Particleboard modulus of elasticity from three point flexural testing.



Note: Error bars show 95% confidence intervals. *Eucalyptus rudis* result is based on only 5 panels.

Figure 27: Particleboard internal bond strength.



Note: Error bars show 95% confidence intervals.

Figure 28: Particleboard thickness swell.

6.6.8 Discussion - particleboard

Particleboard flexural properties for all species, including the pine control, were comparable to commercial panels for standard grade boards. Some drop-off in strength and stiffness was seen in some species (Figure 25 and Figure 26) however, they should not be dismissed without further re-assessment.

Internal bond strengths were acceptable for many species and comparable to that of the *Pinus radiata* control, although the lowest three species, with IBS of ~100-250 kPa, suggest a re-investigation would be warranted.

Thickness swells after 1 hour immersion time were well within the limits for standard grade panels and the results for all species, including the *Pinus radiata* control panels, differed by only about four percentage points.

In general terms the performance of the indigenous species compared well with that of the pine control. A few exceptions exist, with some panels not being fabricated to optimum density, hence having poor performance in flexure and internal bond strength.

An important consideration in the preparation of particleboard is the conformability of the woody material under heat and pressure during panel pressing. This is very evident in processing *Pinus radiata*. However, many of the species investigated produced panels of an ‘open’ core construction. Two exceptions to this were *Codonocarpus cotinifolius* and *Gyrostemon ramulosus,* where the material appeared to be better compacted.

Along with wood conformability the species would also need to be of an acceptable density, below approximately 500 kg/m^3. Heavy, and hence unwieldy panels would not be acceptable in the market place due to handling difficulties. At the time of writing, a small percentage of eucalypt wood is used as core material in some particleboards. This could offer some opportunity commercially if new wood species could be used on a part furnish basis in particleboard manufacture.

6.6.9 Conclusions – panel boards

Selected species for MDF and particleboard production were all successfully converted into panels with minor variations in panel quality. Detailed discussion is presented in Sections 0 (MDF) and 6.6.8 (particleboard).

The lower density species among those tested (*Taxandria juniperina, Eucalyptus rudis, Viminaria juncea, Anthocercis littorea, Gyrostemon ramulosus, Codonocarpus cotinifolius*) should be used for further trials to optimise MDF and particleboard production by investigating and optimising a range of production variables. In the case of MDF, optimising process variables to reduce the ‘fines’ content would have high priority.

Particleboard furnish was not optimised in this study. Future trials should include waferising or flaking of woodchips to produce more commercially relevant particle geometries. Furthermore, the conformability of wood particles was generally poor in the species tested here. Only two species appeared to have promising properties in this respect, *Codonocarpus cotinifolius* and *Gyrostemon ramulosus.*

To conclude, given the preliminary nature of this work, using one collection of wood from (mostly) native populations, it is perhaps surprising how well many species performed in these tests. There is considerable scope to improve the performance of the best of these species through genetic selection and plant breeding, development of appropriate growing techniques, and determination of the most appropriate harvesting age, while optimisation of processing variables to suit these materials is also likely to be fruitful.

6.7 Laboratory testing – sawn timber

6.7.1 Introduction

In this section of the project, the Western Australian Forest Products Commission (FPC) tested timber characteristics and assessed timber quality of twelve species native to southern Western Australia. All work was carried out the FPC’s Timber Technology Centre at Harvey, 140 km south of Perth. This report is based in part on two FPC reports covering this work (Appendix 05 and Appendix 06).

As discussed in Section 6.1.2.2 above, appearance grade timber was the target product for this part of the project

Based on growth rate and form, twelve species with reasonable potential for commercial timber production were selected (Table 13) and tested as follows:

- Log description, including defects
- Sawmilling performance (green sawn recovery)
- Wood properties (moisture content, basic density)
- Drying behaviour (shrinkage, warping, splitting, checking, cell collapse)
- Dressing and grading
- Hardness
- Timber panel manufacture and gluing behaviour
- Machining performance (drilling, routing, planing, sawing)
- Appearance (colour, figure, texture)

6.7.2 Species selection - sawn timber

Species were selected that satisfied the following criteria:

- Timber production potential: likely to grow reasonably quickly into trees of adequate size and form for milling. A group of botanical experts assessed a range of species and provided advice on their timber potential.
- Existing information: little or no wood quality information previously published. The Forest Products Commission provided expert advice on the wood properties and potential utilisation of species previously tested, and helped identify species for which little or no information was available.

Information was collected and reviewed from a range of sources, including:

- WA Herbarium’s online botanical database, FloraBase (Western Australian Herbarium 1998), compiled into a draft species list (Appendix 14),
- botanical experts, especially Wayne O’Sullivan (Arboressence Consultancy) and Peter White (Department of Conservation and Land Management, Narrogin).
- Forest Products Commission website (www.fpc.wa.gov.au),

- report to the Search project by Graeme Siemon of the Forest Products Commission (Appendix 04),
- report to the Search project by Gary Brennan of the Department of Conservation and Land Management, Bunbury, on relevant work performed at the Harvey Timber Technology Centre (Appendix 17),
- various published and unpublished sources including (Chippendale 1973), (Bootle 1983), (Boland *et al.* 1984), (Brennan, Gary K and Newby 1992), (Siemon and Pitcher 1996), (Brennan, Gary K *et al.* 1997), (Siemon and Kealley 1999), (Hill and Brennan 2000), (Piper 2000, 2001) and(Siemon 2001),

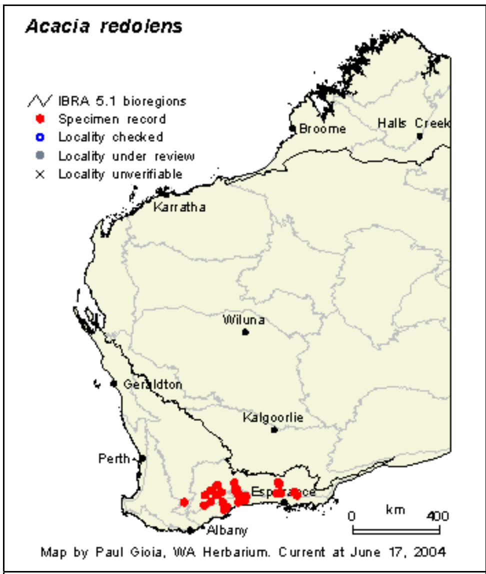
The twelve species selected for wood testing in the Search Project are listed in Table 13. Distribution maps for each species are reproduced in Figure 29. Note that *Acacia aff redolens* refers only to the tree form of *A. redolens* recorded north and east of Esperance (see *A. redolens* distribution map). These populations are likely to be separated into a new species related to *A. redolens*.

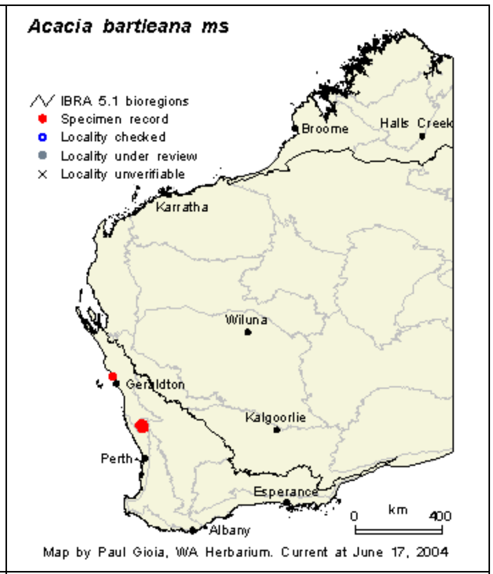
Table 13. Species selected for sawn timber testing.

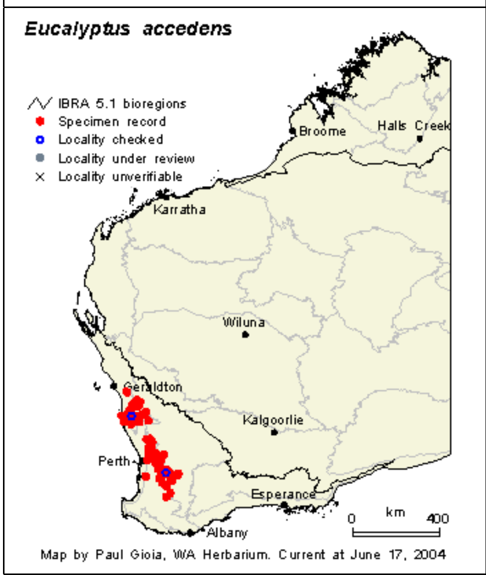
Taxon	Height (m)	Comments
Acacia aff*. redolens*	3 (5)	Tree form, found near Esperance. Possibly a new species related to *A. redolens*.
Acacia bartleana Maslin (ms)	8 (12)	Medium-sized tree, reasonable form, fast growing. Previously known as *A. microbotrya var. subfalcata.*
Eucalyptus accedens	15 (25)	Fast growing timber species for wetter fringes of wheatbelt. Used interchangeably with *E. wandoo*, but wood characteristics not tested.
Eucalyptus argyphea	15	Mallet, planted trees currently cut commercially at Dryandra, but not previously tested.
Eucalyptus clivicola	15	Green Mallet, found on breakaway country inland from south coast.
Eucalyptus kondininensis	20	Mallet, good growth rates observed on difficult sites.
Eucalyptus moderata	15	Close wheatbelt relative of *E. transcontinentalis*, a species with timber potential. Previously known as *E. semivestita*.
Eucalyptus occidentalis	20	Southern areas, suits wetter sites, but insect and parrot prone. Under test by the Australian Low Rainfall Tree Improvement Group.
Eucalyptus ornata	10	Mallet, limited distribution.
Melaleuca preissiana	9	Moist sites only. Previous wood tests affected by technical problems.
Melaleuca rhaphiophylla	10	Moist sites, but wider distribution than *M. preissiana*.
Taxandria juniperina	12 (27)	Tall, fast growing, good form, Busselton to Albany. Needs moist sites in the target zone. Previously known as *Agonis juniperina*.

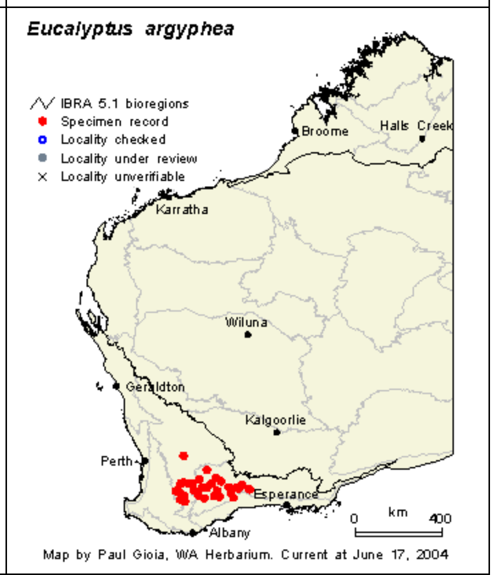
- Heights sourced from FloraBase (heights of exceptional specimens in brackets)
- Growth potential (includes growth rate, form, hardiness etc) and comments sourced from botanical experts.
- Shading = species selected for testing.

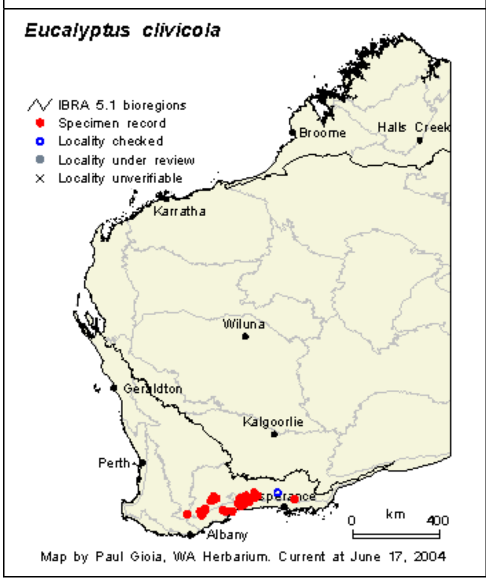
Note that many species were passed over in this selection process because sufficient work had already been done on them, not because their potential as timber species was judged to be low. If anything, some of the species not tested in the Search Project may have better commercial prospects than the species chosen for testing here, and are already being promoted by the Forests Products Commission and others.

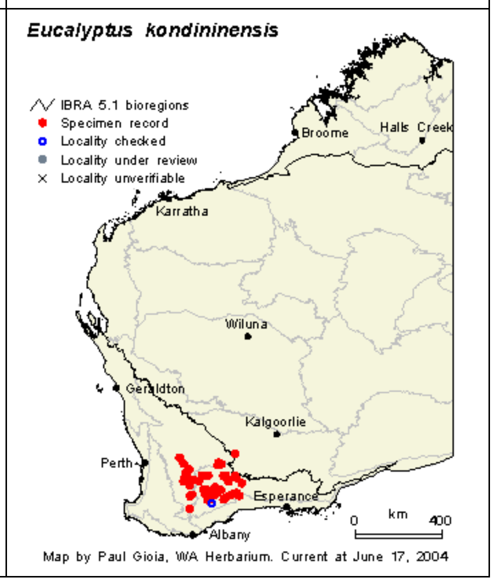

Acacia redolens
IBRA 5.1 bioregions
Specimen record
Locality checked
Locality under review
Locality unverifiable
Broome
Halls Creek
Karratha
Wiluna
Geraldton
Kalgoorlie
Perth
Esperance
Albany
0 km 400
Map by Paul Gioia, WA Herbarium. Current at June 17, 2004


Acacia bartleana ms
IBRA 5.1 bioregions
Specimen record
Locality checked
Locality under review
Locality unverifiable
Broome
Halls Creek
Karratha
Wiluna
Geraldton
Kalgoorlie
Perth
Esperance
Albany
0 km 400
Map by Paul Gioia, WA Herbarium. Current at June 17, 2004


Eucalyptus accedens
IBRA 5.1 bioregions
Specimen record
Locality checked
Locality under review
Locality unverifiable
Broome
Halls Creek
Karratha
Wiluna
Geraldton
Kalgoorlie
Perth
Esperance
Albany
0 km 400
Map by Paul Gioia, WA Herbarium. Current at June 17, 2004


Eucalyptus argyphea
IBRA 5.1 bioregions
Specimen record
Locality checked
Locality under review
Locality unverifiable
Broome
Halls Creek
Karratha
Wiluna
Geraldton
Kalgoorlie
Perth
Esperance
Albany
0 km 400
Map by Paul Gioia, WA Herbarium. Current at June 17, 2004


Eucalyptus clivicola
IBRA 5.1 bioregions
Specimen record
Locality checked
Locality under review
Locality unverifiable
Broome
Halls Creek
Karratha
Wiluna
Geraldton
Kalgoorlie
Perth
Esperance
Albany
0 km 400
Map by Paul Gioia, WA Herbarium. Current at June 17, 2004


Eucalyptus kondininensis
IBRA 5.1 bioregions
Specimen record
Locality checked
Locality under review
Locality unverifiable
Broome
Halls Creek
Karratha
Wiluna
Geraldton
Kalgoorlie
Perth
Esperance
Albany
0 km 400
Map by Paul Gioia, WA Herbarium. Current at June 17, 2004

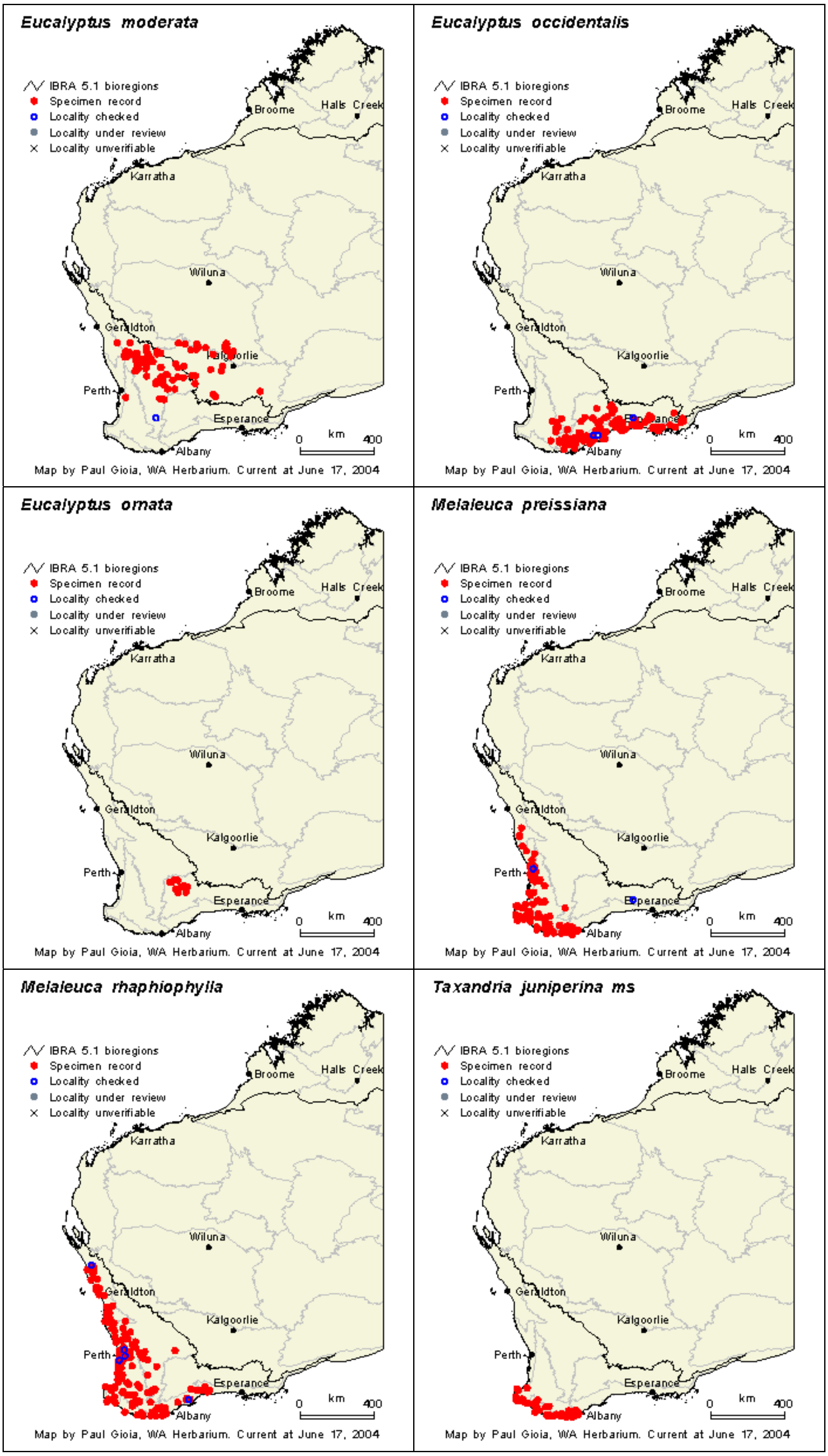


Figure 29. Distribution maps of twelve WA species tested for sawn timber. Courtesy of FloraBase (Western Australian Herbarium 1998) http://www.calm.wa.gov.au/science/florabase.html

6.7.3 Log harvesting

Since most logs were harvested from native stands, care was taken to cut logs with the minimum disturbance to each stand. In some instances, logs were taken from recent windfall trees, or trees that had suffered storm damage, or trees with multiple stems, from which a single suitable log could be removed. The length of log needed for these trials was only 1.2 metres, making it possible to choose trees with significant form or other defects (forks, bends, heavy branching, scarring), as long as a straight log of sufficient length could be cut. Trees were also selected in a way that would improve the stand, by removing trees that were likely to be competing with nearby good quality trees, rather than cutting down isolated trees, or the best trees in a stand.

Where possible, two logs were harvested from three separate populations of each species (Table 14). Target logs of about 350 mm diameter were sought, to approximate the size that might be targeted by sawlog growers (see photographs in Figure 30. In practice, it was not practicable to collect six logs from all selected species, and sizes varied slightly from the target.

Table 14. Species and number of logs harvested for sawn timber testing.

Species	Common name	Harvest locations	Logs per location	Total logs harvested
Acacia aff. redolens	Wattle	1	2	2
Acacia bartleana Mas. (ms)	Golden tooth wattle	2	2, 1	3
Eucalyptus accedens	Powderbark wandoo	3	2, 2, 2	6
Eucalyptus argyphea	Silver mallet	3	2, 2, 2	6
Eucalyptus clivicola	Green mallet	2	2, 1	3
Eucalyptus kondininensis	Kondinin blackbutt	3	2, 2, 2	6
Eucalyptus moderata	Wheatbelt redwood	3	2, 2, 2	6
Eucalyptus occidentalis	Flat-topped yate	4	2, 2, 1, 1	6
Eucalyptus ornata	Silver mallet	3	2, 2, 2	6
Melaleuca preissiana	Preiss's paperbark (Moonah)	3	2, 2, 2	6
Melaleuca rhaphiophylla	Swamp paperbark	3	2, 2, 2	6
Taxandria juniperina	Warren River cedar	3	2, 2, 2	6

Figure 30. Harvesting logs for timber testing. (Photos: Wayne O'Sullivan)

Logs were end-sealed immediately after cutting, then transported to Harvey Timber Technology Centre for milling. At Harvey, logs were kept inside a ‘wet shed’ at the Timber Technology Centre (Figure 31), where they were sprayed regularly from roof sprinklers to keep them moist prior to sawmilling.

Figure 31. Harvested logs in the wet shed at Harvey Timber Technology Centre.

6.7.4 Log descriptions

Each log was examined, described and measured (see Section 6.7.5 below). Log faults such as sweep, large taper, bumps, branches, decay on the end and borer damage were noted, and comments made on whether they were likely to affect recovery.

Details of defects in the harvested logs are given in Table 15. Calculated volumes for each log are contained in Table 16 and total log volumes for each species are given in Table 17.

Table 15. Defects in logs of twelve Western Australian timbers sampled for wood property and processing assessments.

Log number	Rot width (mm)	Rot thickness (mm)	Rot length (mm)	Borer gallery diameter (mm)	Borer gallery length (mm)	Sweep (mm/m)	Other defect (or comment)
Acacia aff redolens							
66a	-	-	-	-	-	-	This ‘log’ is a limb off 66b
66b	-	-	-	-	-	130	-
67	-	-	-	-	-	-	-
***Acacia bartleana* Maslin (ms)**							
61	-	-	-	-	-	-	-
62	-	-	-	-	-	-	60 mm branch
63	-	-	-	60	90	-	-
Eucalyptus accedens							
13	-	-	-	-	-	-	-
14	-	-	-	40	900	25	Some small borer holes
15	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-
Eucalyptus argyphea							
19	-	-	-	-	-	-	6 gum pockets 5 x 30
20	-	-	-	-	-	-	5 gum pockets 5 x 30
21	-	-	-	-	-	15	8 gum pockets 5 x 30
22	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-
24	-	-	-	-	-	-	15 gum pockets 5 x 20
Eucalyptus clivicola							
55	-	-	-	-	-	-	-
56	-	-	-	-	-	-	-
57	-	-	-	-	-	-	-
Eucalyptus kondininensis							
31	-	-	-	-	-	-	-
32	-	-	-	-	-	-	-
33	-	-	-	-	-	20	1 gum pocket 10 x 50
34	-	-	-	-	-	-	-
35	-	-	-	-	-	22	-
36	-	-	-	-	-	-	-
Eucalyptus moderata							
73	-	-	-	-	-	-	-
74	-	-	-	50	full	30	10 mm taper
75	-	-	-	-	-	-	-
76	-	-	-	-	-	-	-
77	-	-	-	-	-	-	-
78	-	-	-	-	-	-	-
Eucalyptus occidentalis							
37	-	-	-	-	-	-	-
38	30	28	200	-	-	-	-
39	50	28	50	-	-	-	30 mm branch
40	-	-	-	-	-	60	-
41	-	-	-	30	full	-	-
42	-	-	-	-	-	-	4 gum pockets 5 x 30

Log number	Rot width (mm)	Rot thickness (mm)	Rot length (mm)	Borer gallery diameter (mm)	Borer gallery length (mm)	Sweep (mm/m)	Other defect (or comment)
Eucalyptus ornata							
43	-	-	-	-	-	-	-
44	-	-	-	70	full	-	-
45	40	28	70	-	-	-	-
46	-	-	-	-	-	-	1 gum pockets 10 x 200, 8 gum pockets 5 x 40
47	-	-	-	-	-	-	15 gum pockets 3 x 60
48	-	-	-	45	250	-	8 gum pockets 10 x 50, 1 gum pocket 15 x 80
Melaleuca preissiana							
01	-	-	-	-	-	-	-
02	-	-	-	40	180		-
03	-	-	-	-	-	-	-
04	60	full	200	-	-	-	-
05	-	-	-	-	-	-	70 mm bump
06a	-	-	-	-	-	65	-
06b	50	full	400	-	-	30	-
Melaleuca rhaphiophylla							
25	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-
30	-	-	-	-	-	60	-
Taxandria juniperina							
07	-	-	-	-	-	-	-
08	-	-	-	40	480	-	-
09	-	-	-	-	-	-	2 bulls eye borer holes 20 x 50
10	50	full	70	-	-	-	-
11	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-

6.7.5 Sawmilling

Each species was milled separately, using a WoodMizer horizontal bandsaw, owned and operated by Stephen Stone of Gristone Timber (Figure 32 and Figure 33).

Because of the large number of logs in the trial, through-and-through sawing was used to break the logs down into 28 mm slabs (Figure 34). The logs were back sawn to maximise green sawn recovery and to make a feature of the board face.

The central slab from each log was wrapped in plastic film immediately after sawing, to minimise drying. These slabs were subsequently used for moisture content and shrinkage testing.

Figure 32. Horizontal bandsaw converting logs into slabs. Sawmilling by Stephen Stone of Gristone Timber.

Figure 33. Eucalyptus argyphea log being sawn into 28mm slabs.

Figure 34. Slabs produced by horizontal bandsaw. Species pictured are (from top left) *Acacia aff. redolens*, *A. bartleana* (previously known by the interim working name "*A. subfalcata*"), *Eucalyptus accedens*, *E. argyphea*, *E. clivicola*, *E. kondininensis*, *E. moderata* and *Melaleuca preissiana.*

Individual boards were cut from the 28 mm thick milled slabs using a vertical bandsaw (Figure 35). Boards were cut 105 mm wide where possible, then 80 mm or 60 mm width were cut from the remaining timber as falldown recovery. Each board was carefully marked to maintain its identity throughout the trial.

Figure 35. Vertical bandsaw used to convert slabs to boards.

Before milling, the small end diameter under bark (SEDUB), large end diameter under bark (LEDUB), and log length were measured for each log. Smalian's equation (the mean cross-sectional area of the small and large ends multiplied by log length) was then used to calculate the volume of each log. Green sawn recovery (as boards) was estimated for each log (Table 16), and summarised for each species (Table 17). Major reasons for reductions in recovery were also recorded (Table 16).

While heart is included in the mean green sawn recoveries, it was evident that it would need to be docked out when dried dressed graded recoveries were estimated. Green sawn recoveries for *Eucalyptus ornata* and *E. moderata* had high standard deviations because one log of each species had significant defects, yielding less than 30% as sawn timber. Similarly, recovery from the poorest two logs of *Melaleuca rhaphiophylla* was less than 40%.

Table 16. Log volumes, board volumes and green sawn recoveries from individual logs and reasons for downgrade in logs of twelve Western Australian species.

Log number	Log volume (m^3)	Board volume (m^3)	Green sawn recovery (%)	Reason for recovery loss from log
Acacia* aff. *redolens				
66	0.055	0.041	74.5	heart, branch stub
67	0.056	0.034	59.9	heart
***Acacia bartleana* Maslin (ms)**				
61	0.106	0.071	67.1	heart
62	0.061	0.038	61.9	heart, branch stub
63	0.038	0.018	48.0	heart, borer gallery
Eucalyptus accedens				
13	0.059	0.043	73.2	heart
14	0.075	0.043	57.0	heart, borer galleries / holes, sweep
15	0.066	0.054	82.1	heart
16	0.115	0.081	70.9	heart
17	0.042	0.030	70.5	heart
18	0.033	0.019	56.7	heart
Eucalyptus argyphea				
19	0.054	0.040	73.8	heart, gum pockets
20	0.050	0.037	73.7	heart, gum pockets
21	0.062	0.037	59.2	heart, gum pockets, sweep
22	0.025	0.014	54.5	heart
23	0.044	0.029	65.8	heart
24	0.047	0.036	75.7	heart, gum pockets
Eucalyptus clivicola				
55	0.036	0.026	72.6	heart
56	0.042	0.026	63.7	heart
57	0.047	0.025	53.2	heart
Eucalyptus kondininensis				
31	0.053	0.026	49.4	heart
32	0.048	0.034	70.7	heart
33	0.090	0.053	58.5	heart, sweep, gum pocket
34	0.067	0.039	57.7	heart
35	0.050	0.032	63.0	heart, sweep
36	0.073	0.050	67.6	heart
Eucalyptus moderata				
73	0.060	0.038	64.4	heart
74	0.137	0.037	27.3	heart, borer gallery, sweep
75	0.054	0.030	55.0	heart
76	0.046	0.028	59.3	heart
77	0.041	0.026	64.5	heart
78	0.047	0.027	56.2	heart
Eucalyptus occidentalis				
37	0.068	0.042	62.4	heart
38	0.186	0.105	56.5	heart, rot
39	0.093	0.067	71.3	heart, branch stub
40	0.086	0.042	49.1	heart
41	0.091	0.054	59.7	heart, borer gallery
42	0.059	0.039	67.4	heart, gum pockets

Log number	Log volume (m^3)	Board volume (m^3)	Green sawn recovery (%)	Reason for recovery loss from log
Eucalyptus ornata				
43	0.056	0.035	63.3	heart
44	0.087	0.021	23.8	heart, borer gallery
45	0.079	0.055	68.8	heart, rot
46	0.069	0.038	55.8	heart, gum pockets
47	0.060	0.041	68.6	heart, gum pockets
48	0.082	0.052	62.6	heart, gum pockets, borer gallery
Melaleuca preissiana				
01	0.093	0.066	70.4	heart, borer galleries
02	0.076	0.044	57.6	heart
03	0.042	0.019	45.8	heart
04	0.086	0.053	61.8	heart, rot
05	0.146	0.084	57.4	heart
06	0.210	0.107	51.0	heart, sweep
Melaleuca rhaphiophylla				
25	0.076	0.044	57.7	heart
26	0.075	0.051	67.8	heart
27	0.081	0.047	58.3	heart
28	0.097	0.048	48.9	heart
29	0.065	0.025	37.8	heart
30	0.048	0.019	39.9	heart, sweep
Taxandria juniperina				
07	0.067	0.037	54.4	heart, borer galleries and holes
08	0.044	0.032	71.0	heart
09	0.052	0.033	63.3	heart removed
10	0.085	0.039	45.9	heart, rot
11	0.065	0.041	62.8	heart
12	0.085	0.043	50.0	heart

Table 17. Total log volume, board volume and mean green sawn recoveries of twelve Western Australian native species.

Species	Total volumes (m^3)		Green sawn recovery (%)	
	Logs	Boards	Mean of total volumes	Mean of log recoveries*
Acacia aff. *redolens*	0.111	0.075	67.6	67.2 (10.3)
Acacia bartleana Maslin (ms)	0.205	0.127	62.0	59.0 (9.9)
Eucalyptus accedens	0.390	0.270	69.2	68.4 (9.9)
Eucalyptus argyphea	0.282	0.193	68.4	67.1 (8.8)
Eucalyptus clivicola	0.125	0.077	61.6	63.2 (9.7)
Eucalyptus kondininensis	0.381	0.234	61.4	61.2 (7.7)
Eucalyptus moderata	0.385	0.186	59.9	54.5 (13.9)
Eucalyptus occidentalis	0.583	0.349	55.9	61.1 (7.9)
Eucalyptus ornate	0.433	0.242	48.3	57.2 (17.0)
Melaleuca preissiana	0.653	0.373	57.1	57.3 (8.5)
Melaleuca rhaphiophylla	0.442	0.234	52.9	51.7 (11.7)
Taxandria juniperina	0.398	0.225	56.5	57.9 (9.4)

* Includes standard deviation of individual green sawn recoveries (in brackets). Note: *Acacia aff redolens* results are for two logs; *A. bartleana* and *Eucalyptus clivicola* results are for three logs; all other species results are for six logs.

6.7.6 Wood properties – density and shrinkage

The central slab sawn from each log was used to prepare specimens for wood density and shrinkage assessment. Several 28 mm square sticks were cut and then dressed to 25 mm square. Five specimens of 100 mm length were randomly selected, ensuring that both sapwood and heartwood were represented and that they were free of brittle heart. Mass and dimensions were measured twice a week until the specimens stabilised.

Because of the high relative humidity conditions during winter, the room where the drying specimens were stored was kept at 30°C. Final drying to obtain oven-dry mass for basic density assessment was at 103°C until constant weight was achieved.

The parameters assessed were:

- Green moisture content, green density, air-dry density and basic density,
- tangential, radial and longitudinal shrinkage during drying to air-dry conditions.

Mean values for moisture content (as a percentage of the oven-dry weight of wood), green density, air-dry density and basic density are given in Table 18.

Both acacias and all of the eucalypts had low green moisture content because of their high wood density, with only small differences between green density and air-dry density. Of the eucalypts, *Eucalyptus occidentalis* had the largest standard deviations in air-dry and basic densities, while *E. moderata* had the least.

The two *Melaleuca* species and *Taxandria juniperina* had medium density wood, and much higher green moisture contents than the acacias and eucalypts.

Table 18. Wood density and moisture content (mean values and standard deviations)

Species	Log No	Moisture content (%)	Green density (kg/m^3) *	Air-dry density (kg/m^3) *	Basic density (kg/m^3) *
Acacia aff. *redolens*	66 - 67	30	1001 (-)	890 (-)	768 (-)
Acacia bartleana Maslin (ms)	61 - 63	45	1207 (-)	1014 (-)	835 (-)
Eucalyptus accedens	13 - 18	32	1167 (28)	1039(44)	883 (47)
Eucalyptus argyphea	19 - 24	32	1096 (74)	1059 (66)	828 (56)
Eucalyptus clivicola	55 - 57	30	1155 (-)	1094 (-)	886 (-)
Eucalyptus kondininensis	31 - 36	28	1180 (36)	1145 (43)	921 (50)
Eucalyptus moderata	73 - 78	31	1206 (32)	1154 (38)	919 (28)
Eucalyptus occidentalis	37 - 42	45	1119 (53)	1001 (108)	771 (87)
Eucalyptus ornata	43 - 48	33	1168 (33)	1097 (49)	878 (38)
Melaleuca preissiana	1 – 6	121	1067 (30)	820 (113)	489 (51)
Melaleuca rhaphiophylla	25 - 30	140	1054(28)	622 (53)	440 (40)
Taxandria juniperina	7 - 12	100	995 (75)	636 (37)	498 (32)

* Standard deviation of individual wood density values where more than five logs.

Note: moisture content is expressed here on a dry basis – that is, weight of water divided by oven-dry weight of wood. Basic density is oven-dry weight divided by green volume.

Shrinkage results for the 100 mm test blocks air dried to 12% moisture content are presented in Table 19. Photographs of test blocks for two species, *Eucalyptus argyphea* and *Melaleuca preissiana* are contained in Figure 36.

Tangential and radial shrinkage were very large in *M. preissiana* (23.2 per cent and 11.2 per cent respectively) and large in *M. rhaphiophylla* (15.0 per cent and 6.7 per cent respectively), reducing their feasibility as sawn timber species.

Shrinkage in the eucalypts was much lower, ranging from the lowest, *Eucalyptus accedens* (3.1 per cent and 1.5 per cent respectively) up to *E. occidentalis* (9.1 per cent and 4.5 per cent respectively). The two acacias had shrinkage values at the lower end of the eucalypt range, while *Taxandria juniperina* had shrinkage rates near the upper end of the eucalypt range.

Table 19. Shrinkage from green to 12 per cent moisture content of twelve Western Australian timbers.

Timber species	Tangential shrinkage (%)	Radial shrinkage (%)	Longitudinal shrinkage (%)
Acacia aff. *redolens*	2.2 (-)	1.3 (-)	0.08
Acacia bartleana Maslin (ms)	5.8 (-)	2.4 (-)	0.01
Eucalyptus accedens	3.1 (1.2)	1.5 (0.3)	0.04
Eucalyptus argyphea	6.5 (0.6)	4.0 (0.7)	0.01
Eucalyptus clivicola	5.7 (-)	2.9 (-)	0.01
Eucalyptus kondininensis	6.4 (2.2)	3.5 (1.1)	0.01
Eucalyptus moderata	6.2 (0.4)	4.4 (0.7)	0.07
Eucalyptus occidentalis	9.1 (1.7)	4.5 (0.7)	0.28
Eucalyptus ornata	6.6 (0.7)	3.7 (0.9)	0.06
Melaleuca preissiana	23.2 (7.5)	11.2 (5.2)	1.40
Melaleuca rhaphiophylla	15.0 (2.9)	6.7 (2.4)	0.26
Taxandria juniperina	8.2 (1.2)	4.4 (1.0)	0.01

Standard deviation of tangential and radial shrinkage (in brackets) is given for species for which more than five logs were sawn. No standard deviations are given for longitudinal shrinkage because of the very low values involved.

Figure 36. Shrinkage blocks.
Left: *Eucalyptus argyphea* in drying room, held at 30^{o}C.
Right: *Melaleuca preissiana* showing severe distortion during drying.

6.7.7 Drying

Appearance timber is dried before use, most importantly to stabilise it, but also to improve its surface finish, and to prevent decay.

Once a tree is felled, the timber dries until it is in equilibrium with the surrounding air, at a moisture content between 6% (dry environments) and 20% (humid environments) (Walker 1993). Drying speed depends on many factors including wood thickness, atmospheric conditions, the wood's initial moisture content, and its structure. During drying, some shrinkage is common, as cell structure and shape changes, which can lead to damage such as distortion, checking (splits along the grain), or collapse of wood fibres (causing the wood surface to become buckled and corrugated).

Kiln drying can improve the recovery of appearance grade timber, by allowing the drying process to be controlled. Drying conditions are set to optimise two competing commercial objectives - minimising the drying time, while also minimising damage to the drying timber.

Boards from the twelve species used in this trial were dried in two batch kilns at the Forest Products Commission's Harvey Timber Technology Centre (Figure 37). The timber was dried in two separate batch kilns, because there was too much material for a single kiln, and also because the large variations in wood density required different drying schedules to be used. Species were separated into two groups - high density and low density.

To monitor drying rate and degrade, sample boards were prepared for each species using the method described in the Australian Timber Seasoning Manual (Waterston 1997). During drying, these sample boards were assessed weekly for moisture content, surface checking and warping. The drying schedule was adjusted if drying degrade was evident. For the early stages of drying in both kilns, mild drying conditions were thought to be essential, to avoid damage to the wood.

Estimated initial moisture contents of the sample boards used to monitor drying progress are given in Table 20.

Table 20. Estimated initial moisture contents of sample boards.

Species	Log no.	Green weight	Oven-dry weight	Moisture content
Acacia aff. redolens	66	289.24	208.10	39.0
Acacia bartleana	62	119.59	80.15	49.2
Eucalyptus accedens	15	120.98	83.07	45.6
Eucalyptus argyphea	19	137.54	93.02	47.9
Eucalyptus clivicola	56	149.16	111.54	33.7
Eucalyptus kondininensis	33	128.47	98.40	30.6
Eucalyptus moderata	75	101.88	73.56	38.5
Eucalyptus occidentalis	40	105.88	61.55	72.0
Eucalyptus ornata	43	139.01	97.44	42.7
Melaleuca preissiana	1	94.52	44.10	114.3
Melaleuca rhaphiophylla	27	116.90	53.29	119.4
Taxandria juniperina	7	114.21	58.70	94.6

Figure 37 Left: Peter Piper (FPC) and Gary Brennan (CALM) loading timber boards into drying kiln at Harvey Timber Technology Centre.
Right: Periodic inspection of boards for surface checking and other defects during kiln drying.

6.7.7.1 Lower density species

A relatively conservative drying schedule (Table 21) was developed for the kiln containing the lower density species *Melaleuca preissiana*, *M. rhaphiophylla*, *Taxandria juniperina* and *Eucalyptus occidentalis*. This latter species was included in this group to balance the wood volumes in the two kilns. Although *E. occidentalis* had a higher density than the other species in the kiln, it was chosen because it had a considerably lower air-dry density than all the other eucalypts in this study.

It proved not to be possible to follow the planned drying schedule. Surface checking (cracks along the grain) commenced almost immediately, even at an initial equilibrium moisture content (EMC) of 19 per cent. *Melaleuca preissiana* was particularly susceptible, requiring significant extra time at a higher EMC. To accommodate this species, the kiln temperature was decreased from 30ºC to 20ºC and relative humidity increased from 90 per cent to 95 per cent for ten days, but the *Melaleuca* timber continued to deteriorate and did not recover. This attempt to dry the *Melaleuca* without damage slowed the drying rate for all other species in that kiln. A new drying schedule for the lower density species was developed as drying progressed (Table 22).

Melaleuca preissiana boards also exhibited rapid and early deformation (Figure 38), even though a concrete weight (580 kg/m^2) was placed on the bundle before drying was commenced. Excessive movement in this species continued, and a heavier weight was used after four weeks of very slow drying. The difficult drying behaviour of *M. preissiana* confirmed the findings of a previous drying trial (Piper 2001), although at that time the species' poor performance was thought to have been caused, in part, by a technical fault that resulted in a loss of temperature control during drying. However, this new work suggests that the difficult drying behaviour is inherent in this species.

Figure 38. Kiln dried *Melaleuca preissiana* board, showing distortion and collapse.

Table 21. Drying schedule proposed for 100 x 28 mm boards of lower density species.

Time (days)	Dry bulb temperature Set Point (C^o)	Relative Humidity Set Point (%)	Equilibrium moisture content (%)	Air velocity (m/s)	Moisture content (%)
	30	88	19	0.5	Green
	33	84	17	0.5	50 -40
to be	35	80	15	0.5	40 - 30
determined	37	76	14	0.5	30 - 25
	40	72	13	1.0	25 - 20
	45	60	10	1.0	20 - 15
	50	45	7	1.0	15 - 10

Table 22. Revised drying schedule for 100 x 28 mm boards of lower density species, *Melaleuca preissiana*, *M. rhaphiophylla* and *Taxandria juniperina*, with higher density *E. occidentalis* included to make up the stack volume.

Date	Dry bulb temperature Set Point (C^o)	Relative Humidity Set Point (%)	Equilibrium moisture content (%)	Air velocity (m/s)
08 May 2003	10	95	23+	0.2
12 May 2003	30	88	19	0.2
05 June 2003	Heavier weight used			
10 July 2003	33	84	17	0.2
11 Sept 2003	37	76	14	1.0
21 Oct 2003	Steamed			
23 Oct 2003	40	72	12	1.0
06 Nov 2003	Finish			

6.7.7.2 Higher density species

For the eight higher density species (six eucalypts and two acacias) a drying schedule more conservative than the schedule for the lower density timbers was chosen. This schedule, shown in Table 23, was developed for Goldfields high density timbers (Siemon and Kealley 1999), and was also recommended by Gary Brennan from the Department of Conservation and Land Management's Revegetation Systems Unit. This conservative approach to drying was intended to minimise the amount of drying defect that was likely to occur with boards from a range of different species and therefore different drying behaviour. Previous experience with high density Goldfields timbers had shown that very slow drying is required with this type of timber to prevent damage.

The actual drying schedule followed is shown in Table 24. Under this conservative treatment, the timber from all species behaved well, with very little surface degrade in the form of checking.

Table 23. Drying schedule planned for 100 x 28 mm boards of eight higher density timbers (six eucalypts and two acacias).

Time (days)	Dry bulb temperature Set Point (C^o)	Relative Humidity Set Point (%)	Equilibrium moisture content (%)	Air velocity (m/s)	Moisture content (%)
	20	95	19	0.2	Green
22	19	91	20.5	0.2	35.8 - 30.7
60	25	89	20	0.2	30.7 - 23.3
76	31	76	14	0.5	23.3 - 18.0
98	35	69	12.2	0.5	18.0 - 15.0
112	44	59	10	1.0	15.0 - 11.3
120	50	45	7.5	1.0	11.3 - 9.9
122					

Table 24. Actual drying schedule used for 100 x 28 mm boards of the eight higher density species.

Date	Dry bulb temperature Set Point (C^o)	Relative Humidity Set Point (%)	Equilibrium moisture content (%)	Air velocity (m/s)
08 May 2003	10	95	23+	0.2
12 May 2003	19	91	21	0.2
10 Jul 2003	25	86	18.5	0.2
11 Sep 2003	31	76	14.5	0.5
16 Sep 2003	31	76	14.5	0.5
21 Oct 2003	Steamed			
23 Oct 2003	35	69	12	1.0
06 Nov 2003	Finish			

6.7.7.3 Drying curves

The timber in each batch kiln was dried to 12 per cent moisture content. Drying curves for each of the sample boards (one per species) from May to late October are shown in Figure 39 (low density species), Figure 40 (high density eucalypts) and Figure 41 (acacias). The timber was dried for three weeks longer than shown in the figures, but due to an oversight, the final moisture contents were not estimated when drying was terminated on 6 November 2003.

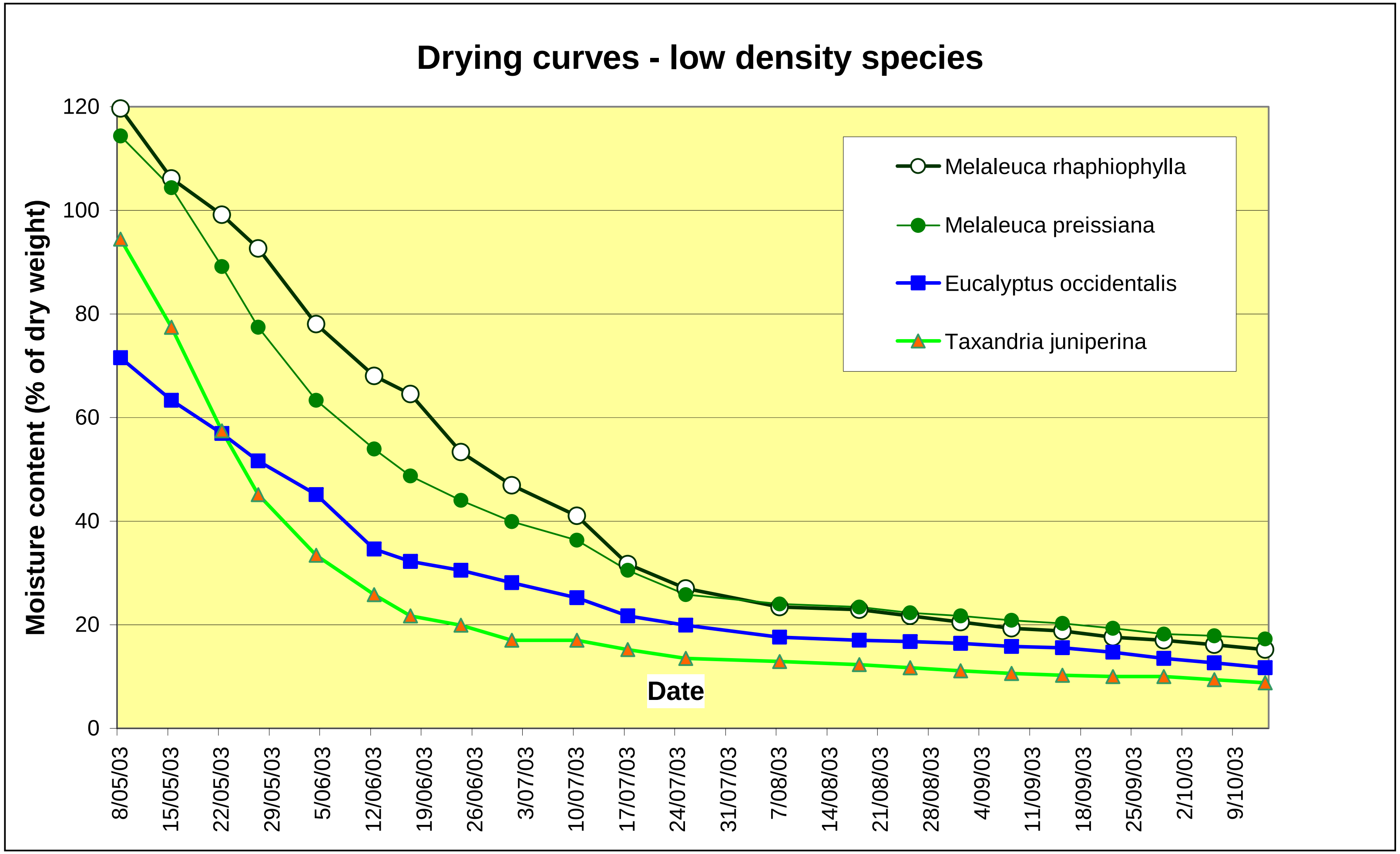


Figure 39. Drying curves for lower density timbers, using 'lower density timber' drying schedule.

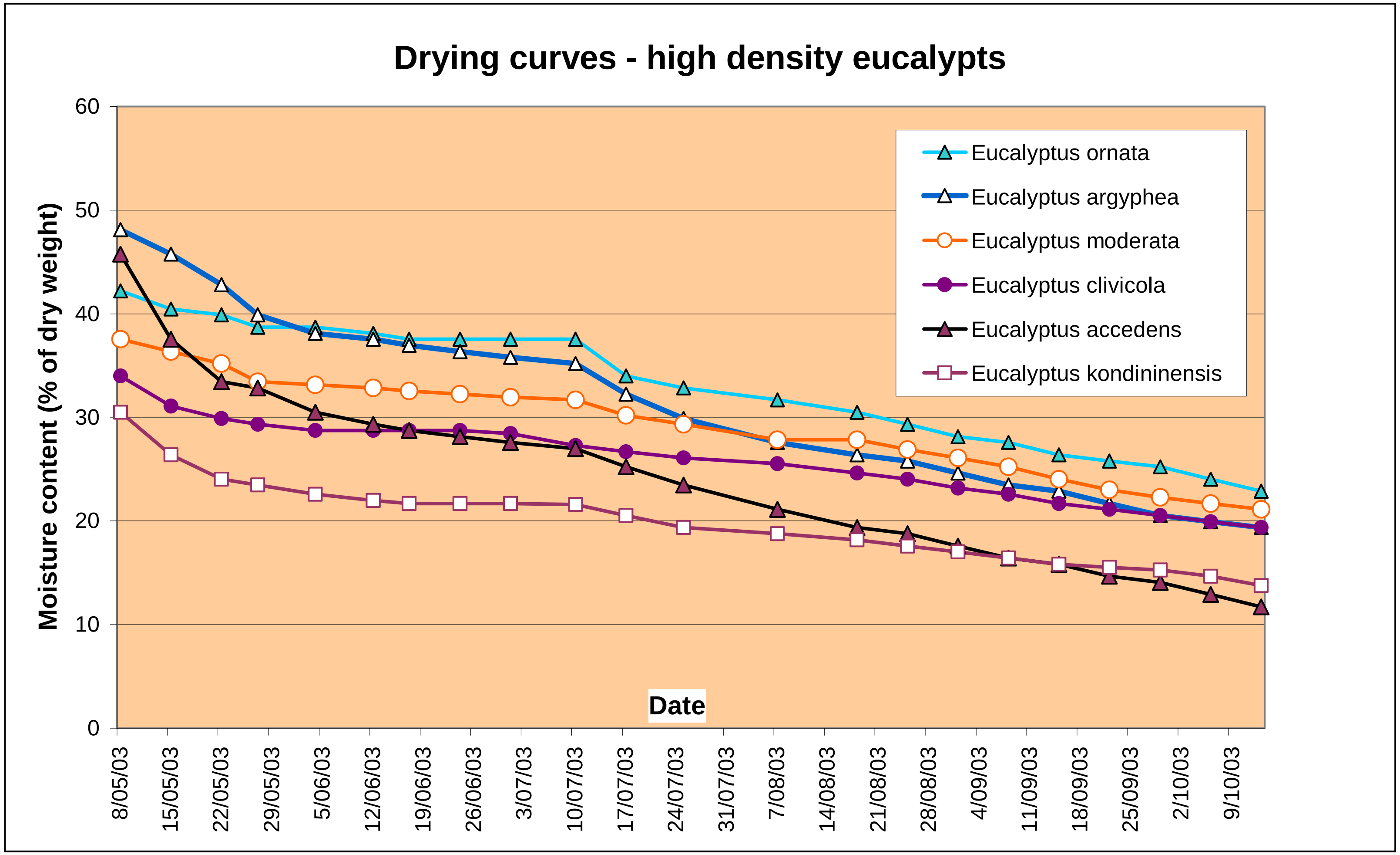


Figure 40. Drying curves for high density eucalypt boards, using conservative 'high density timber' drying schedule.

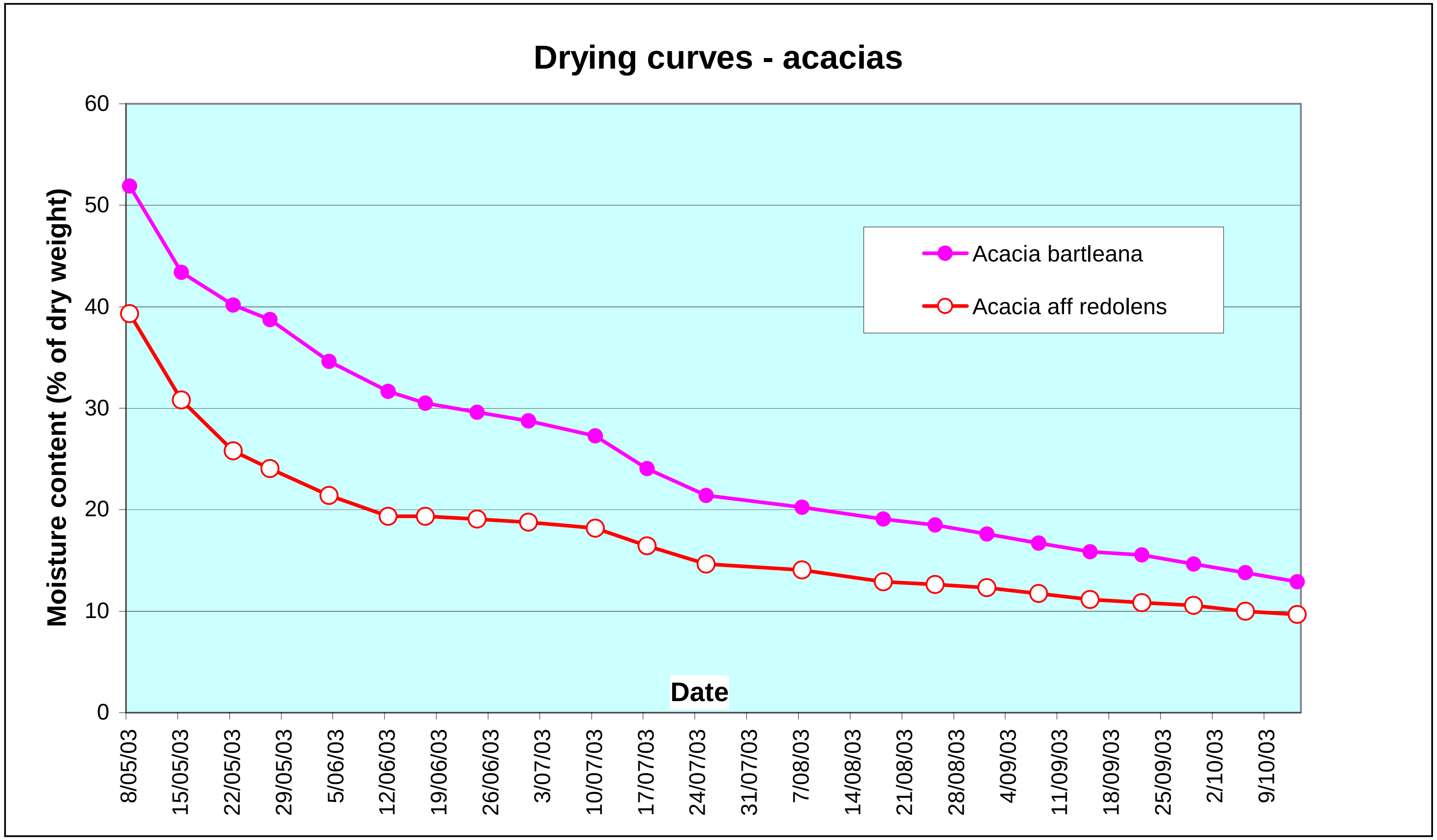


Figure 41. **Drying curves for *Acacia bartleana* and *A. aff redolens* boards, using conservative ‘ high density timber’ drying schedule.**

6.7.8 Dressing and Grading

Boards were dressed to 15 mm thickness for grading and manufacture into test panels. Board widths varied after dressing, because a range of widths were sawn from the original slabs to maximise recovery.

The boards of most species dried without significant distortion or surface damage. However, as discussed above, some *Melaleuca preissiana* boards suffered severe distortions and collapse during drying, which could not be fully reversed by steam conditioning (Figure 38). This species also had the highest incidence of surface checking due to drying. Some boards were too severely damaged to be dressed satisfactorily and were unusable.

Dressed boards were graded into four classes, select, medium feature, high feature or reject, in accordance with the specifications of Australian Standard AS2796.2:1999 (Standards Australia 1999). These grades are defined by the amount of natural and production-induced features found in each board. Natural features include gum veins and knots, while the main production-induced feature introduced by drying is checking. ‘Select’ material has the least amount of these features, and commands the highest price. ‘Medium feature’ and ‘high feature’ grades allow greater amounts of feature, and attract correspondingly lower prices, although their prices still generally exceed those paid for structural timber (source: ‘Australian hardwood drying best practice manual’ (Forest and Wood Products Research and Development Corporation 2003)).

A summary of the grading results for boards in this trial is contained in Table 25. More detailed results are contained in Table 26.

The highest percentage recoveries of select grade timber were recorded for *Eucalyptus moderata*, *E. kondininensis* and *E. clivicola*, with 78%, 73% and 63% recoveries respectively. At the other end of the scale, the two *Acacia* species had very low recoveries of select grade timber, only 9% and 12%.

If the two top timber grades, select grade and medium feature grade, are considered together, then *Eucalyptus clivicola* and *E. moderata* gave the best results among the eucalypts, with 95% and 94% respectively, while the lowest eucalypt recovery was for *E. ornata* (62%). The non-eucalypts had combined recoveries of the top two grades between 62% (*M. rhaphiophylla*) and 88% (*Acacia bartleana*), except for *Acacia aff. redolens*, which had very low recovery of these higher grades (29%).

The most common defects found in the timber from the twelve species (on a percentage basis) were borer holes, drying checks, gum pockets, tight knots, and loose knots or knot holes. The other ten defects identified during grading of these boards were relatively uncommon.

Eleven of the twelve species had borer holes (the exception was *E. moderata*), with *Acacia bartleana* (45%), *Acacia aff redolens* (38%) and *Taxandria juniperina* (34%) having the highest incidence. *Melaleuca preissiana* was the worst affected by drying checks (33%), while gum pockets were most commonly found in *Eucalyptus argyphea* (39%) and *E. ornata* (35%). Tight knots were most common in *Eucalyptus accedens* (24%), and loose knots, or knotholes were most common in *E. occidentalis* (21%).

Table 25. Summary of timber grading to AS2796.2:1999.

Species	Percentage of boards in each grade				Most common defect (% of boards affected)
	Select	Medium feature	High feature	Reject	
Acacia aff. redolens	12	17	29	42	Borer holes (38%)
Acacia bartleana	9	79	0	12	Borer holes (45%)
Eucalyptus accedens	39	35	7	19	Tight knots (24%)
Eucalyptus argyphea	20	48	18	14	Gum pockets (39%)
Eucalyptus clivicola	63	32	5	0	Borer holes (16%)
Eucalyptus kondininensis	73	16	9	2	Tight knots (8%)
Eucalyptus moderata	78	16	3	3	Loose gum veins (9%)
Eucalyptus occidentalis	41	33	9	17	Loose knots (21%)
Eucalyptus ornata	36	26	14	23	Gum pockets (35%)
Melaleuca preissiana	33	46	10	10	Drying checks (33%)
Melaleuca rhaphiophylla	44	18	15	24	Drying checks (15%)
Taxandria juniperina	26	51	4	19	Borer holes (34%)

Table 26. Summary of timber grading to AS2796.2:1999.

Species	No. of boards	Grade: Select	Grade: Medium feature	Grade: High feature	Grade: Reject	Tight knots	Loose knots or knot holes	Epicormic check	Tight gum veins	Loose gum veins	Gum pockets	Kino	Stain	Wane	Borer holes	Borer canals	Drying checks	Rot	Enclosed bark	Encased knots
Acacia aff. redolens	24	3	4	7	10	2	2								9		4		5	
Acacia bartleana	33	3	26	0	4		4		2	1	5			1	15		3	2	1	1
Eucalyptus accedens	72	28	25	5	14	17	2						1	4	10		3	7		1
Eucalyptus argyphea	56	11	27	10	8	2	4	5	4	3	22		1		3		1			
Eucalyptus clivicola	19	12	6	1	0	1					1				3		2			
Eucalyptus kondininensis	64	47	10	6	1	5	3				2	1		4	1	1				1
Eucalyptus moderata	64	50	10	2	2	2	4		1	6				3						
Eucalyptus occidentalis	92	38	30	8	16	13	19				3			6	13		5	4		
Eucalyptus ornata	77	28	20	11	18	2	4		5	6	27			1	4					
Melaleuca preissiana	48	16	22	5	5	1	2	1						4	5	4	16	1		
Melaleuca rhaphiophylla	55	24	10	8	13	5	3				2			2	6	1	8	2	4	
Taxandria juniperina	70	18	36	3	13	5	3	1					1		24		10	2	6	

All numbers in this table refer to the number of boards graded.

6.7.9 Hardness

A minimum of six hardness measurements was made per species on either a board or the docked ends of glued panels. The measurements were made using a modified vice that simulates the conventional Janka hardness test. A tension wrench was used to embed a steel ball with 11.2 mm diameter into the timber to a depth of its radius (5.6 mm). The load in N.m was then converted to kN using an equation (below) developed at Harvey Timber Technology Centre, to allow comparisons with published Janka hardness data.

Janka hardness load (kN) = 0.22 x Load (N.m) – 0.828

Table 27. Janka hardness tests of twelve species from southern Western Australia.

Species	Number of specimens tested	Torque wrench reading (N.m)		Estimated Janka hardness (kN)
		Mean	SD	
Acacia aff. redolens	16	49.6	8.0	10.1
Acacia bartleana	17	73.4	8.6	15.3
Eucalyptus accedens	6	52.1	13.1	10.6
Eucalyptus argyphea	6	73.2	13.0	15.3
Eucalyptus clivicola	10	69.0	10.1	14.4
Eucalyptus kondininensis	6	61.4	18.8	12.7
Eucalyptus moderata	10	77.1	8.1	16.1
Eucalyptus occidentalis	6	56.4	6.1	11.6
Eucalyptus ornata	6	70.6	7.0	14.7
Melaleuca preissiana	10	22.3	4.0	4.1
Melaleuca rhaphiophylla	10	22.4	3.9	4.1
Taxandria juniperina	10	27.3	4.1	5.2

Both of the acacias and all of the eucalypts had high Janka hardness values, making them eligible for consideration for uses in which hardness is desirable, such as flooring. For comparison, Janka hardness values for other species used for construction and flooring include *Corymbia maculata* (spotted gum) 11 kN, *Eucalyptus diversicolor* (karri) 9.0 kN, *E. marginata* (jarrah) 8.5 kN, *E. muellerana* (yellow stringybark) 8.5 kN, *E. patens* (WA blackbutt) 6.9 kN and *Callitris glauca* (white cypress pine) 6.5 kN (all data from Bootle (1983).

The two melaleucas and *Taxandria juniperina* had much lower hardness values than the eucalypts and acacias tested in this project, and were closer in hardness to a range of timbers commonly used in joinery and furniture manufacture, including Eastern Australian ash species such as *E. delegatensis* and *E. regnans*, both 4.9 kN, and imported timbers such as American maple and European beech (both 6.4 kN), American oak (6.0 kN), ramin (5.8 kN) and red meranti (2.8 to 3.7 kN). Comparative figures for well-known ‘soft’ timbers include 3.3 kN for *Pinus radiata* (radiata pine), 2.7 kN for *Pinus pinaster* (maritime pine), 1.5 kN for imported Western red cedar and 0.4 kN for balsa (all data from Bootle (1983)).

The method of hardness testing used here is believed to give a reliable ranking of species, and to yield reasonably accurate estimates of hardness. However, the estimate for *Eucalyptus accedens* is low in comparison to the published figure of 15 kN for *E. wandoo* (wandoo) (Bootle 1983), a species thought to have similar timber characteristics, and under whose name *E. accedens* is often sold. This difference in measured hardness may be due to a genuine difference in the hardness of the two species, or it may have been due, in part, to the deliberate selection of small to medium sized *E. accedens* trees for this trial, to simulate the size of tree likely to be produced from commercial plantings.

6.7.10 Timber panel manufacture

Two panels were manufactured from selected boards of each species for machining trials and demonstration purposes. Timber boards were edge-glued and restrained with woodworking clamps, to produce panels with final dimensions of 600 x 600 mm, as well as sufficient surplus material at the ends for glueline assessment (Figure 42). It was difficult to find sufficient good quality boards of *Acacia aff redolens*, because only two small logs had been harvested, and the recovery of high grade boards was low (see foreground panels in Figure 42).

The original intention was to use winter grade 'Resobond RA 3-W' (resorcinol formaldehyde) for the high density species. Although this adhesive bonds better to high density wood than urea formaldehyde, it produces a dark red glue line that can detract from the appearance of light-coloured timber. During the study, 'Titebond' became available and was used for gluing all species. It is a new aliphatic resin emulsion adhesive that produces a clear glueline and is suitable for high density timbers.

After trimming to the required size, the panels were face-glued onto plywood sheets to increase their thickness for ease of handling, and to reduce timber movement with seasonal changes. Finally the panels were sanded, waxed and polished.

Figure 42. Assembly of timber panels from dressed boards.

6.7.11 Glue line cleavage test

The adhesion of glue to timber can be assessed by measuring the amount of wood failure when a glueline is cleaved. A high rate of wood failure (as opposed to glue failure) in the cleavage plane indicates that the glue has adhered strongly to the wood.

Surplus material at the end of each panel was trimmed, to provide strips for the test. A 10mm groove was sawn into the top of each glue line (with the glued strip standing on edge), to provide a seat for a brick bolster, which was then hit with a mallet until cleavage occurred. Each cleaved glue line was assessed to determine the percentage of wood failure, expressed as a percentage of the surface area of the glue line. The method is described in AS 5067-2003 (Standards Australia 2003), for non-structural glued laminated timber (that is, timber glued with the join running parallel to the timber grain). This standard was considered to be more relevant for these timbers than AS1328.1:1998 (Standards Australia 1998c), for structural glued timber laminates.

The minimum requirement for satisfactory gluing performance for lower density woods (density less than 600 kg/m^3) is for wood failure to make up at least 30 per cent of every individual cleaved glueline, and for average wood failure across all cleaved glue lines to be 70 per cent or greater. The requirement for higher density woods (density greater than 600 kg/m^3) is similar, except for a lower requirement for average wood failure of 50 per cent or greater. Test results are given in Table 28.

Table 28. Gluing properties of twelve species from southern Western Australia (based on AS 5067-2003).

Species	Acceptable glue lines (30% or greater wood failure)	Average wood failure %	
	(15 glue lines tested per species)	Mean	SD
Acacia aff. redolens	11	39	16
Acacia bartleana	3	16	11
Eucalyptus accedens	0	1	1
Eucalyptus argyphea	5	26	34
Eucalyptus clivicola	1	6	9
Eucalyptus kondininensis	2	12	18
Eucalyptus moderata	0	4	4
Eucalyptus occidentalis	1	9	18
Eucalyptus ornata	0	5	4
Melaleuca preissiana	13	53	29
Melaleuca rhaphiophylla	15	77	23
Taxandria juniperina	15	100	0

The results indicated that the three species with lower density wood, *Melaleuca preissiana*, *M. rhaphiophylla* and *Taxandria juniperina*, gave the best gluing results, followed by *Acacia* aff. *redolens*. Only *Taxandria juniperina* and *Melaleuca rhaphiophylla* met the requirements of AS 5067-2003 (Standards Australia 2003).

The high density species, that is the eucalypts and acacias, did not meet the target glue line specification with the particular glue used in these panels, and therefore may not be suited to laminated uses requiring high glue line strength. Other glue formulations or gluing conditions may be required to improve their performance for this particular use. However, the timbers are likely to be satisfactory for other uses not involving lamination.

The problem of poor adhesion in high density hardwoods is common in Australian timbers. Work is under way in the Co-operative Research Centre (CRC) for Wood Innovations (www.crcwood.unimelb.edu.au) to investigate methods of surface treatment to improve bonding performance of hardwoods. Project 2.1 within the CRC deals with 'Surface engineering of… solid wood products for enhanced adhesion and long-term retention of bondability'. Recent work to modify the bonding surfaces of WA karri and jarrah has produced promising results, suggesting that eucalypt bonding can be significantly improved by this technology (Graeme Siemon, FPC, pers. comm.).

6.7.12 Machining trials

The following machining and finishing tests were carried out on a panel of each species by Timber Technology staff at Harvey: sanding, sawing with the grain, sawing across the grain, moulding edges, routing circles, routing crosses and boring. Results of the machining trials are given in Table 29

Table 29. Machining properties of twelve species from southern Western Australia.

Species	Sanding	Sawing with grain (ripping)	Sawing across grain (docking)	Moulding edges	Routing circles	Routing crosses	Boring
Acacia aff. redolens	1	1	1	1	2	1	1
Acacia bartleana	1	1	1	1	2	1	1
Eucalyptus accedens	1	1	1	1	1	1	1
Eucalyptus argyphea	1	1	1	1	2	1	2
Eucalyptus clivicola	1	1	1	1	2	1	1
Eucalyptus kondininensis	1	1	1	1	2	1	1
Eucalyptus moderata	1	1	1	1	1	1	1
Eucalyptus occidentalis	1	1	1	1	2	1	1
Eucalyptus ornata	1	1	1	1	2	2	1
Melaleuca preissiana	1	1	1	1	1	1	1
Melaleuca rhaphiophylla	1	1	1	1	2	1	1
Taxandria juniperina	1	1	1	1	2	1	1

1 = Excellent – No further work
2 = Very Good - Minor chipping and fluffiness
3 = Good - Much small chipping, fluffiness, or a few deep chips
4 = Fair - Much small chipping, fluffiness and larger chips or large chips requiring extensive work
5 = Poor - Deep chipping, extensive and almost not worth repairing

All species performed well in these machining tests. Most scores were '1', except for routed circles, for which most species were graded '2'. *Eucalyptus accedens*, *E. moderata* and *Melaleuca preissiana* were rated '1' in all tests.

6.7.13 Colour, grain and texture

Colour of the dressed boards was estimated using the Methuen Handbook of Colour (Kornerup and Wanscher 1978), and comments made on grain and texture. Results are contained in Table 30.

Table 30. Heart colour, grain and texture assessment of twelve species from southern Western Australia.

Species	Inner heart colour	Grain	Texture
Acacia aff. redolens	6C4 Brownish orange	Straight	Fine/medium
Acacia bartleana	6C4 Brownish orange	Straight	Fine/medium
Eucalyptus accedens	5B3 Greyish orange	Slightly interlocked	Fine
Eucalyptus argyphea	6C4 Brownish orange	Slightly interlocked	Fine
Eucalyptus clivicola	5B4 Greyish orange	Slightly interlocked	Fine
Eucalyptus kondininensis	6C4 Brownish orange	Slightly interlocked	Fine
Eucalyptus moderata	8E4 Reddish brown	Slightly interlocked	Fine
Eucalyptus occidentalis	6B4 Greyish orange	Slightly interlocked	Fine
Eucalyptus ornata	7D4 Light brown	Slightly interlocked	Fine
Melaleuca preissiana	8E5 Greyish orange	Straight	Medium
Melaleuca rhaphiophylla	7D5 Light brown	Straight	Medium
Taxandria juniperina	5B3 Greyish orange	Straight	Medium/coarse

6.7.14 Summary - sawn timber testing

This section of the Search Project tested the wood characteristics of twelve species not previously tested, to investigate their potential utilisation for sawn timber. A selection of results is summarised in Table 31.

The selected species included nine high density timbers (two acacias and seven eucalypts) and three lower density timbers (two melaleucas and *Taxandria juniperina*). The lower density species occur naturally in moist areas, and are found mostly on the higher rainfall fringes of the Search Project's target area. If grown for commercial timber, they are likely to be restricted to wet sites on farms - either naturally wet sites, or sites to which extra water could be directed. Most of the higher density species occur naturally in lower rainfall areas more typical of the target area, and could be considered for a wider range of sites.

Most species exhibited satisfactory drying behaviour, although lengthy drying regimes were required, especially for the higher density timbers. The exception was *Melaleuca preissiana*, which suffered severe distortion, collapse and surface checking. This species, along with *M. rhaphiophylla* also had high rates of radial and tangential shrinkage during drying (Table 19).

Average recoveries of green sawn timber varied from 52% (*Melaleuca rhaphiophylla*) to 68% (*Eucalyptus accedens*). The small number of logs in the trial (six logs for nine species, three logs for two species, and two logs for one species) made the results variable. For some species, average recoveries were strongly affected by a single poor quality log.

Most species produced a high percentage (62% to 95%) of dressed boards graded as ‘select’ or ‘medium feature’. *Acacia aff redolens* was the exception, with only 29% of boards of this species being graded in those two categories. Borer holes were the main defect in most species, apart from gum pockets in *Eucalyptus argyphea* and *E. ornata*, drying checks in the two melaleucas, and loose knots in *E. occidentalis*.

The lower density species displayed good gluing performance when laminated, but none of the high density species reached the standard (AS 5067-2003) with the adhesive used in this trial, which could reduce the range of uses for which they are suited. Gluing performance could possibly be improved slightly by using a different adhesive, or by chemical modification of the surfaces to be glued, an area of active research within the Cooperative Research Centre for Wood Innovations. All species produced good results in the various machining tests.

In summary, all of the eucalypts and one of the acacias (*Acacia bartleana*) produced reasonably high yields of good quality timber suitable for commercial use. The potential of these species to be grown for commercial sawn timber depends on factors such as their growth rate, form, and the potential impediments of long drying times and poor gluing performance when laminated. These issues would need further investigation if any of these species were to be developed commercially.

Acacia aff redolens, a ‘species’ known from only a few sites to the north and east of Esperance, produced very low recoveries of usable timber. This was partly due to the relatively poor quality of the logs procured for this trial. A more thorough investigation of the natural occurrence of this ‘species’ may uncover stands of better quality trees more suited to timber production. Apart from its poor gluing performance, in common with the other high density species, the wood of this species performed satisfactorily in the various tests.

Melaleuca preissiana was by far the most difficult timber to dry, and could not be recommended for large-scale timber production. However, once the timber was dried and dressed, it performed well, especially in machining tests. *Melaleuca rhaphiophylla* behaved much better during drying, and also gave good gluing and machining results.

Taxandria juniperina is a good medium density timber with excellent gluing properties, but the high incidence of borer holes in the timber is a concern and would need further investigation.

Overall the trial indicated that, from a timber utilisation perspective, most of these twelve species have potential for commercial development in Western Australia. However, the poor economics of growing long-cycle timber trees in lower rainfall areas (see Section 7 for a discussion of this issue) is likely to limit their attraction to growers and prevent them from developing into large-scale tree crop industries in this region. Species that can grow satisfactorily on sites not suited to cropping, such as *Eucalyptus occidentalis*, may have a competitive advantage on ‘poorer’ agricultural sites, and therefore have the best commercial prospects.

Table 31. Summary data for twelve tree species from southern Western Australia.

Species	Basic density (kg/m^3)	Green sawn recovery (%)	Dry dressed boards graded 'select' or 'medium feature' (%)	Main defect (with % of boards affected)	Gluing performance	Machining performance
Acacia aff. redolens	768	67.2	29	Borer holes (38%)	Poor	Good
Acacia bartleana	835	59.0	88	Borer holes (45%)	Poor	Good
Eucalyptus accedens	883	68.4	74	Tight knots (24%)	Very Poor	Excellent
Eucalyptus argyphea	828	67.1	68	Gum pockets (39%)	Poor	Good
Eucalyptus clivicola	886	63.2	95	Borer holes (16%)	Very Poor	Good
Eucalyptus kondininensis	921	61.2	89	Tight knots (8%)	Poor	Good
Eucalyptus moderata	919	54.5	94	Loose gum veins (9%)	Poor	Excellent
Eucalyptus occidentalis	771	61.1	74	Loose knots (21%)	Very Poor	Good
Eucalyptus ornata	878	57.2	62	Gum pockets (35%)	Very Poor	Good
Melaleuca preissiana	489	57.3	79	Drying checks (33%)	Marginal	Excellent
Melaleuca rhaphiophylla	440	51.7	62	Drying checks (15%)	Good	Good
Taxandria juniperina	498	57.9	77	Borer holes (34%)	Excellent	Good

6.7.15 Timber appearance

One of the most important characteristics of timber, the attractiveness of its appearance, is not discussed in this report, since this is a very subjective judgment that defies scientific assessment, and is subject to individual preferences and changes in fashion and tastes.

Rather than attempting to describe the wood of each species, photographs of test panels, after routing and drilling tests were completed, are included in this report. See Figure 43 to Figure 54.

Figure 43. ***Acacia aff. redolens*** **- test panel.**

Figure 44. ***Acacia bartleana*** **- test panel.**

Figure 45. *Eucalyptus accedens* - test panel.

Figure 46. *Eucalyptus argyphea* - test panel.

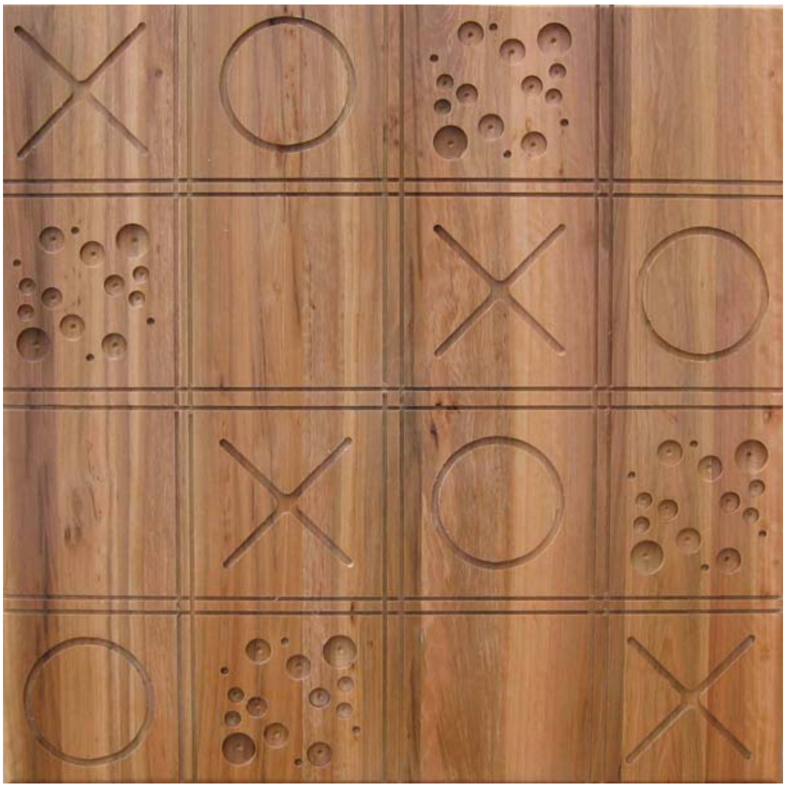


Figure 47. ***Eucalyptus clivicola* - test panel.**

Figure 48. ***Eucalyptus kondininensis* - test panel.**

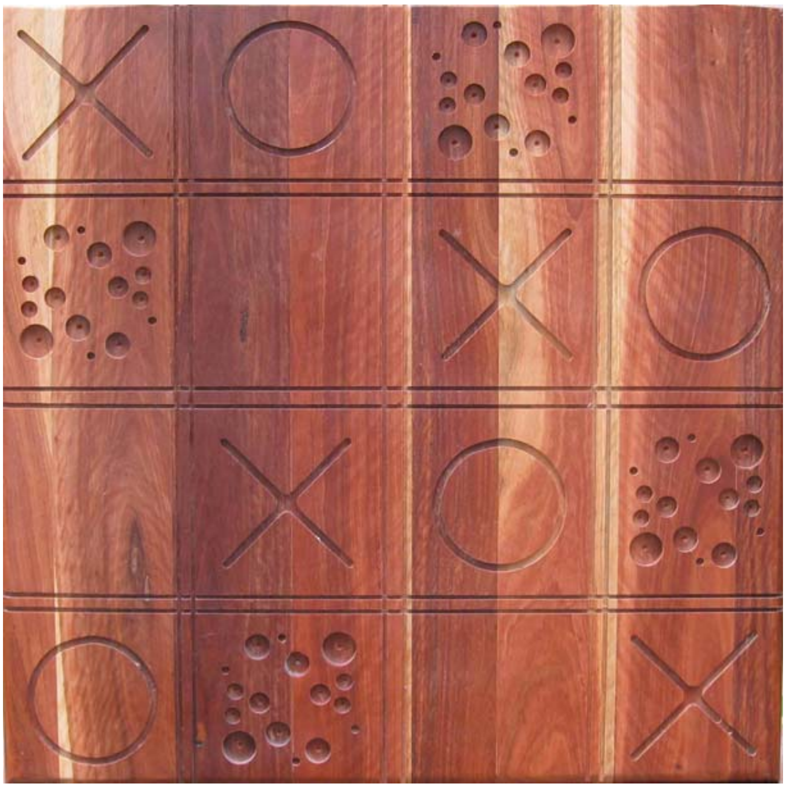


Figure 49. ***Eucalyptus moderata*** **- test panel.**

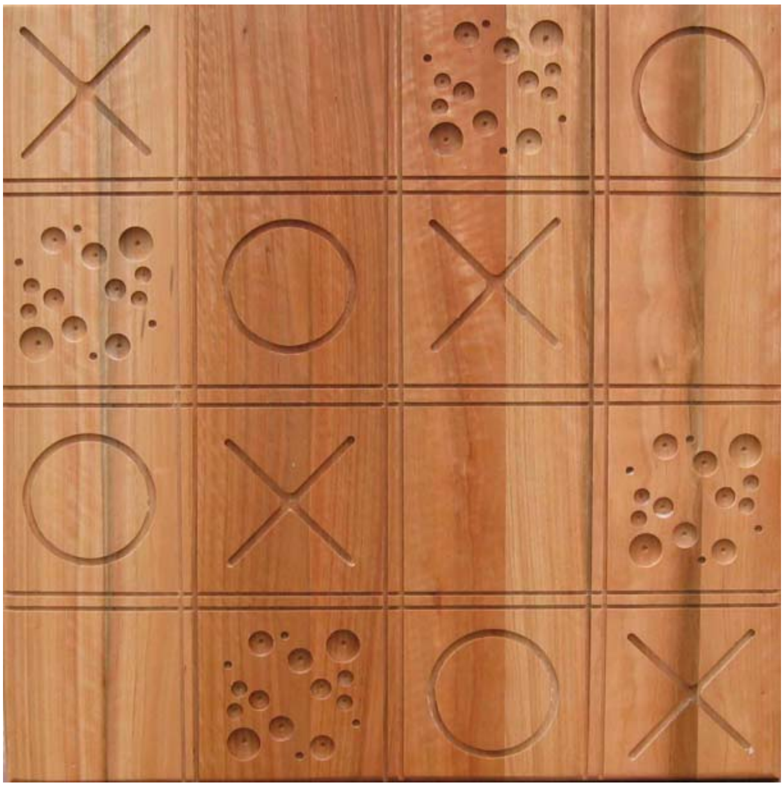


Figure 50. ***Eucalyptus occidentalis*** **- test panel.**

Figure 51. *Eucalyptus ornata* - test panel.

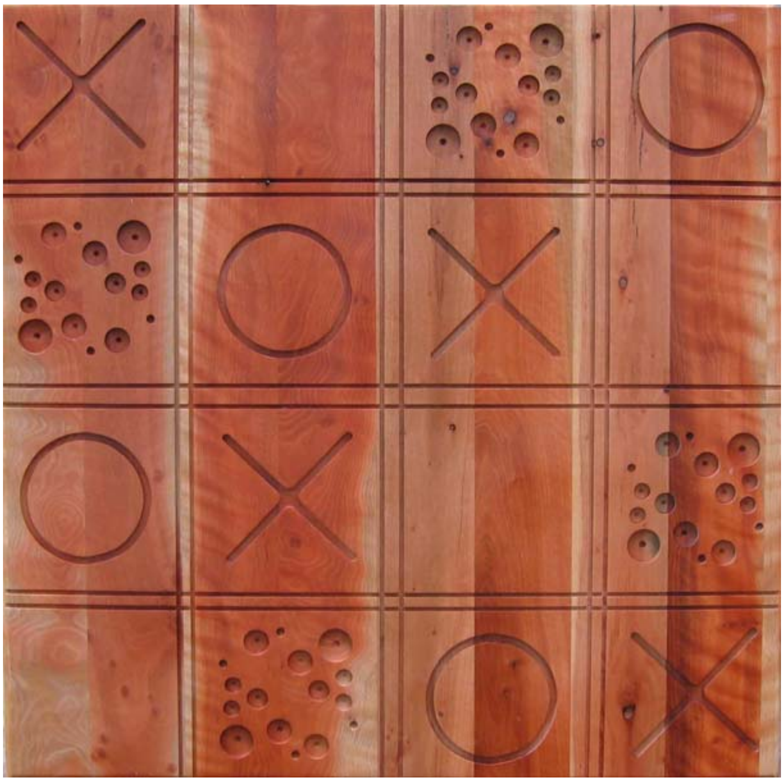


Figure 52. *Melaleuca preissiana* - test panel.

Figure 53. ***Melaleuca rhaphiophylla*** **- test panel.**

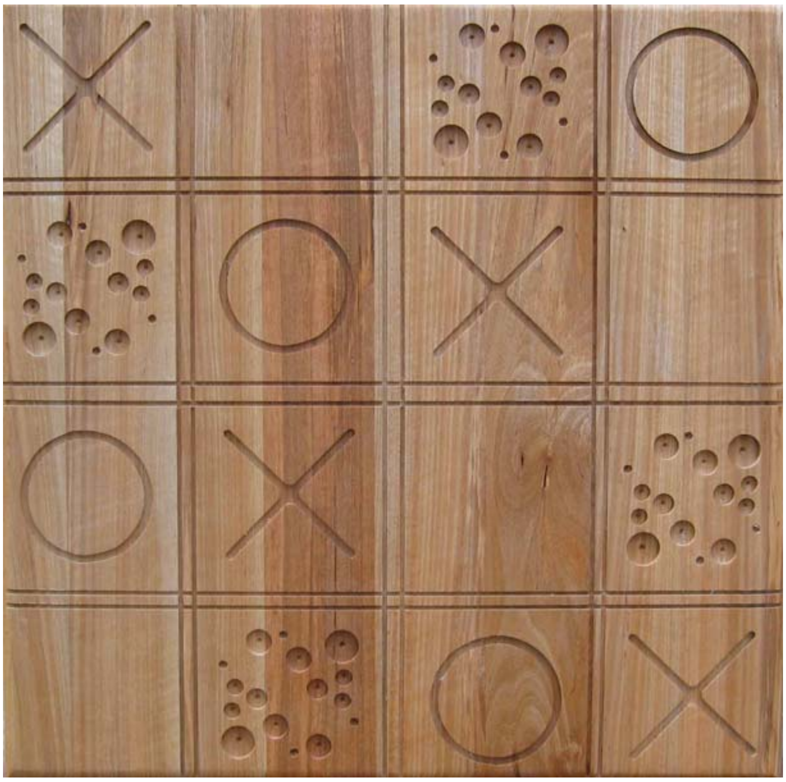


Figure 54. ***Taxandria juniperina*** **- test panel.**

6.8 Laboratory testing – combustion

6.8.1 Technical investigations

Combustion investigations were performed for the Search Project by CSIRO Energy Technology, at facilities in North Ryde and Newcastle in New South Wales. A report of those investigations is contained in Appendix 3.

6.8.2 Introduction

Bioenergy alone is unlikely to drive new crop development. Current free-market prices for liquid and solid fuels are too low to support cropping enterprises based solely on energy production. However, bioenergy is likely to be an essential co-product for any new, large-scale industry based on woody crops – both to increase revenue, and to dispose of surplus biomass and process wastes. Pulp and panel board industries are well suited to bioenergy production. These large industries use only the woody fraction of biomass, leaving large volumes of surplus biomass available for bioenergy production, if it can be collected and delivered in an economically efficient way.

Apart from the logistics of handling biomass, feedstock energy characteristics have a major influence on the success and economic performance of bioenergy enterprises. Any solid carbonaceous material, when subjected to high temperatures and sufficient oxygen, will thermally decompose to carbon dioxide and water; the water being due to oxidation of hydrogen in the fuel. The ideal biomass fuel would consist of carbon, hydrogen and oxygen alone. However, in practice, biomass feedstocks usually contain inorganic elements which are converted to ash, and free moisture, which lowers the available energy content of the fuel.

Preliminary investigations were undertaken in the Search Project to test the combustion characteristics of a group of species with potential to become new woody crops. Characteristics tested included the calorific value and ash content of biomass samples, as well as their propensity to cause corrosion or fouling in boilers, due to the formation of undesirable compounds. Formation of these compounds at high temperature is difficult to predict from the constituents of the biomass, as their formation depends on boiler temperature, a range of chemical reactions within the boiler, and the passage of the compounds through the boiler.

CSIRO developed predictive tests in which samples of biomass are combusted in a laboratory-scale furnace. Fouling deposits and high temperature corrosion are measured on metal samples placed in the flue gas stream. These tests provide a reasonable indication of the propensity for these combustion characteristics to occur in practice. However the tests provide neither absolute nor exact measurements. Rather, this testing indicates the characteristics of the particular sample under the laboratory-scale furnace conditions employed. Since biomass is a highly variable feedstock, compared to say coal, the results found by this method for single biomass samples may not hold at larger scales. For example, approximately 100,000 tonnes of biomass would pass through a 10MW electrical boiler and steam turbine plant each year. Intensive testing of many samples of a proposed biomass feedstock would be required before employing it in a bioenergy plant at that scale.

6.8.3 Species selection

Among the Western Australian native woody species that showed the greatest promise in testing for pulp, paper or panel boards, a number were chosen for combustion testing. Because a wide range of species showed aptitude for at least one of these products, a list of 26 species was selected for basic combustion studies. From those species, the 20 most promising were selected for advanced corrosion and fouling tests (Table 32).

Table 32. Species tested for combustion properties.

Species	Standard combustion	Fouling and corrosion
Acacia bartleana Maslin (ms)	✓	
Acacia lasiocalyx	✓	✓
Acacia murrayana	✓	
Acacia rostellifera	✓	
Acacia saligna	✓	✓
Agonis flexuosa	✓	✓
Alyogyne huegelii	✓	✓
Anthocercis littorea	✓	✓
Bursaria occidentalis	✓	✓
Codonocarpus cotinifolius	✓	✓
Eucalyptus astringens	✓	
Eucalyptus erythrocorys	✓	
Eucalyptus kochii ssp plenissima	✓	
Eucalyptus loxophleba ssp lissophloia	✓	✓
Eucalyptus occidentalis	✓	✓
Eucalyptus rudis	✓	✓
Grevillea candelabroides	✓	✓
Grevillea leucopteris	✓	✓
Gyrostemon ramulosus	✓	✓
Hakea oleifolia	✓	✓
Jacksonia sternbergiana	✓	✓
Melaleuca preissiana	✓	✓
Senna pleurocarpa	✓	✓
Taxandria juniperina	✓	✓
Trymalium floribundum	✓	✓
Viminaria juncea	✓	✓

6.8.4 Material collection

Sufficient material was collected to produce at least 1 kg dry weight of each of three plant components – wood, bark, and foliage (a mixture of leaves and twigs). Most of the material was collected in conjunction with collections for pulp and panel board testing. Material was collected from the same populations, and usually from the same plants. Collection locations were recorded, and all collections were accompanied by voucher specimens, to ensure that the taxonomic identity of the material can be confirmed and tracked in future.

All collected material was oven dried at approximately 70 degrees Celsius before shipping to the laboratory. Oven drying at this temperature was designed to dry the material sufficiently to prevent microbial decay, but without causing excessive loss of volatile components, and hence, reduction in calorific value.

At the laboratory, samples of each component (wood, bark and tops) were mixed in equal proportions (1:1:1) to make up composite samples for testing. This ratio was chosen because it is simple and reproducible, not because it is necessarily the ratio of materials that any future bioenergy industry will use. The actual ratio of material used in any new industries will depend on many factors, such as species, age harvested, harvesting strategy and method, and the proportion of plant components used for other products. Since it is not feasible to estimate the most likely feedstock ratio for future bioenergy applications using these species, the simple 1:1:1 ratio was used in these tests.

6.8.5 Standard combustion tests

The first part of this investigation involved testing the basic combustion characteristics of each species to determine its proximate analysis (ash, volatile matter and fixed carbon content), calorific value, ultimate analysis (composition of major elements) and ash fusion temperature (a measure of the likelihood of ash softening and creating fouling problems by sticking to boiler surfaces). These standard tests for materials being considered for combustion uses were performed for CSIRO Energy Technology by the Newcastle laboratories of CCI Australia Pty Ltd.

Selected results from basic combustion testing of 26 Western Australian native species are presented in Table 34. These results are expressed on a dry basis, to enable meaningful comparisons to be made between species, and between these species and other fuel types. However, in reality, moisture content has a large effect on combustion properties, especially calorific value, and is an important determinant of the value of a material for combustion purposes. For materials with a low ash content, the effect of moisture content on calorific value is approximately linear. For example dry biomass with a gross calorific value (GCV) of 20MJ/kg would have a GCV of about 10MJ/kg at a moisture content of 50% (expressed as a percentage of its green weight).

Ash is produced by the non-combustible, inorganic components of a fuel, and therefore has a negative, diluting effect on its calorific value. Apart from being an added material handling cost, the other potential negative aspect of ash is that it can present a disposal problem. Although there is a range of potential uses for ash, many of these are constrained by the nature of the ash and its constituents, especially its pH, and its heavy metal content. Even for chemically benign ashes, the uses to which they can be put are limited and are rarely profitable for the ash producer, although they may reduce the cost of disposal. The ash content of biomass and its chemical nature are determined by a range of factors including species, plant component, and the environment in which it is grown. Therefore, a case-by-case investigation of ash properties is required for any new bioenergy project based on biomass.

Combustion properties presented here are expressed on a dry basis, because it is difficult to predict the moisture content these species would contain if used in future bioenergy production. For example, biomass could be used directly from the field with little or no delay or pre-treatment, in which case it would have high moisture content. Typical “green” biomass often has a moisture content around 50%. Alternatively, green biomass could be partially dried, either passively by allowing it to lie in the field for some time before collection, or by active methods. For example, in an integrated treatment plant, it would be possible to use surplus low-level heat to dry biomass before combustion, to increase its calorific value. In many cases, biomass destined for combustion would be waste material from a processing stage to extract some other commercial product, in which case the moisture content of the biomass residue would depend on the process conditions.

Combustion data for some other organic materials are presented in Table 33, for comparison with data for the native species tested in this project. Most of this data was extracted from the on-line 'Biofuels Database' (CSIRO Energy Technology 2002) at http://www.det.csiro.au/science/energyresources/biomass.htm. Other Internet sources of combustion data include:

BioBase http://www.ieabioenergy-task32.com/database/biobank.html (IEA Bioenergy).

Phyllis http://www.ecn.nl/phyllis/ (Energy Research Centre of the Netherlands (ECN)).

BIOBIB http://www.vt.tuwien.ac.at/biobib/ (University of Technology Vienna).

The data for these other materials (Table 33) also demonstrates the difference between calorific value of materials in their 'as received' state (at the laboratory in this case) and the calorific value of their combustible components, free of moisture and ash. In practice, for the biomass sources with high moisture content, strategies would be employed to reduce moisture content prior to their combustion if it were feasible and economic to do so. For example, wheat straw and sugar cane trash dry rapidly if exposed to air after harvest.

Note that biomass has a lower GCV than coal due to the basic constituents of the fuels. For example, biomass has around 40% oxygen, while bituminous coal has 10% or less.

Table 33. Some combustion data for other bioenergy materials.

Biomass type	% Moisture	% Ash	Gross Calorific Value	
	As received at laboratory			Dry, ash-free
Bituminous coal - Eraring	3.3	22.8	24.7	33.1
Brown coal - Gippsland	60.6	2.3	10.4	27.1
Bagasse	61.5	32.0	5.1	19.6
Sugar cane trash	50.0	9.6	9.0	19.9
Paper sludge	7.8	26.2	13.0	19.2
Dynamic lifter	18.9	32.7	10.1	18.4
Rice hulls	10 0	26.1	12.6	19.0
Wheat straw - WA	56.8	2.8	8.0	19.0

Source: All data was extracted from the Biofuels Database (CSIRO Energy Technology 2002) at http://www.det.csiro.au/science/energyresources/biomass.htm, except moisture content of sugar cane trash, which is an estimate drawn from a technical paper on potential bioenergy options in Thailand, http://www.eppo.go.th/encon/encon-DC-Cogen09-Chap4.doc.

The effect of moisture content and ash content on the calorific value of the 26 native species tested for the Search Project is shown in a series of figures. For comparison, data for coal and several other biomass fuels listed in Table 33 are also included. For the plant species tested, the initial calorific value (Figure 55) is the calorific value when freshly harvested. Much of the variation in calorific value between species at this point is due to variations in moisture content (Figure 56). If the effect of moisture content is removed, the calorific values of the 26 native species are similar (Figure 57). Note that the moisture contents used here for the 26 native species are indicative only. They are the mean values for moisture content found for wood of each species during the wood coring program. In reality, the initial moisture contents of the combustion samples actually used would have differed somewhat from these values due to natural variation in moisture content. Also, the combustion samples included bark and foliage, for which moisture content data were not collected. In a practical sense, these initial moisture contents should be considered to be an upper limit, since drying begins once the material is harvested. As discussed above, the actual moisture content of a biofuel at the point of use depends on the way it is handled and treated between harvest and use.

Residual ash content also reduces the calorific value of a biofuel. The biomass samples tested in this project had relatively low ash contents compared to many other fuel types (Figure 58). The composite effects of moisture content and ash content on the calorific value of each of the native species tested is shown in Figure 60.

After removing the effect on calorific value of ash and moisture, to give a measure of the underlying energy content of the fuel, most biomass has a gross calorific value between 19 and 20.5 MJ/kg. This was found to be the case for most of the samples analysed in this study (Figure 59). The exception was *Taxandria juniperina*, which had a surprisingly high GCV of 22.7 MJ/kg (dry basis), or 23.1 MJ/kg (dry, ash-free basis). Elevated calorific values in biomass are usually due to unusual factors such as high oil content. The reason for an elevated GCV in *Taxandria juniperina* was not examined, but is likely to be due to oil content, a feature of many species in this genus. Elevated calorific value is of course a positive attribute from a bioenergy perspective. However, depending on the nature of the oil , it may be more profitable to extract the oil for other, higher value uses before combusting the residue.

Table 34. Combustion properties of 26 Western Australian species.

Species	Proximate analysis (%)			Gross Calorific Value		Ultimate analysis (%)				
	Ash at 815°C	Volatile Matter	Fixed Carbon	MJ/kg	kcal/kg	Carbon	Hydrogen	Nitrogen	Sulphur	Oxygen
Acacia bartleana Maslin (ms)	2.2	74.1	23.7	20.42	4878	51.5	5.94	1.37	0.12	38.9
Acacia lasiocalyx	1.8	80.1	18.1	19.54	4668	49.3	5.96	1.01	0.12	41.8
Acacia murrayana	1.5	78.2	20.3	19.80	4730	49.9	6.07	1.91	0.10	40.5
Acacia rostellifera	5.3	75.3	19.4	18.55	4430	47.8	5.52	0.88	0.32	40.2
Acacia saligna	3.3	76.1	20.6	19.18	4582	48.8	5.74	1.20	0.21	40.8
Agonis flexuosa	3.7	77.3	19.0	19.22	4590	49.0	5.70	0.50	0.09	41.0
Alyogyne huegelii	5.1	72.0	22.9	17.89	4272	46.5	5.48	0.60	0.28	42.0
Anthocercis littorea	4.5	77.8	17.7	18.23	4354	46.6	5.74	1.17	0.16	41.8
Bursaria occidentalis	2.6	78.9	18.5	19.95	4764	49.9	6.01	0.63	0.06	40.8
Codonocarpus cotinifolius	4.0	79.6	16.4	19.44	4644	48.4	5.02	1.39	0.66	40.5
Eucalyptus astringens	1.6	75.3	23.1	20.46	4886	51.3	5.87	0.45	0.06	40.7
Eucalyptus erythrocorys	2.2	79.9	17.9	19.16	4576	48.7	5.74	0.41	0.05	42.9
Eucalyptus kochii ssp *plenissima*	2.2	79.8	18.0	19.81	4732	50.2	6.03	0.57	0.08	40.9
Eucalyptus loxophleba ssp *lissophloia*	3.0	76.6	20.4	18.96	4528	48.8	5.79	0.44	0.06	41.9
Eucalyptus occidentalis	2.4	78.2	19.4	19.33	4616	49.4	5.82	0.51	0.07	41.8
Eucalyptus rudis	2.7	80.3	17.0	19.37	4626	48.9	5.97	0.66	0.08	41.7
Grevillea candelabroides	3.2	78.9	17.9	19.02	4542	48.2	5.88	0.41	0.19	42.1
Grevillea leucopteris	3.0	77.9	19.1	18.95	4526	48.7	5.84	0.33	0.11	42.0
Gyrostemon ramulosus	4.8	76.1	19.1	19.04	4548	48.2	5.94	1.72	0.84	38.5
Hakea oleifolia	3.5	75.9	20.6	18.95	4526	48.2	5.75	0.31	0.29	42.0
Jacksonia sternbergiana	2.3	75.9	21.8	19.55	4670	50.4	5.80	1.27	0.10	40.1
Melaleuca preissiana	2.2	80.6	17.2	20.83	4976	51.6	6.23	0.68	0.19	39.1
Senna pleurocarpa	3.3	77.7	19.0	18.84	4500	48.2	5.89	1.05	0.09	41.5
Taxandria juniperina	1.6	78.8	19.6	22.72	5426	50.6	5.98	0.36	0.09	41.4
Trymalium floribundum	3.2	77.4	19.4	19.04	4548	48.6	5.81	0.57	0.00	41.8
Viminaria juncea	2.0	72.8	25.2	19.74	4714	51.8	5.85	1.11	0.10	39.1
Mean	3.0	77.4	19.7	19.46	4648	49.2	5.82	0.83	0.17	41.0

Note: All samples were mixtures of 1/3 wood, 1/3 bark and 1/3 leaf and twig. All results are reported on a dry basis. Sulphur is total sulphur; oxygen is calculated by difference.

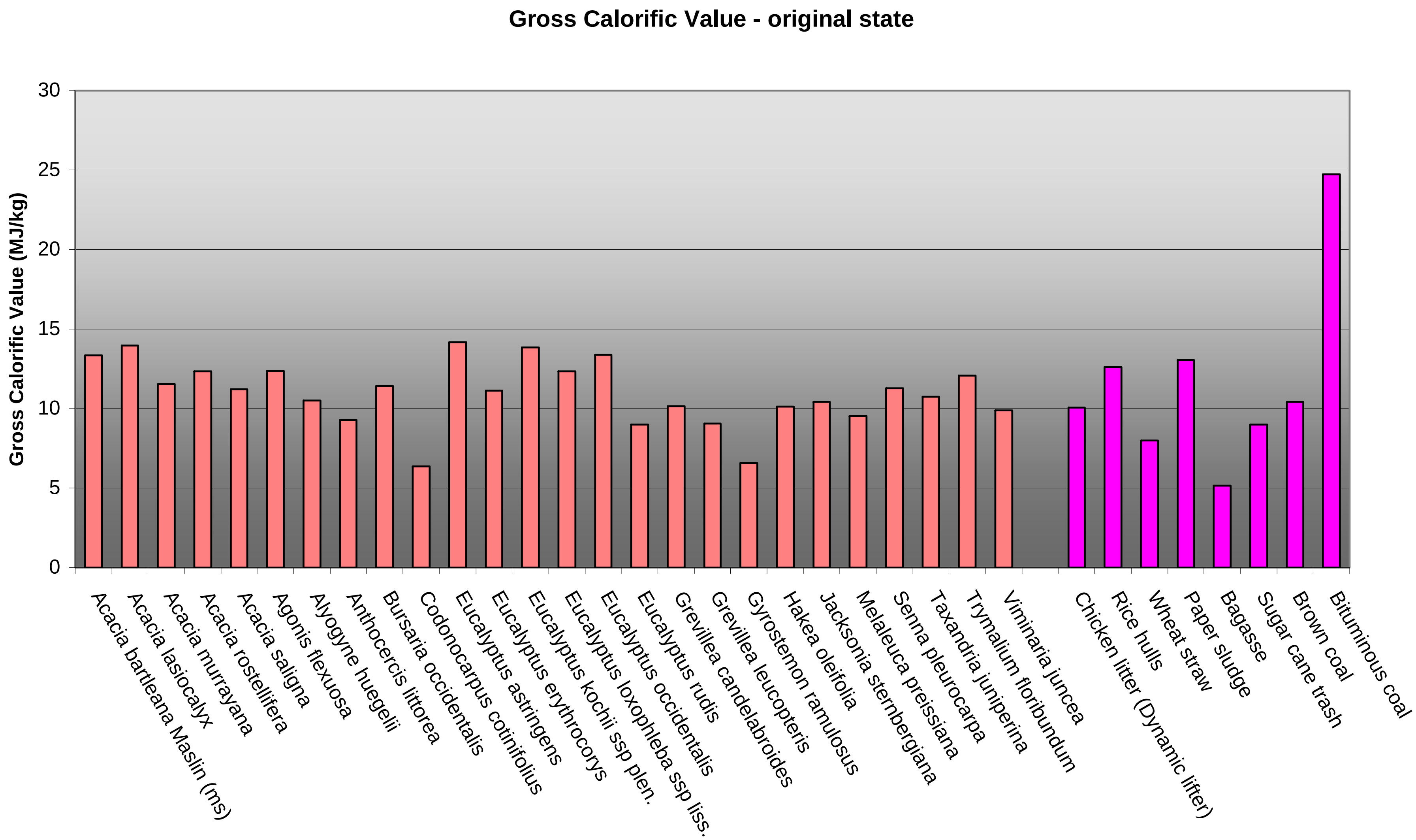


Figure 55. Gross calorific value of 26 Western Australian species - original state.

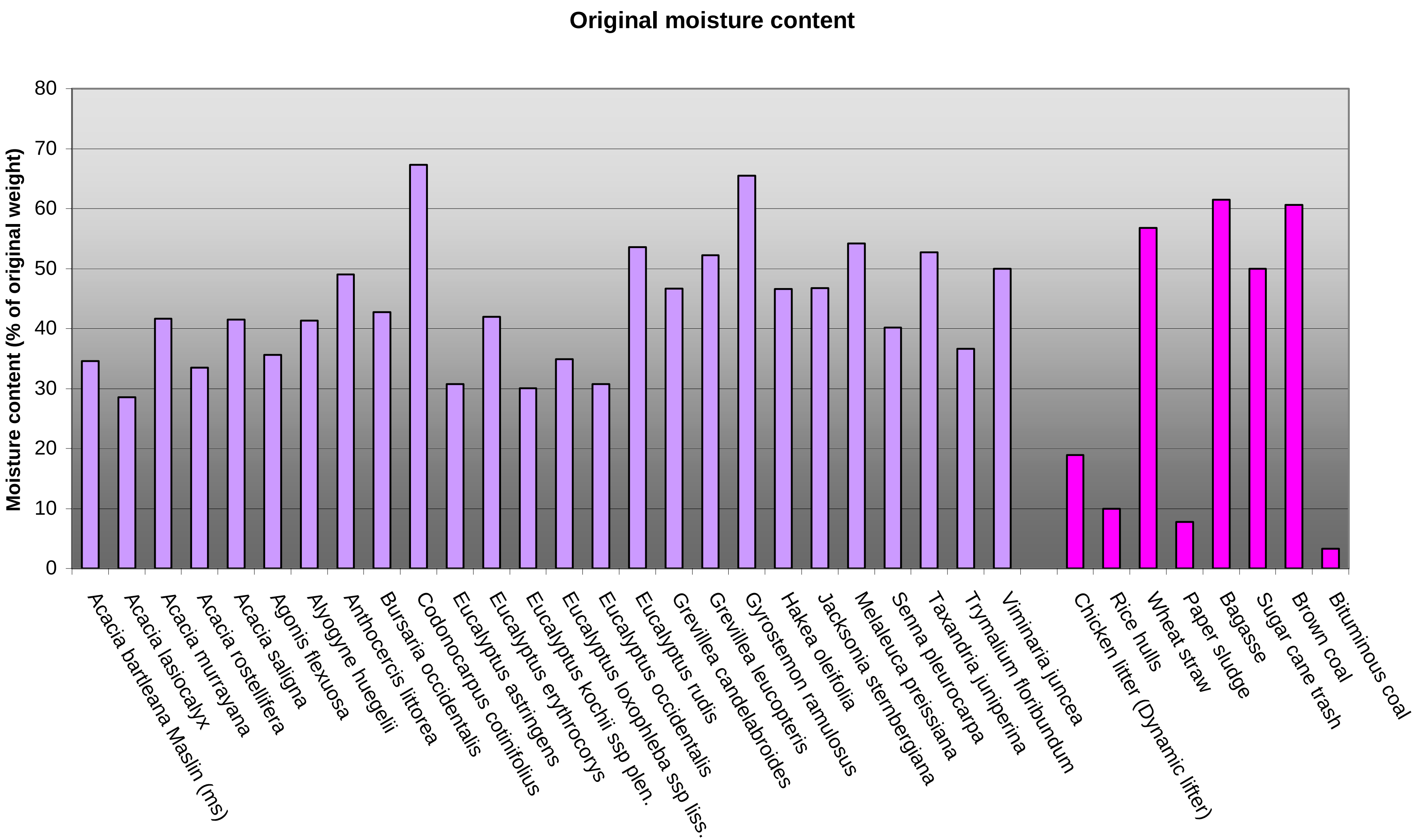


Figure 56. Moisture content of 26 Western Australian species.

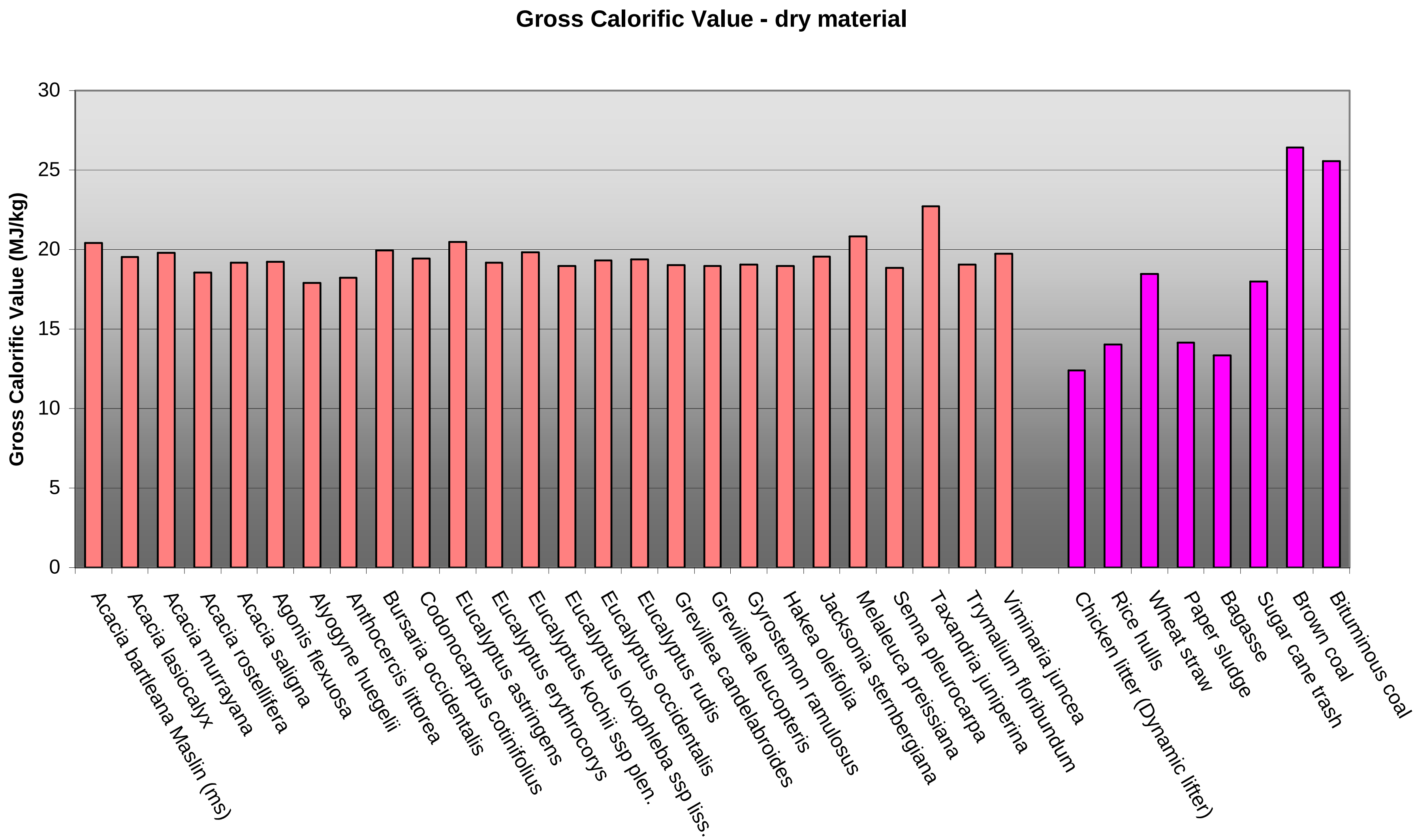


Figure 57. Gross calorific value of 26 Western Australian species - dry material.

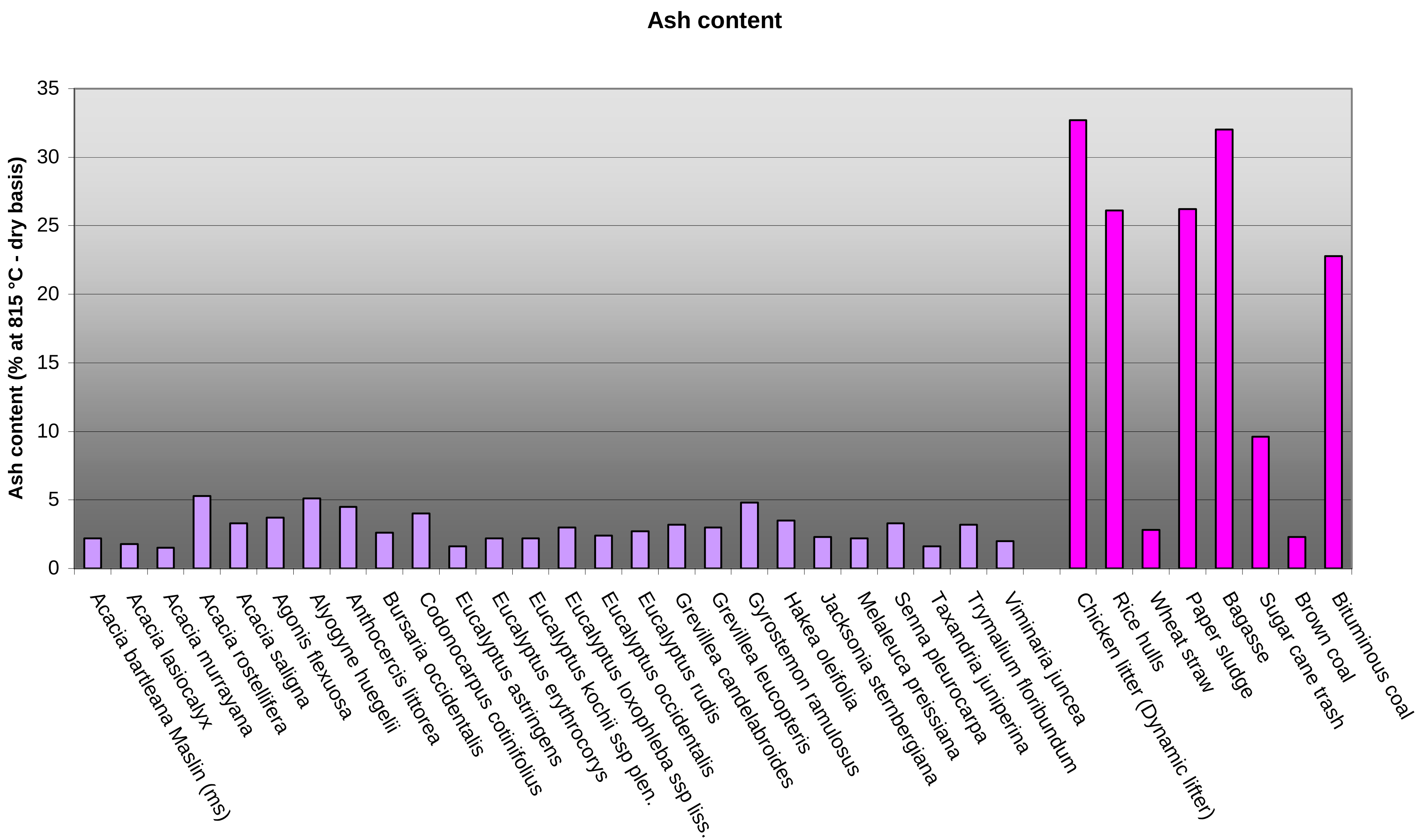


Figure 58. Ash content of 26 Western Australian species – dry basis.

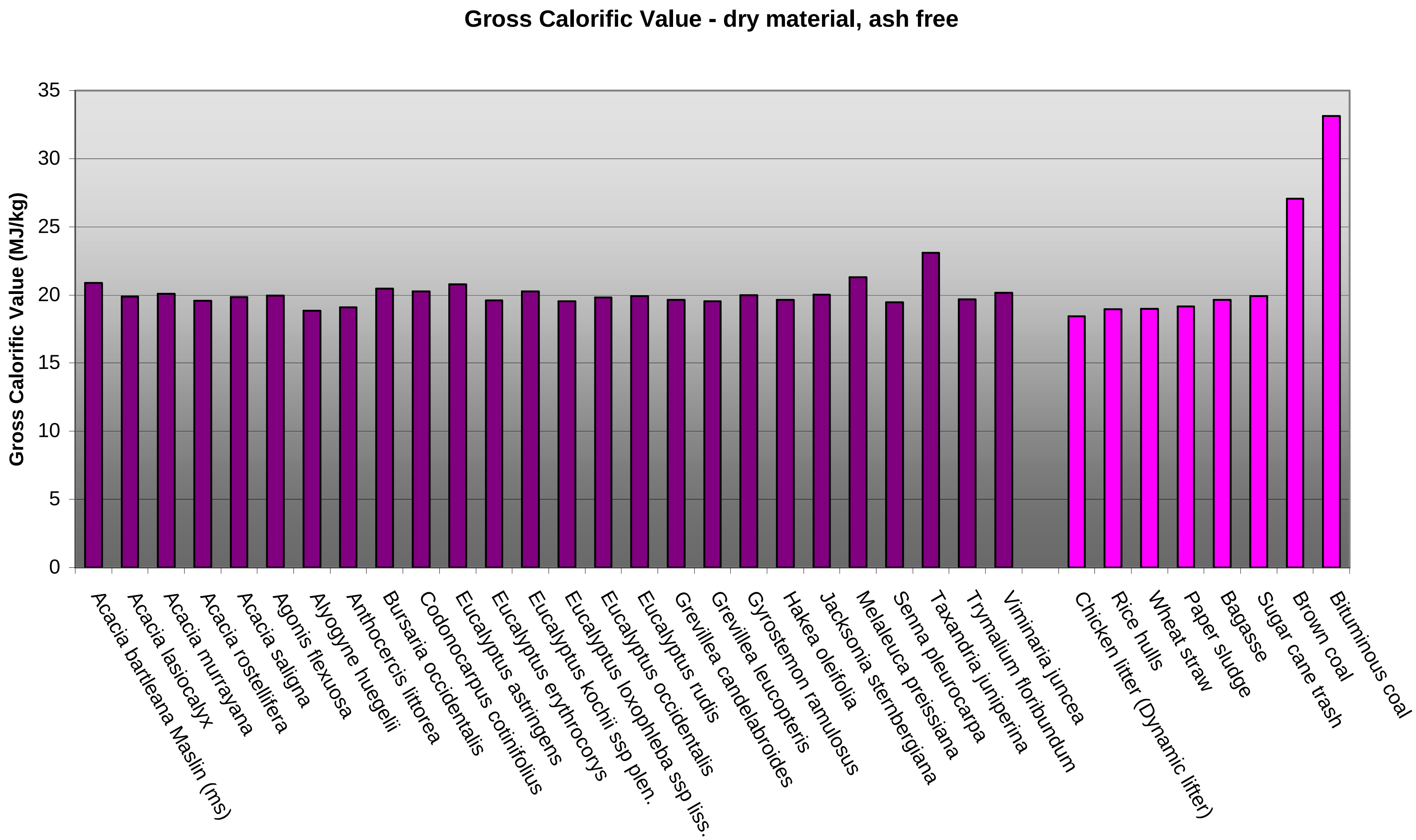


Figure 59. Ash-free gross calorific value of 26 Western Australian species – dry basis.

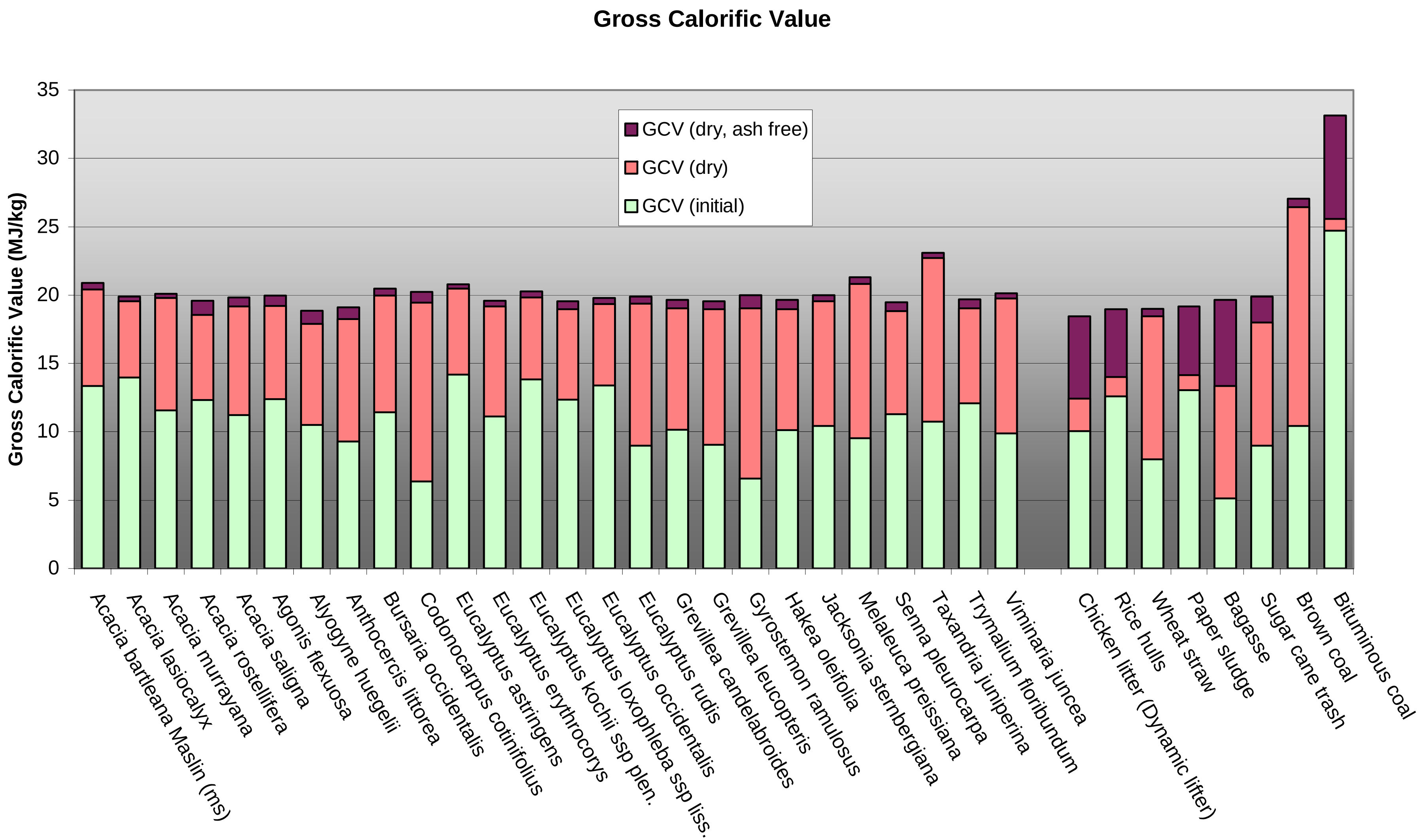


Figure 60. Gross calorific value of 26 Western Australian species – initial, dry and ash free basis.

6.8.6 Combustion data for individual plant components

Some combustion data are available for individual plant components of potential agroforestry species for low to medium rainfall agricultural areas of southern Australia (Table 35). The combustion characteristics of collected material was tested by CSIRO Energy Technology, as part of a bioenergy project sponsored jointly by the Australian Greenhouse Office (AGO), Joint Venture Agroforestry Program (JVAP) and the Murray-Darling Basin Commission (MDBC). As part of a national collection, material was collected from a number of species growing on farms in Western Australia, including a batch of *Acacia saligna* collected by the Search Project.

Combustion properties were analysed for 1:1:1 mixtures of wood, bark and foliage (as in the Search Project), but as well, the plant components of some species were tested individually. The results for gross calorific value (Figure 61) show variation between plant components, partly due to differing ash contents (Figure 62). For all species shown here, the ash content of the wood was less than 1%, but ash contents of foliage and bark were up to an order of magnitude greater. The highest ash contents were in *Eucalyptus globulus* bark (6.5%) and *Acacia saligna* foliage (6.1%).

Table 35. Combustion data for plant components of six agroforestry species.

	Wood	Bark	Foliage	WBF mix
Gross Calorific Value - dry basis (MJ/kg)				
Acacia saligna	18.8	19.0	19.5	19.2
Eucalyptus cladocalyx	19.2	18.2	21.6	19.7
Eucalyptus globulus	19.0	16.5	21.7	19.2
Eucalyptus horistes	19.5	19.5	21.2	20.0
Pinus brutia	20.0	17.6	20.1	19.2
Pinus pinaster	19.7	20.4	20.7	20.3
Ash content (% dry weight)				
Acacia saligna	0.8	3.3	6.1	3.3
Eucalyptus cladocalyx	0.5	3.0	2.6	2.0
Eucalyptus globulus	0.5	6.5	3.7	3.0
Eucalyptus horistes	0.3	1.5	2.1	1.4
Pinus brutia	0.4	5.0	3.4	2.9
Pinus pinaster	0.4	2.0	2.4	1.6
Gross Calorific Value - dry basis, ash free (MJ/kg)				
Acacia saligna	19.0	19.7	20.8	19.8
Eucalyptus cladocalyx	19.3	18.8	22.2	20.1
Eucalyptus globulus	19.1	17.7	22.5	19.8
Eucalyptus horistes	19.5	19.8	21.6	20.3
Pinus brutia	20.1	18.5	20.8	19.8
Pinus pinaster	19.7	20.8	21.2	20.6

All data was obtained from the Biofuels Database (CSIRO Energy Technology 2002) http://www.det.csiro.au/science/energyresources/biomass.htm except WBF mix for Acacia saligna, which was analysed separately for the Search Project (using the same batch of material as used for the individual component tests).

When adjusted for ash content (Figure 63) some clear differences between components remain. The foliage of all three eucalypts had higher calorific values than their corresponding woods and barks, most likely due to the presence of combustible oils in the foliage.

In all cases, mixed samples (WBF mix) produced results that were close to the mean of the results for the components in the mixture. Similar relationships to those observed in this group of samples are likely to hold for other species tested within the Search Project as mixed samples.

These results demonstrate that the combustion performance of biomass from agroforestry species will be influenced by the type of plant components that are used. For example, if much of the wood component is removed for other uses, such as pulping or panel board manufacture, then the residual biomass will have a higher ash content than if the wood component was also included.

Two variables that affect calorific value are ash content and more importantly, moisture content. The simplest method of reducing ash content is to segregate out plant components with a high ash content before combustion. However, in most cases this is unlikely to be done, unless a suitable use can be found for the segregated plant component, or unless its combustion properties are so poor that its segregation is essential. Moisture content has a great effect on calorific value of biomass, but is relatively simple to manipulate from a technical viewpoint. However, the degree of drying that occurs to a biofuel prior to combustion will be determined by economic considerations. Even simple techniques such as allowing biomass to air-dry in the field after harvest may be uneconomic if the cost of collecting the material is increased significantly as a result.

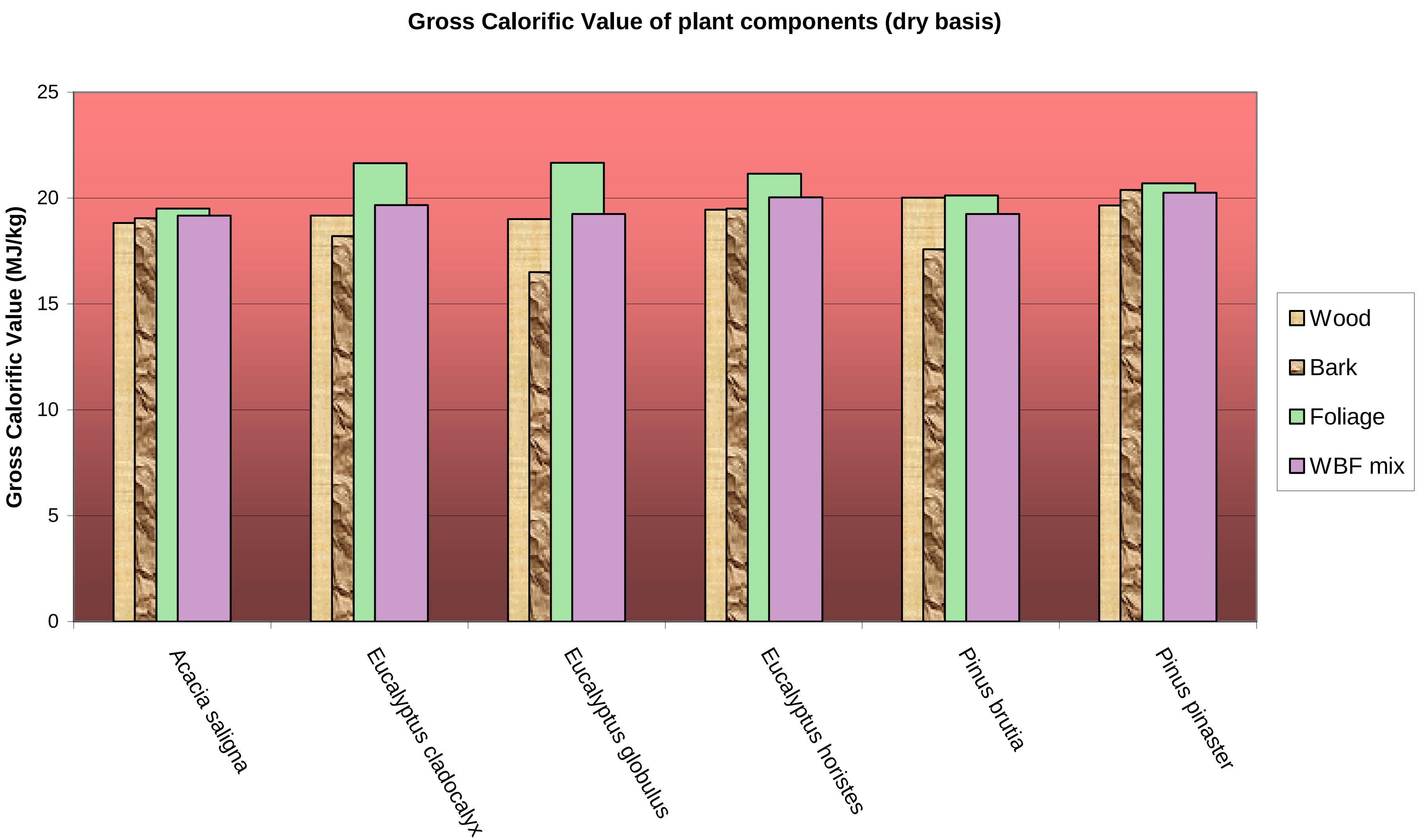


Figure 61. Gross calorific value of plant components (dry basis) - wood, bark, foliage and all three mixed (WBF mix).

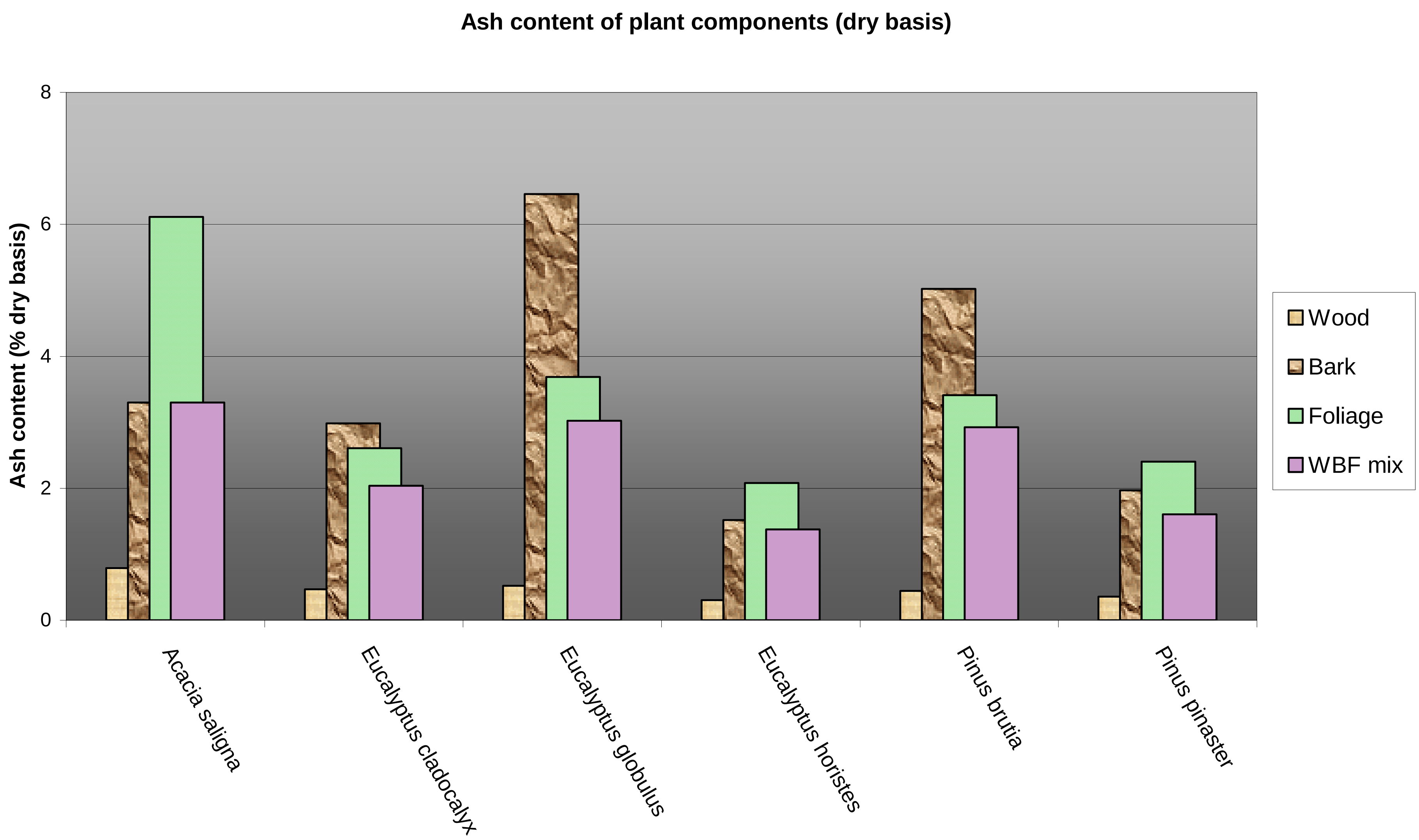


Figure 62. Ash content of plant components (dry basis) - wood, bark, foliage and all three mixed (WBF).

Figure 63. Gross calorific value of plant components (dry basis, ash free) - wood, bark, foliage and all three mixed (WBF).

6.8.7 Ash fusion temperature

For the 26 native species included in these combustion tests, ash fusion temperatures are reported in Table 37. Values for each species for the lowest category of temperatures (when the ash begins to deform) are displayed in Figure 64. Note that the limit of measurement in these tests was 1560°C.

In addition, ash fusion temperature data for individual plant components of six agroforestry species was obtained from the Biofuels Database (CSIRO Energy Technology 2002) and arranged in Table 36. These data were collected during the joint AGO, JVAP and MDBC bioenergy project described above. Data for the lowest temperature, at which ash from these species begins to deform is shown in Figure 65.

Table 36. Ash fusion temperatures for plant components of six agroforestry species.

	Wood	Bark	Foliage	WBF mix
Ash fusion temperature - Deformation				
Acacia saligna	1360	1400	>1560	1545
Eucalyptus cladocalyx	>1560	1340	1220	>1560
Eucalyptus globulus	1550	1400	1510	1450
Eucalyptus horistes	1230	1490	>1560	>1560
Pinus brutia	1260	1445	>1560	1400
Pinus pinaster	>1560	>1560	>1560	1480
Ash fusion temperature - Sphere				
Acacia saligna	1440	1450	>1560	1550
Eucalyptus cladocalyx	>1560	1360	1240	>1560
Eucalyptus globulus	>1560	1440	1520	1515
Eucalyptus horistes	1250	1495	>1560	>1560
Pinus brutia	1280	1450	>1560	1420
Pinus pinaster	>1560	>1560	>1560	>1560
Ash fusion temperature - Hemisphere				
Acacia saligna	1460	1460	>1560	1555
Eucalyptus cladocalyx	>1560	1380	1260	>1560
Eucalyptus globulus	>1560	1445	1530	1520
Eucalyptus horistes	1270	1500	>1560	>1560
Pinus brutia	1290	1455	>1560	1430
Pinus pinaster	>1560	>1560	>1560	>1560
Ash fusion temperature - Flow				
Acacia saligna	1480	1460	>1560	>1560
Eucalyptus cladocalyx	>1560	1400	1280	>1560
Eucalyptus globulus	>1560	1450	1540	1570
Eucalyptus horistes	1300	1510	>1560	>1560
Pinus brutia	1320	1460	>1560	1440
Pinus pinaster	>1560	>1560	>1560	>1560

All data was obtained from the Biofuels Database (CSIRO Energy Technology 2002) http://www.det.csiro.au/science/energyresources/biomass.htm except WBF mix for Acacia saligna, which was analysed separately for the Search Project (using the same batch of material as used for the individual component tests).
Note: The limit of measurement in this test was 1560°C.

Above its fusion temperature, ash begins to soften and stick to boiler surfaces, creating a potential fouling nuisance. Fouling risk in a combustion chamber is therefore reduced if the ash fusion temperature of the fuel is higher than the prevailing combustion temperature.

All of the native species tested for the Search Project (Figure 64) had ash fusion temperatures of 1400^{o}C or greater, performing well relative to other biomass types tested such as wheat straw, bagasse and sugar cane trash. Most combustors dedicated to biomass operate below the lowest ash fusion temperature measured for these samples, however coal-fired boilers do operate at higher furnace temperatures and so biomass co-firing with coal may present a fouling issue for those samples with lower ash fusion temperatures.

Among the six species for which individual components were analysed (Figure 65), fusion temperatures varied between plant components and between species, with no clearly discernible pattern. However, it is clear that the fouling potential of each species is affected by the plant components that are combusted. Therefore, if a new bioenergy species is to be used for combustion, careful testing is required of the mix of plant components that are likely to be utilised.

Table 37. Ash fusion temperatures for 26 Western Australian species.

Species	Ash fusion temperature (°C)			
	Deformation	Sphere	Hemisphere	Flow
Acacia bartleana Maslin (ms)	>1560	>1560	>1560	>1560
Acacia lasiocalyx	1520	1525	1530	1535
Acacia murrayana	>1560	>1560	>1560	>1560
Acacia rostellifera	1455	1460	1465	1470
Acacia saligna	1545	1550	1555	1560
Agonis flexuosa	1445	1450	1455	1470
Alyogyne huegelii	1480	1500	1510	1520
Anthocercis littorea	1525	1530	1535	1540
Bursaria occidentalis	1525	1530	1535	1540
Codonocarpus cotinifolius	1520	1525	1530	1540
Eucalyptus astringens	>1560	>1560	>1560	>1560
Eucalyptus erythrocorys	1550	1555	1560	>1560
Eucalyptus kochii ssp plenissima	1525	1530	1535	1550
Eucalyptus loxophleba ssp lissophloia	1425	1430	1435	1440
Eucalyptus occidentalis	>1560	>1560	>1560	>1560
Eucalyptus rudis	1485	1490	1495	1500
Grevillea candelabroides	1425	1430	1435	1440
Grevillea leucopteris	1480	1485	1490	1500
Gyrostemon ramulosus	1520	1530	1550	1560
Hakea oleifolia	1525	1530	1535	1540
Jacksonia sternbergiana	1530	1535	1540	1550
Melaleuca preissiana	1400	1405	1410	>1560
Senna pleurocarpa	1495	1500	1505	1510
Taxandria juniperina	1525	1530	1535	1540
Trymalium floribundum	1470	1475	1480	1500
Viminaria juncea	1505	1510	1515	1525

Note: All samples were mixtures of 1/3 wood, 1/3 bark and 1/3 leaf and twig.

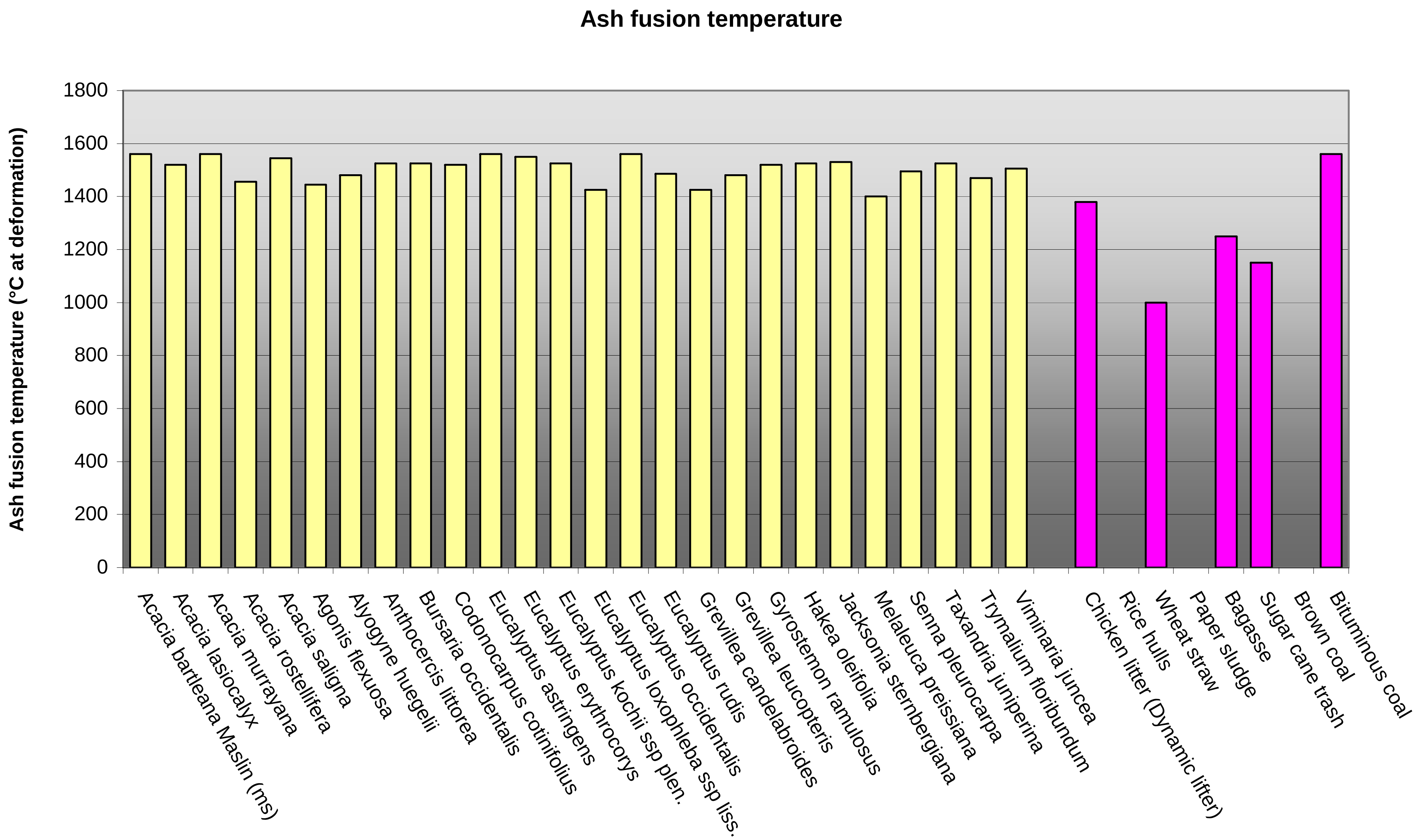


Figure 64. Ash fusion temperature at deformation for 26 Western Australian species and 5 other fuel materials.

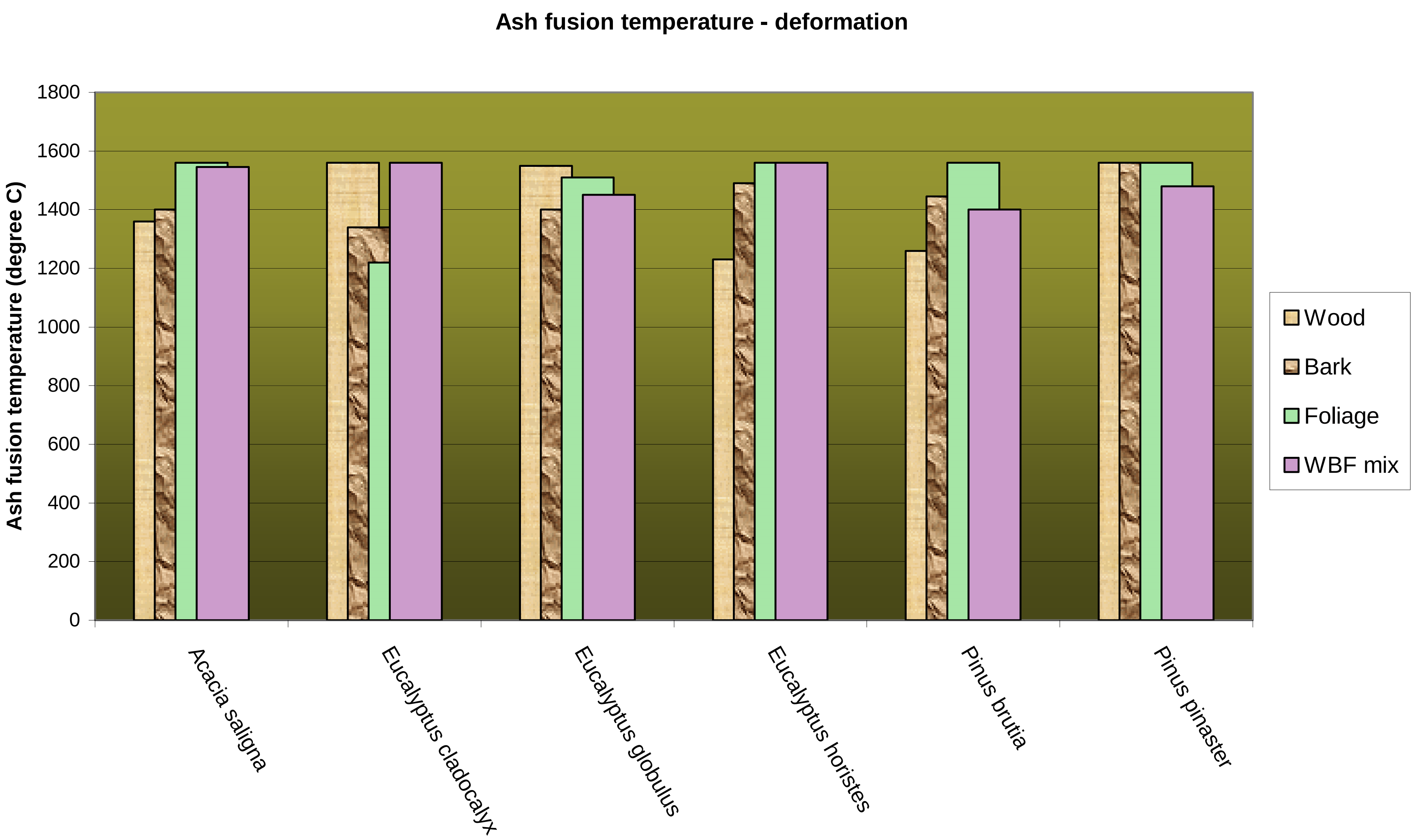


Figure 65. Ash fusion temperature at deformation for plant components and wood-bark-foliage mixtures.

6.8.8 Corrosion and fouling tests

Volatile components from biomass fuels, and vapours formed during their combustion are able to corrode and foul metal surfaces. In the second part of this study, the potential for each test species to cause corrosion and fouling of boiler tubes and heat exchanger surfaces was examined by CSIRO Energy Technology, using a proprietary in-house method. A schematic diagram of the equipment and process is shown in Figure 66. In a simple way, this test simulates the initiation of fouling or corrosion on variable surfaces at different temperatures in a conventional boiler.

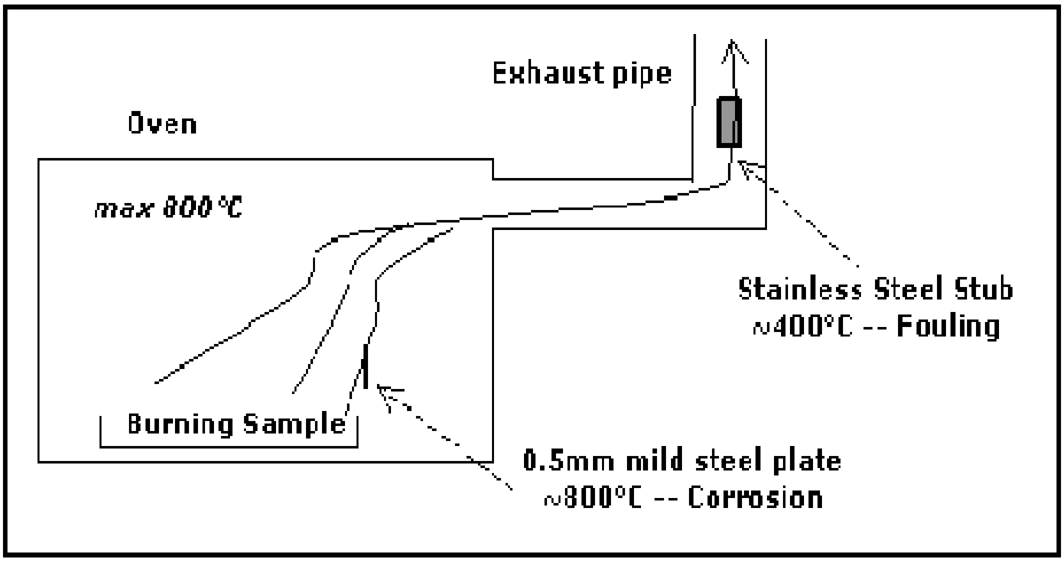


Figure 66. Laboratory set-up for prediction of combustion-related corrosion and fouling.

The test process includes the following steps:

- Biomass is slowly burnt at temperatures up to 800°C with convective air passing over the sample.
- A mild steel plate is positioned close to the burning fuel, so that corrosion can occur on both surfaces at approximately 800°C.
- Corrosion of the plate is examined in cross-section using a scanning electron microscope (SEM). Two measurements are made (Figure 67) to determine the width of the corrosion zone (C) and the amount of wastage of the original steel plate (W). A sample SEM result is shown in Figure 68.
- Measurements of C and W from the steel plate exposed to biomass combustion are compared with similar measurements of C and W from a reference plate exposed to hot air (also at 800^{o}C) in the absence of fuel. Ratios of C and W between the test plate and reference plate are calculated using the following formulae:

  Relative C increase = $C_{biomass} / C_{reference}$

  Relative W increase = $W_{biomass} / W_{reference}$

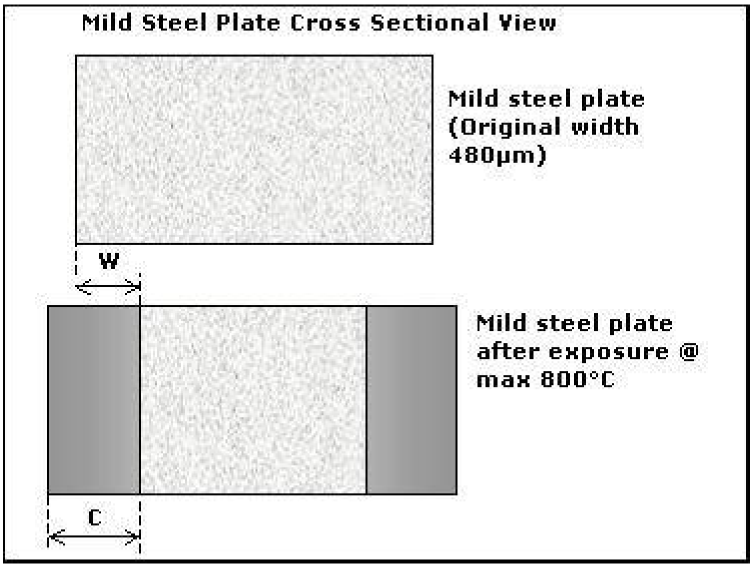


Figure 67. Method for measuring corrosion and wastage on mild steel plate. Source: Biofuels Database (CSIRO Energy Technology 2002) http://www.det.csiro.au/science/energyresources/biomass.htm

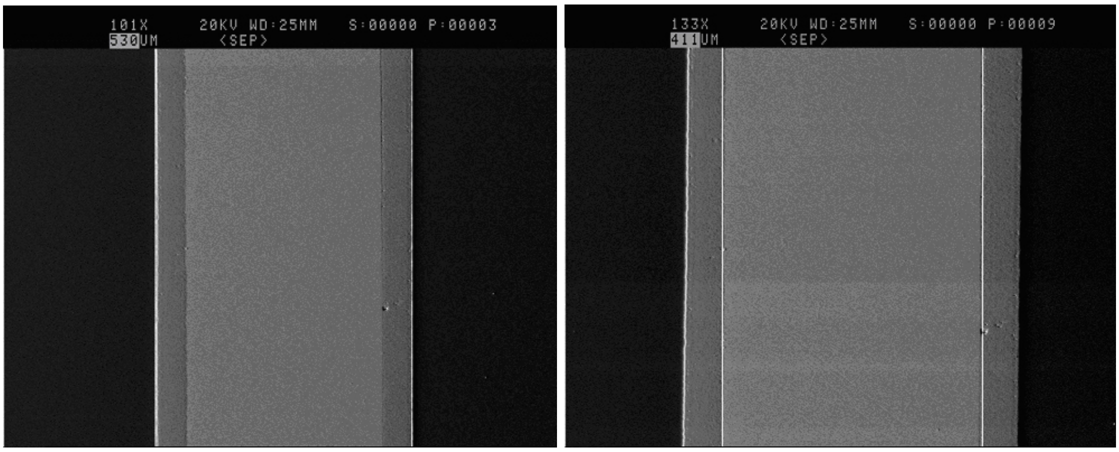


Figure 68. SEM images of corrosion on a mild steel plate at 800°C resulting from combustion of biomass material (*Alyogyne huegelii* in this example). In the left-hand image, the cursor position is used to measure corrosion ($C_{biomass}$), while in the in right-hand image it is used to measure wastage ($W_{biomass}$).

- To estimate fouling, a polished stainless steel stub is positioned upside down in the flue gas stream, where the temperature is approximately 400°C. Fouling deposits on the stainless steel stub are examined by SEM. As an example, the deposit left on the metal stub by the combustion of *Alyogyne huegelii* is shown in Figure 69.
- Energy dispersive X-ray (EDX) spectroscopy is used to identify the elements contributing to the deposits on the stainless steel stub. The example shown here (Figure 70) shows sodium, chlorine and potassium to be the major elements in the ash deposit. These particular elements are commonly associated with compounds that tend to lower ash fusion temperature and cause deposition and fouling.

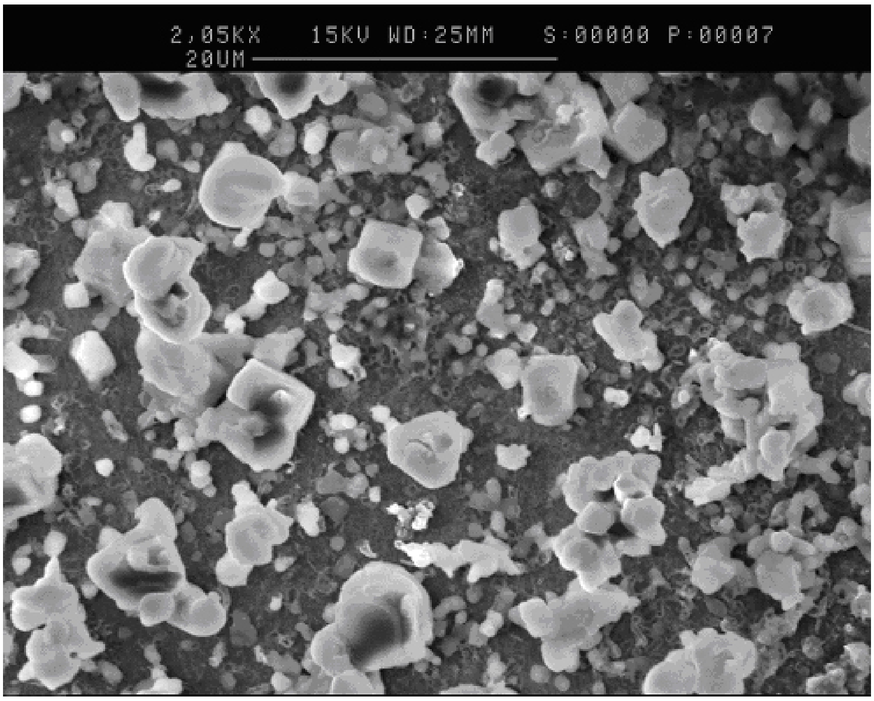


Figure 69. ***Alyogyne huegelii*** **– SEM image of fouling deposit on stainless steel stub.**

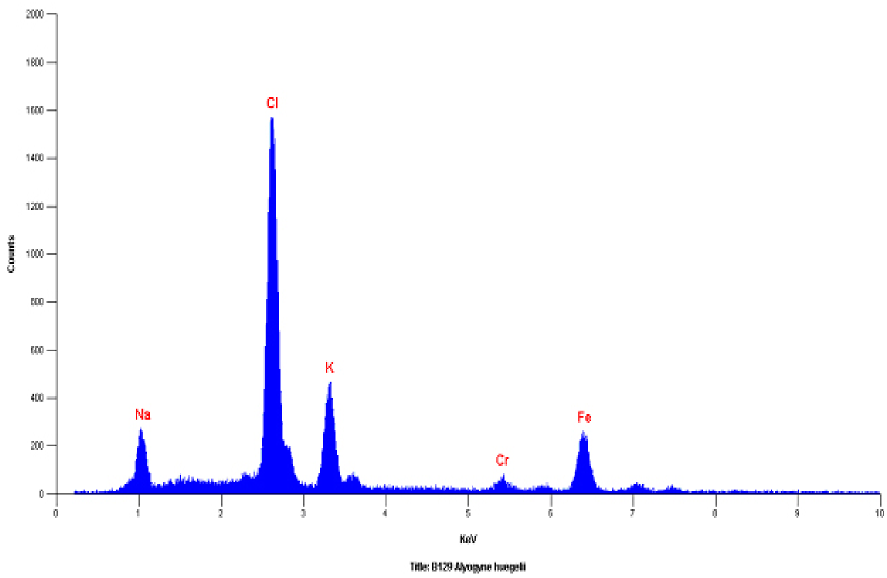


Figure 70. Elemental analysis of a typical area of fouling deposit from *Alyogyne huegelii* by EDX spectroscopy.

6.8.9 Results of corrosion and fouling tests

A summary of results for the corrosion and fouling propensity of the 20 native species tested for the Search Project is contained in Table 38.

No samples were rated as having a high propensity to cause high temperature corrosion. Although *Alyogyne huegelii* and *Gyrostemon ramulosus* were higher than average, they were still within the moderate range relative to other biomass fuels. Data is presented graphically in Figure 71 for wastage of steel plates due to exposure to the combustion gases of each of the 20 native species. Also included is data for several other combustible materials that are either used as fuels or have the potential to be used as fuels. This additional data was extracted from the Biofuels Database (CSIRO Energy Technology 2002) at http://www.det.csiro.au/science/energyresources/biomass.htm.

Similarly, most of the species tested caused only minor fouling of the stainless steel stub in the flue gas. The least fouling (rated negligible) resulted from the combustion of *Codonocarpus cotinifolius*, while the most fouling (rated moderate) was produced by *Anthocercis littorea*, *Bursaria occidentalis*, *Eucalyptus occidentalis*, *Gyrostemon ramulosus*, *Jacksonia sternbergiana*, *Melaleuca preissiana* and *Viminaria juncea*. Potassium and chlorine were the most common elements detected in fouling deposits for all the species tested, while sodium was the third most common.

Scanning electron micrographs of fouling deposits for all of the species tested are presented in Figure 72. They demonstrate the wide variety of fouling behaviour exhibited by these native species, both in the nature of the deposits produced and the amount of fouling.

The results of EDX spectroscopy of fouling deposits for the 20 native species that were tested are shown in Figure 72.

Images of fouling patterns, and analysis of the major elements in fouling deposits for other plant species and fuels are available in the Biofuels Database (CSIRO Energy Technology 2002).

6.8.10 Conclusion

The tests carried out on this group of native Western Australian species showed that all of the species tested have satisfactory characteristics for combustion applications. Their calorific values were within the range of values normally found for biomass, although species with high levels of oils in their foliage appear to have elevated calorific values as a result. Tests of individual components of plants reveal considerable variation in ash content and ash fusion temperature, and minor variations in calorific value. Therefore, the performance of these species in combustion applications will be influenced by the proportion of each plant component that makes up the final feedstock. More importantly, moisture content varies greatly between species and between plant components. Since moisture content has a large effect on calorific value, the way in which biomass is handled (and perhaps treated) before combustion could have a large effect on its moisture content and hence its combustion performance.

Corrosion and fouling tests showed that these species would make acceptable combustion feedstocks, without causing unacceptable corrosion or fouling problems.

Finally, it is important to note that these results are preliminary in nature. Before any of these species are used for commercial combustion applications, more detailed investigation would be required on the specific feedstock that was to be used, especially with respect to proportions of plant components and moisture content. Other issues such as age of material and the environment in which it is produced are also likely to affect a feedstock's performance, but these issues are beyond the scope of this preliminary assessment.

Table 38. Fouling and corrosion results for 20 Western Australian species (selected from 26 species tested for general combustion properties).

Species	Ash at 815^{o}C (% dry basis)	Fouling estimate		Corrosion estimate	
		Stainless steel stub (400^{o}C)	Main elements	Stainless steel (400^{o}C)	Steel (800^{o}C)
Acacia bartleana Maslin (ms)					
Acacia lasiocalyx	1.90	minor	K Cl	negligible	minor
Acacia murrayana					
Acacia rostellifera					
Acacia saligna	2.40	minor	K Cl	minor	minor
Agonis flexuosa	3.20	minor	K Cl	negligible	minor
Alyogyne huegelii	3.95	minor	K Na Cl	negligible	moderate
Anthocercis littorea	4.15	moderate	K Cl Na	minor	minor
Bursaria occidentalis	2.70	moderate	K Cl	negligible	minor
Codonocarpus cotinifolius	3.70	negligible	K Cl	negligible	minor
Eucalyptus astringens					
Eucalyptus erythrocorys					
Eucalyptus kochii ssp plenissima					
Eucalyptus loxophleba ssp lissophloia	3.30	minor	K Cl	negligible	minor
Eucalyptus occidentalis	1.70	moderate	K Cl Na	minor	minor
Eucalyptus rudis	3.40	minor	K Cl	negligible	minor
Grevillea candelabroides	3.20	minor	K Cl	negligible	minor
Grevillea leucopteris	3.70	minor	K Cl	negligible	minor
Gyrostemon ramulosus	4.65	moderate	K Cl	negligible	moderate
Hakea oleifolia	2.60	minor	K Cl	minor	minor
Jacksonia sternbergiana	1.75	moderate	K Cl	negligible	minor
Melaleuca preissiana	2.15	moderate	K Cl Na	minor	negligible
Senna pleurocarpa	3.75	minor	K Cl	negligible	minor
Taxandria juniperina	1.55	minor	K Cl	negligible	minor
Trymalium floribundum	2.80	minor	K Cl	negligible	negligible
Viminaria juncea	1.60	moderate	K Cl Na	minor	minor

Note: Sulphur is total sulphur, oxygen is calculated by difference. All samples were mixtures of 1/3 wood, 1/3 bark and 1/3 leaf and twig. All results are reported on a dry basis.

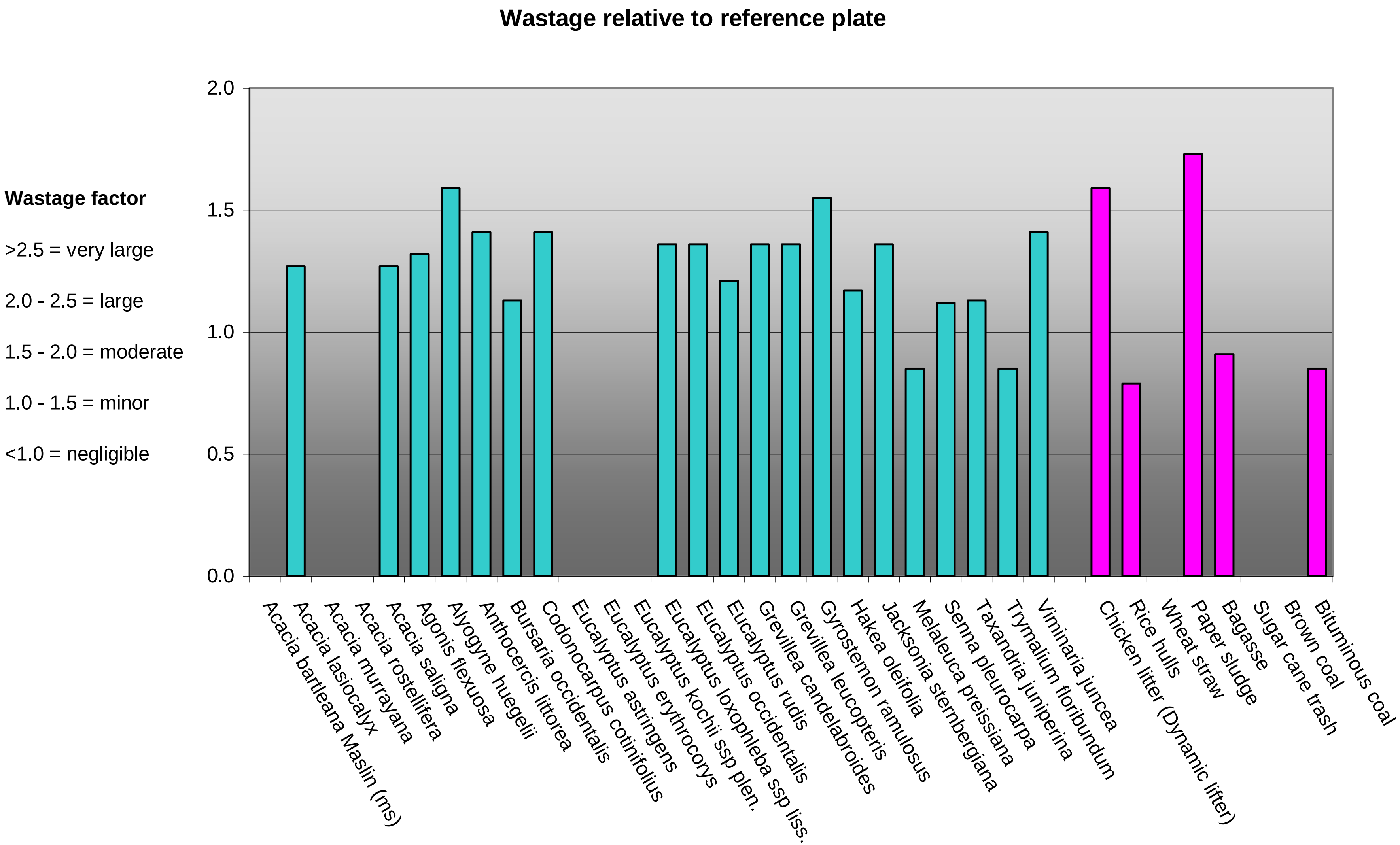
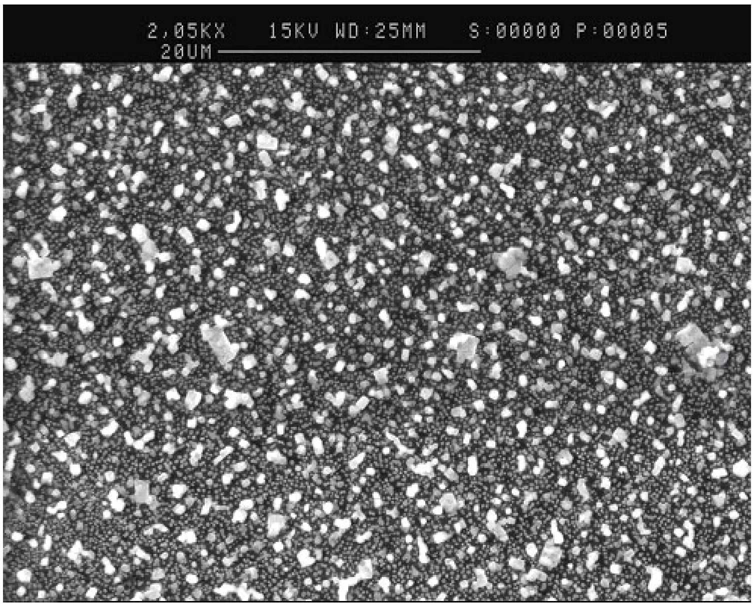
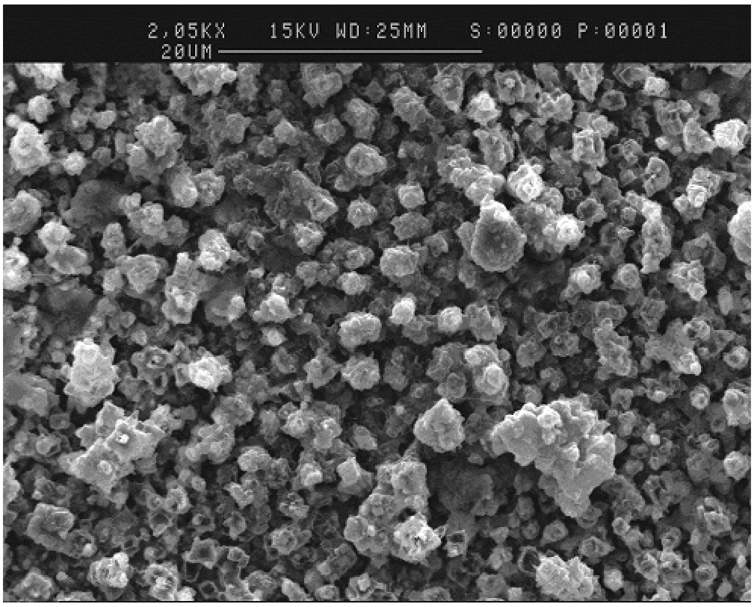


Figure 71. Relative wastage of steel plate exposed to combustion gases of 20 native species and five other fuel sources.

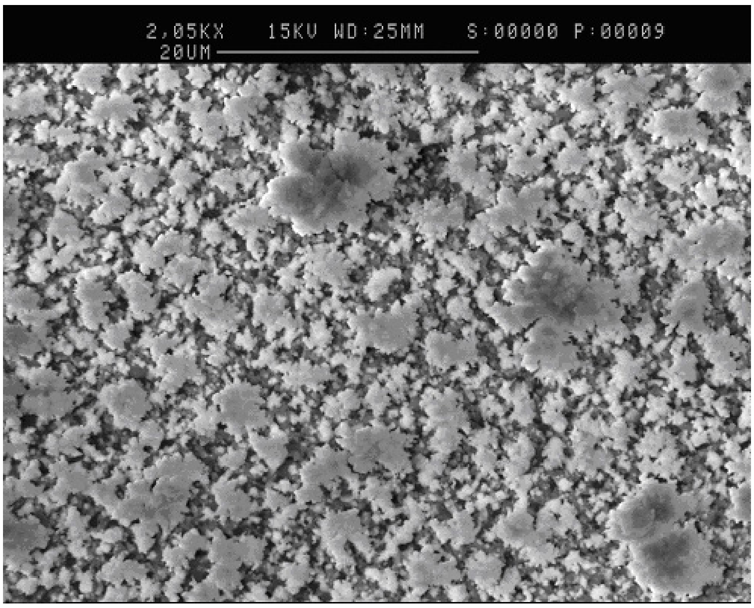
Acacia lasiocalyx



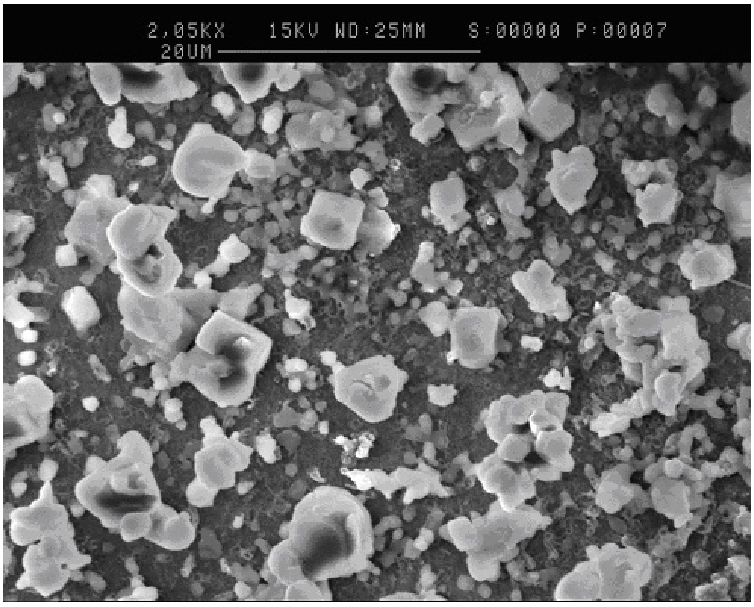
Acacia saligna



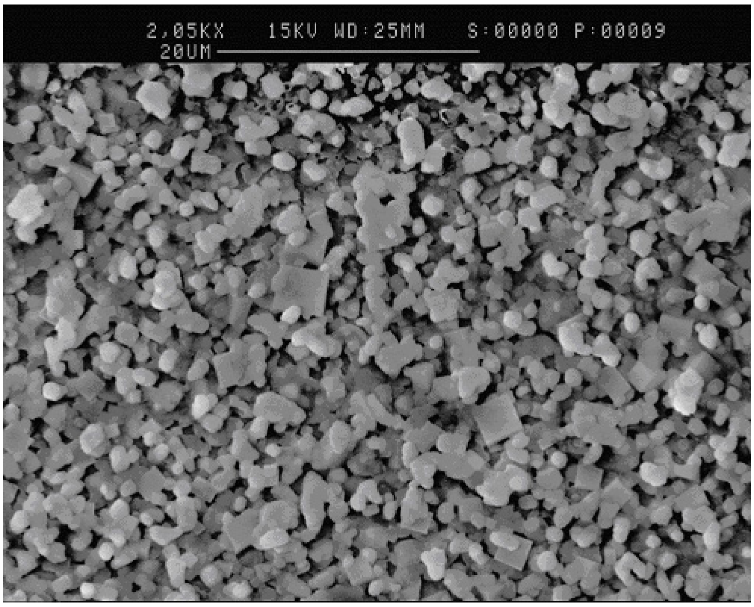
Agonis flexuosa



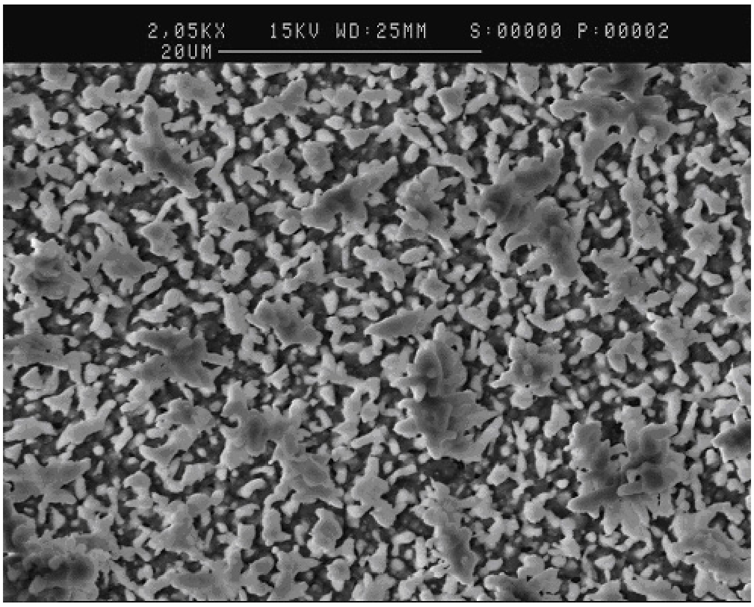
Alyogyne huegelii



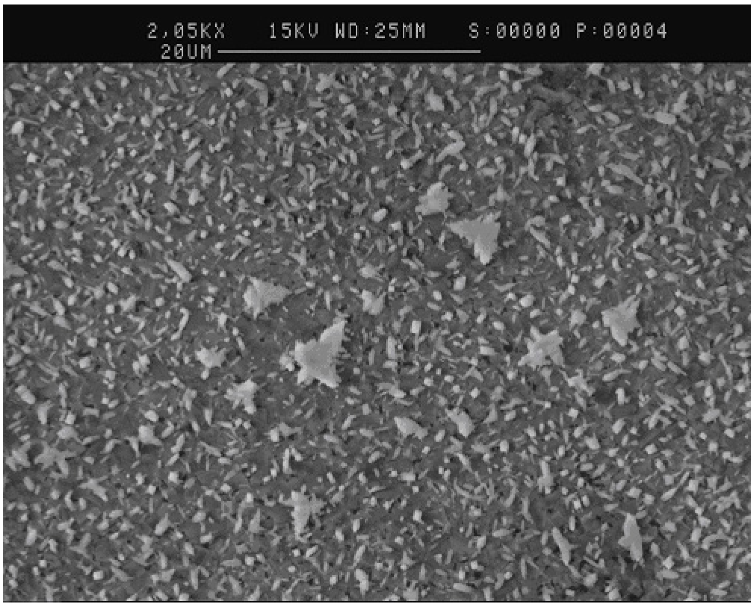
Anthocercis littorea



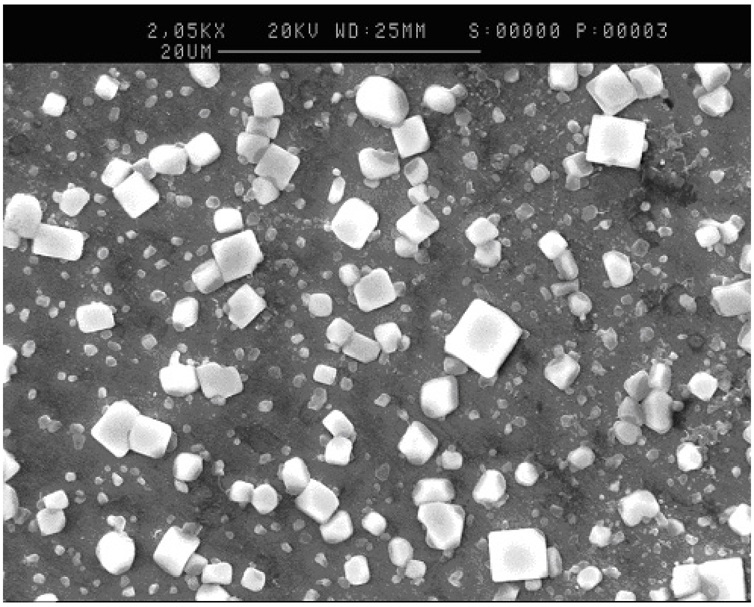
Bursaria occidentalis



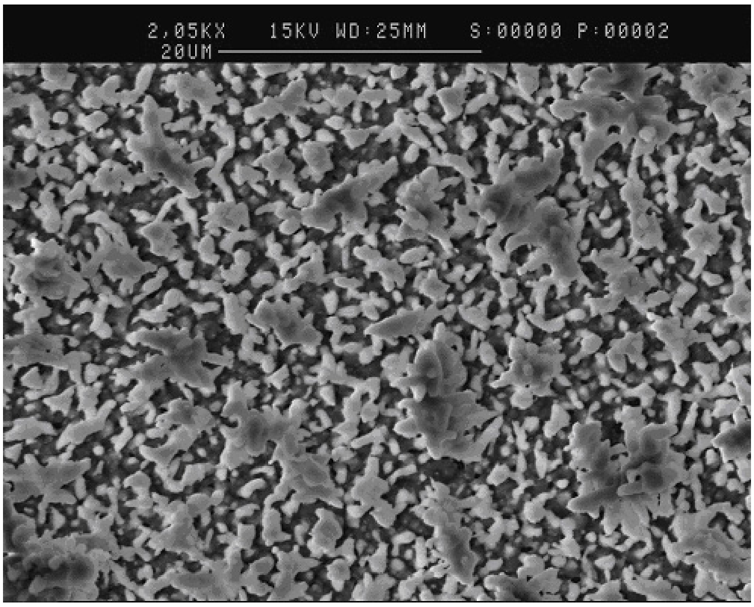
Codonocarpus cotinifolius



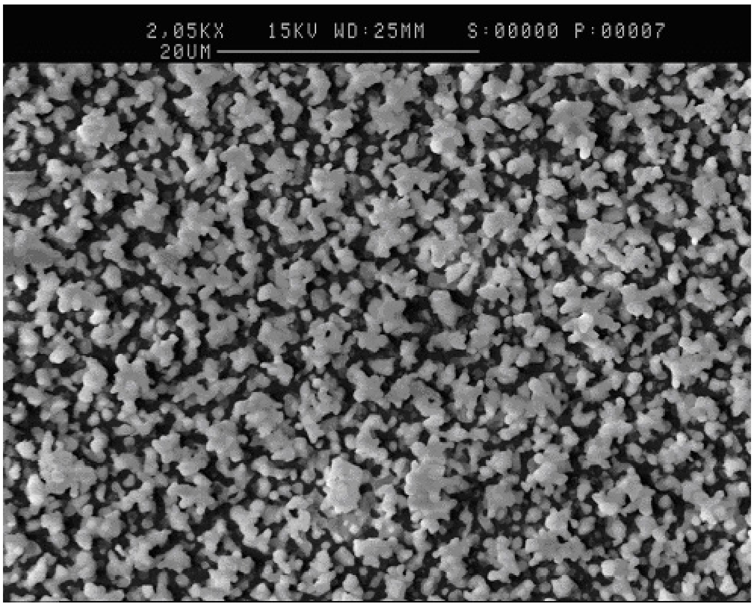
Eucalyptus loxophleba ssp *lissophloia*



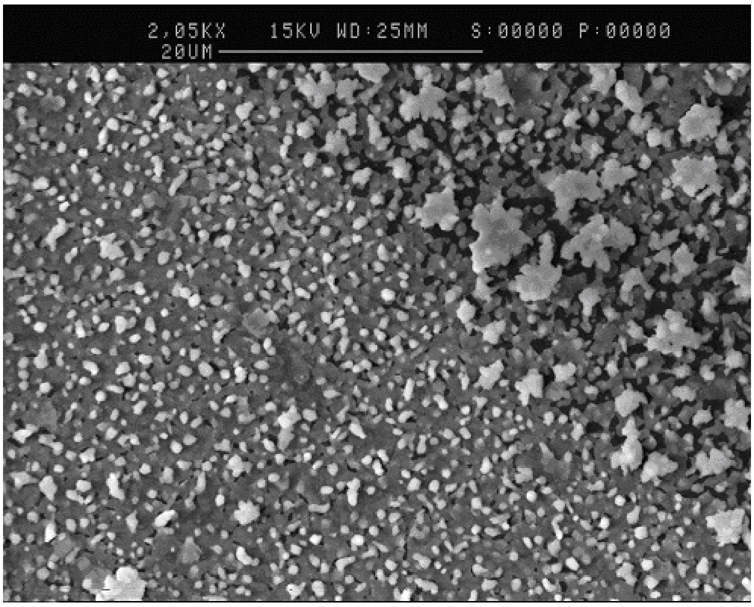
Eucalyptus occidentalis



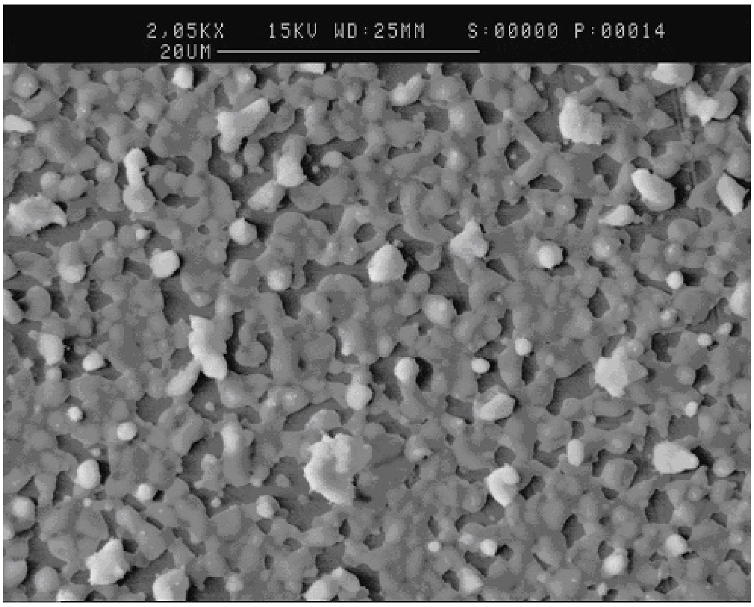
Eucalyptus rudis



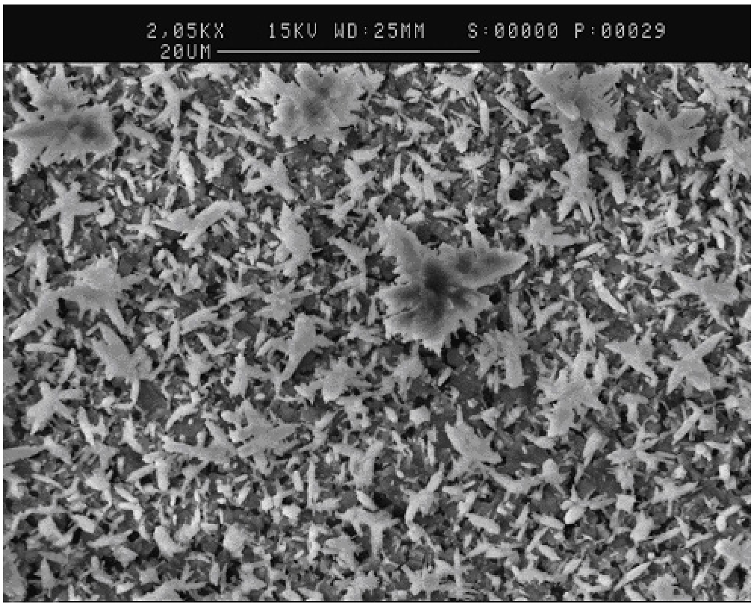
Grevillea candelabroides



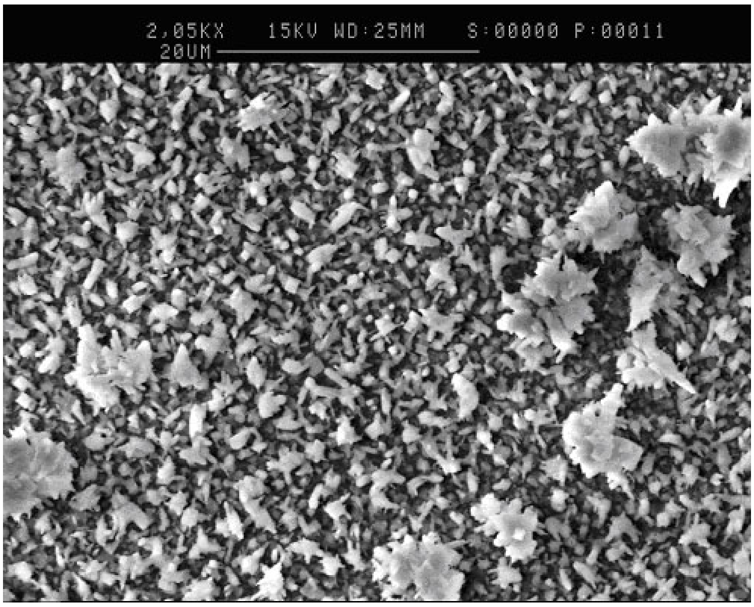
Grevillea leucopteris



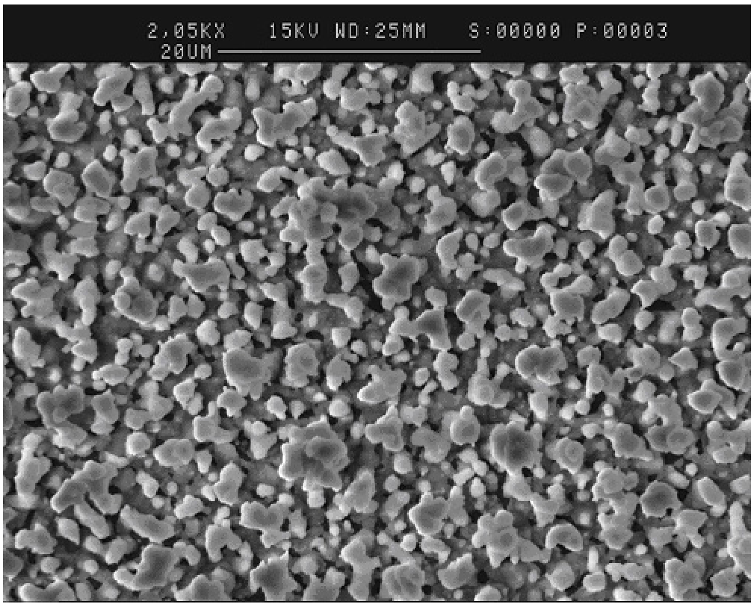
Gyrostemon ramulosus



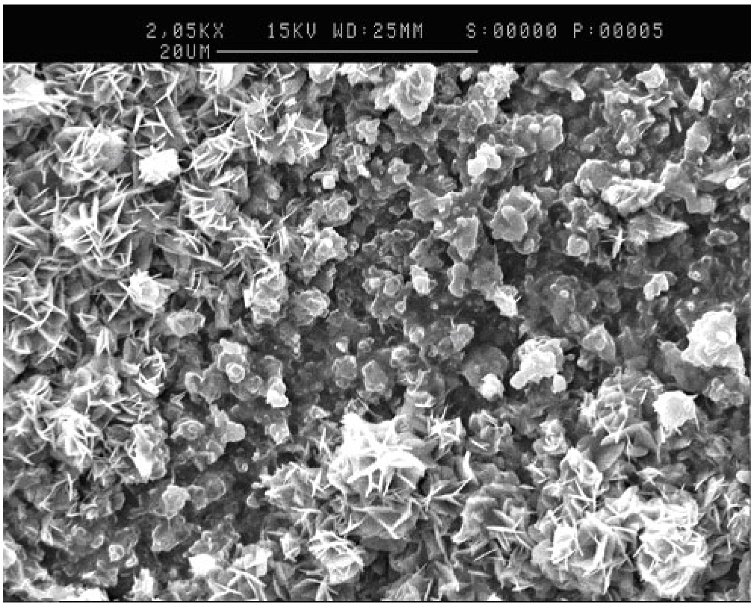
Hakea oleifolia



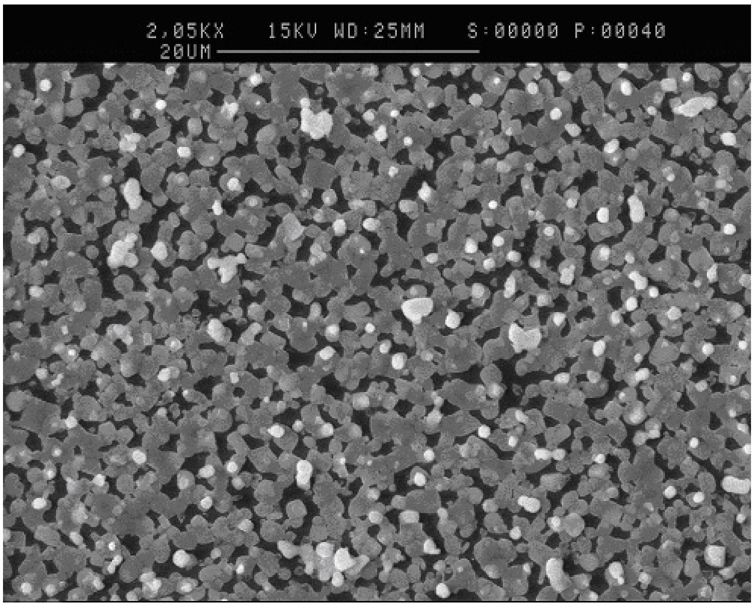
Jacksonia sternbergiana



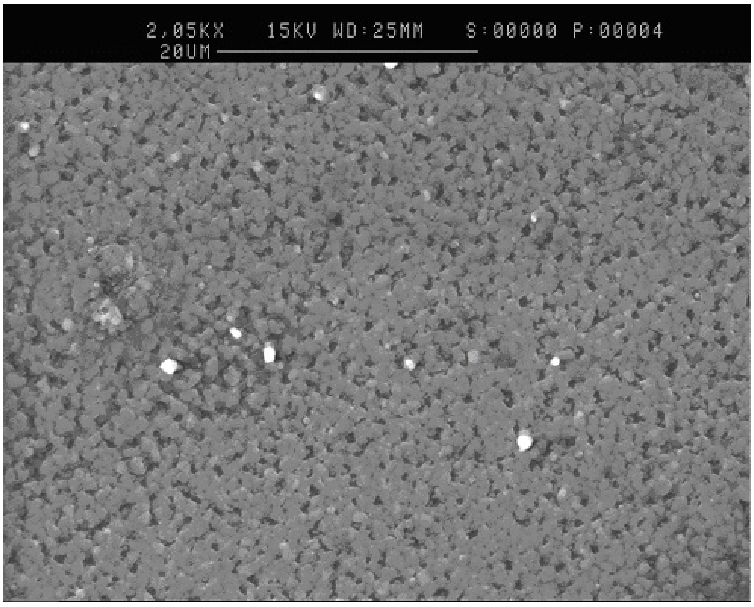
Melaleuca preissiana



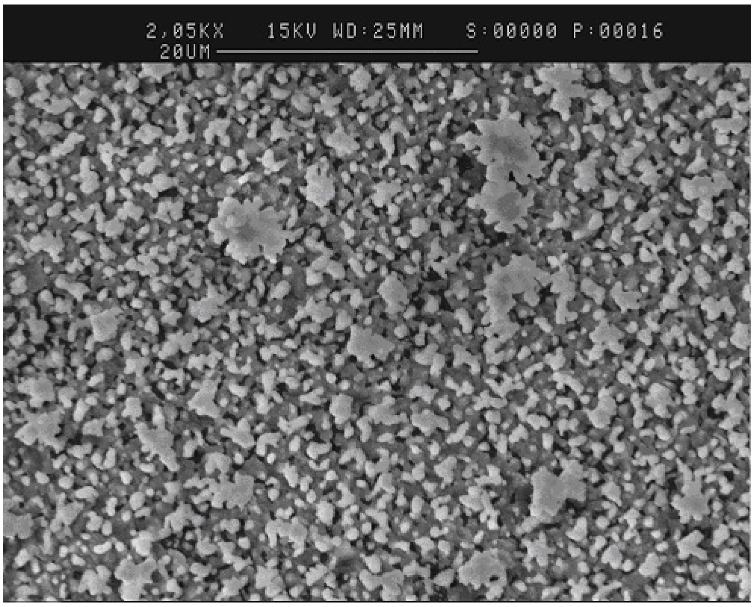
Senna pleurocarpa



Taxandria juniperina



Trymalium floribundum



Viminaria juncea

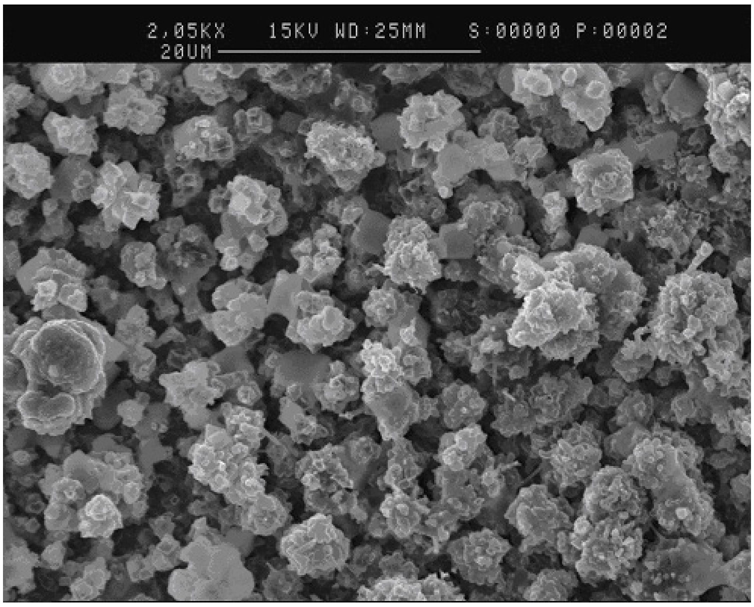
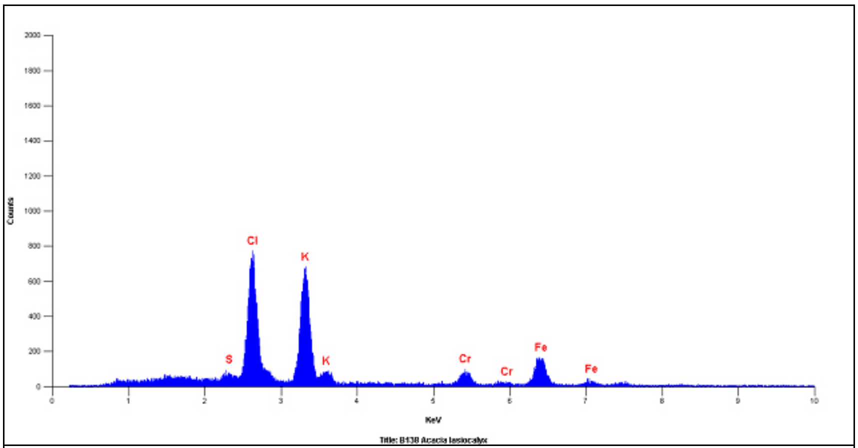
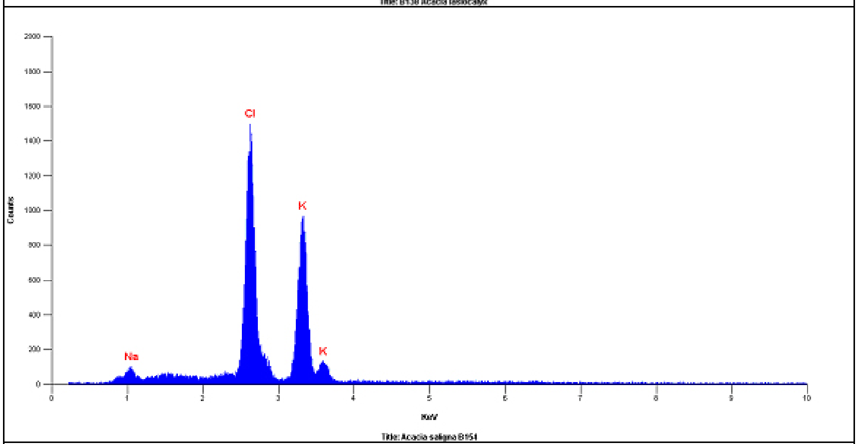


Figure 72. Scanning electron micrographs of fouling deposits for 20 WA species.

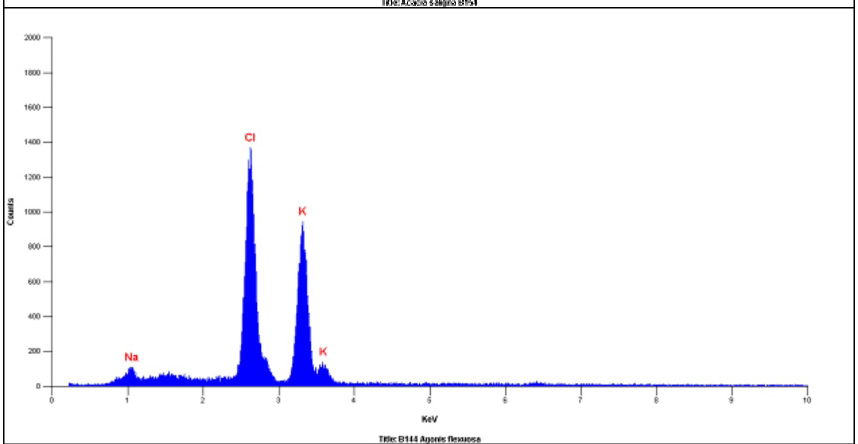
Acacia lasiocalyx



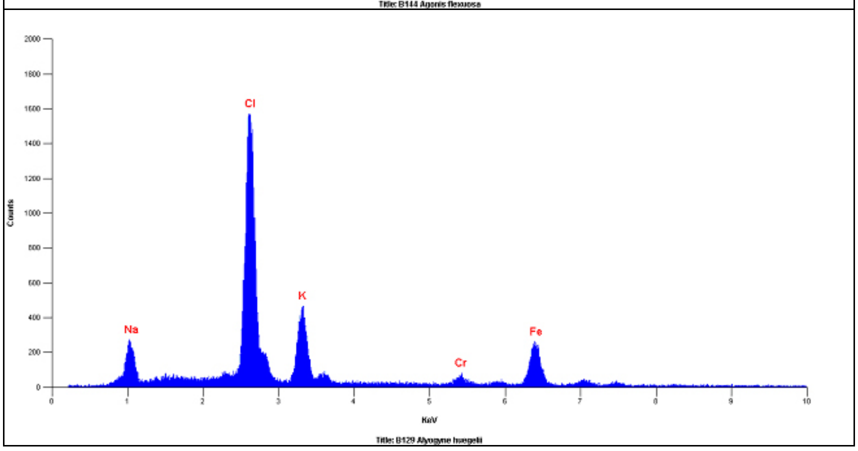
Acacia saligna



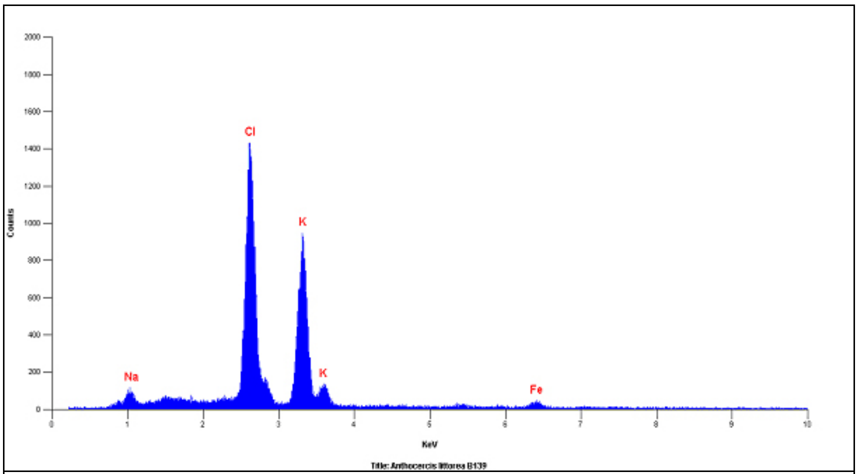
Agonis flexuosa



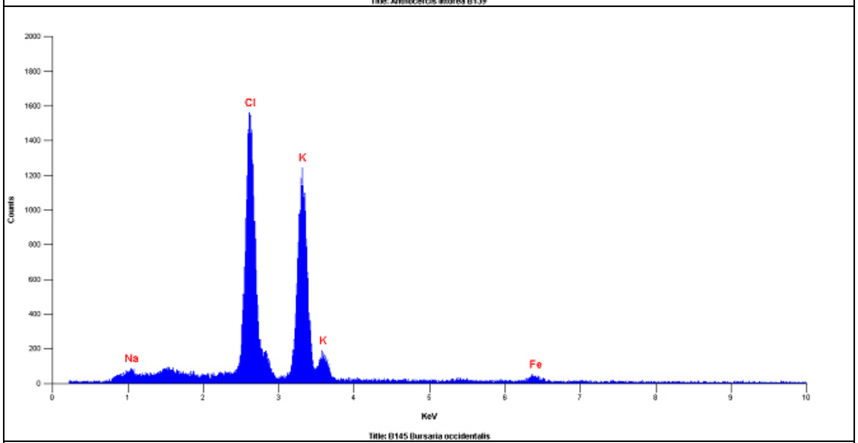
Alyogyne huegelii



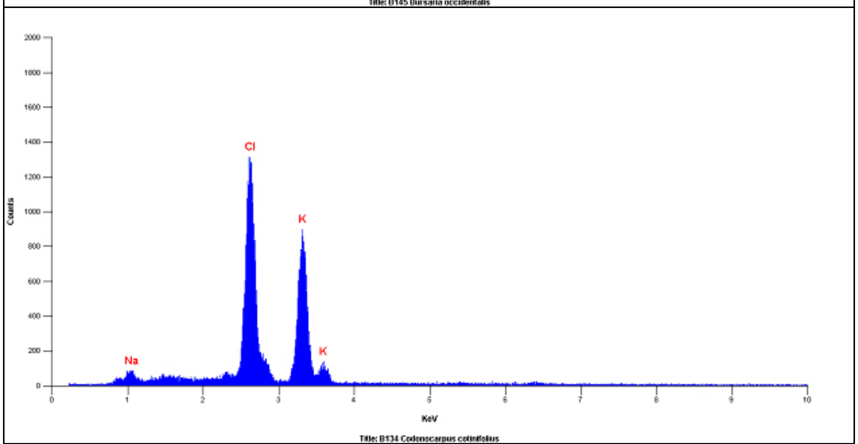
Anthocercis littorea



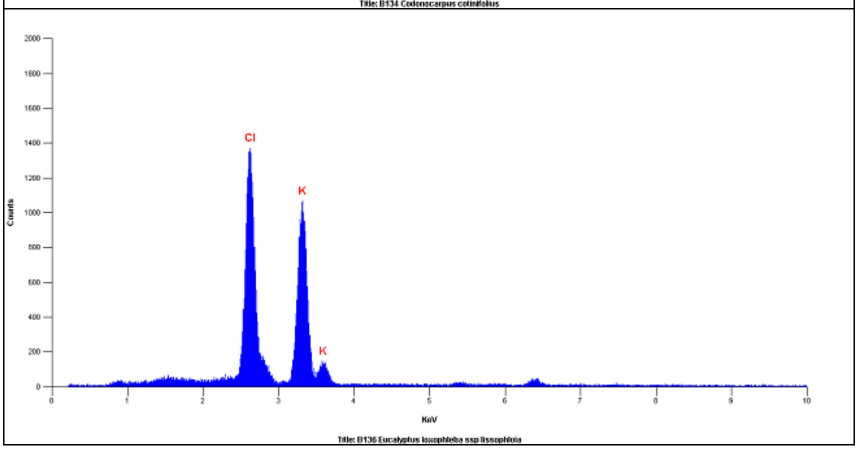
Bursaria occidentalis



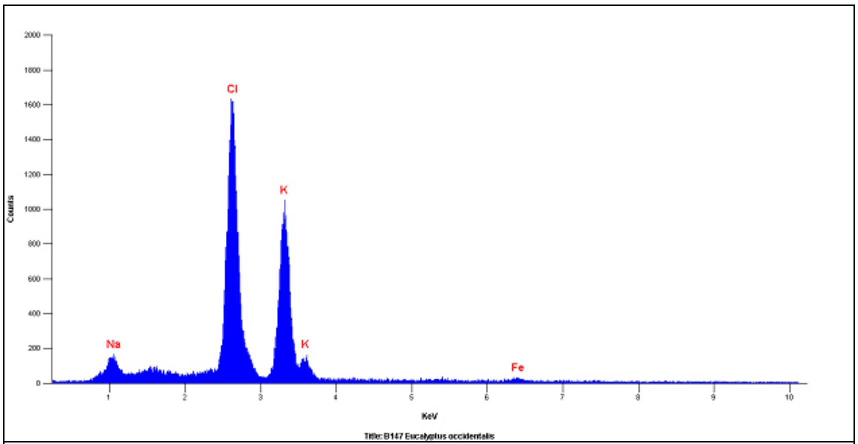
Codonocarpus cotinifolius



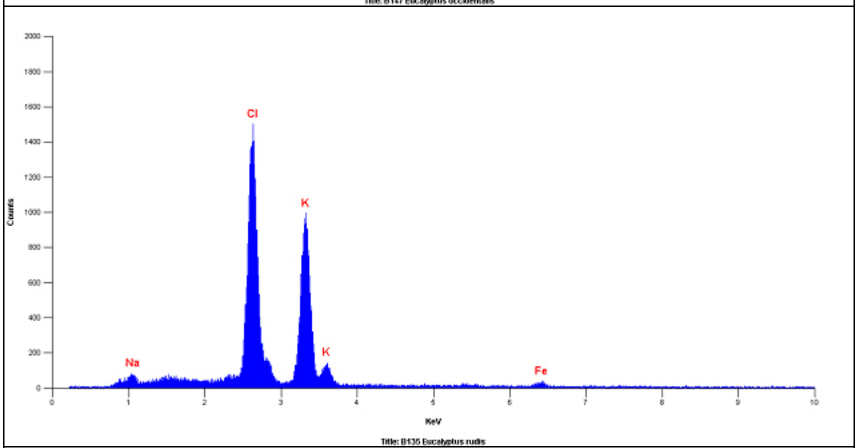
Eucalyptus loxophleba ssp *lissophloia*



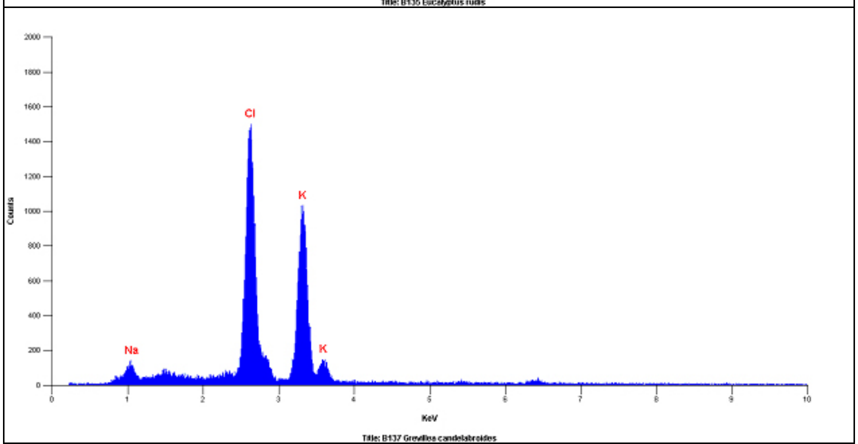
Eucalyptus occidentalis



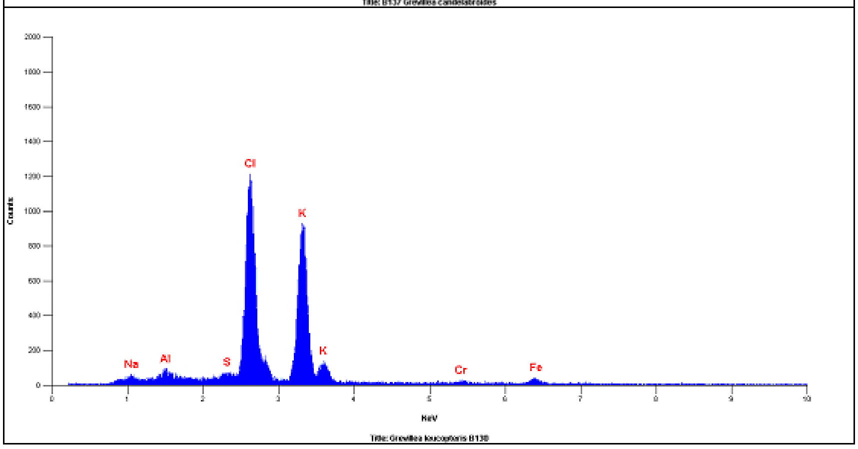
Eucalyptus rudis



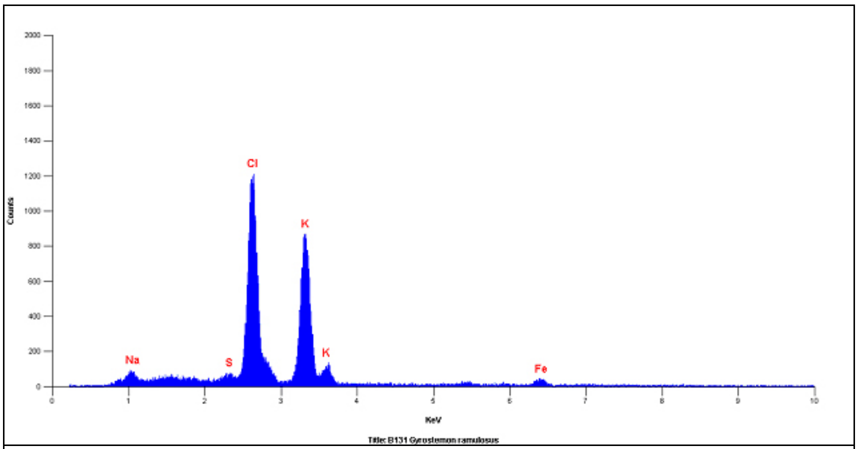
Grevillea candelabroides



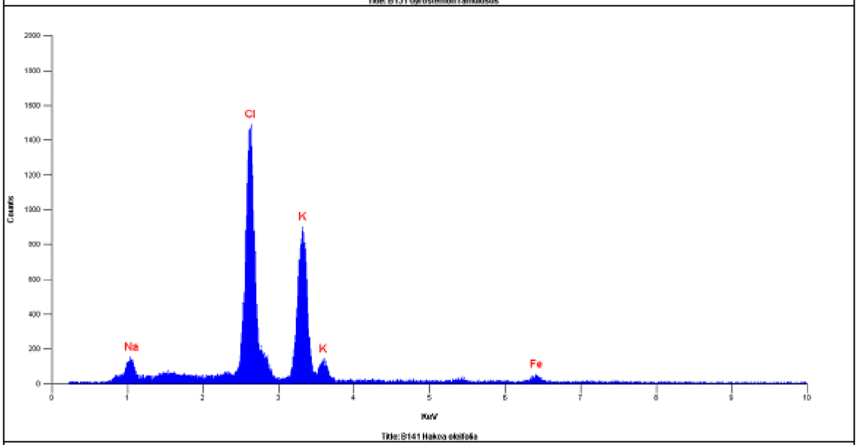
Grevillea leucopteris



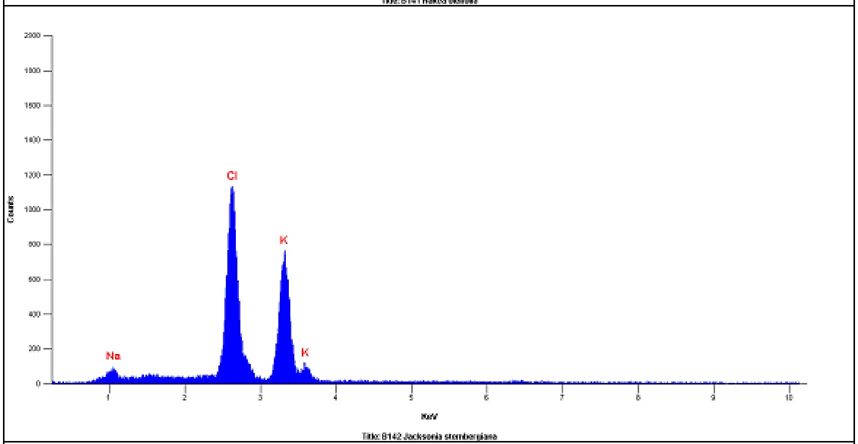
Gyrostemon ramulosus



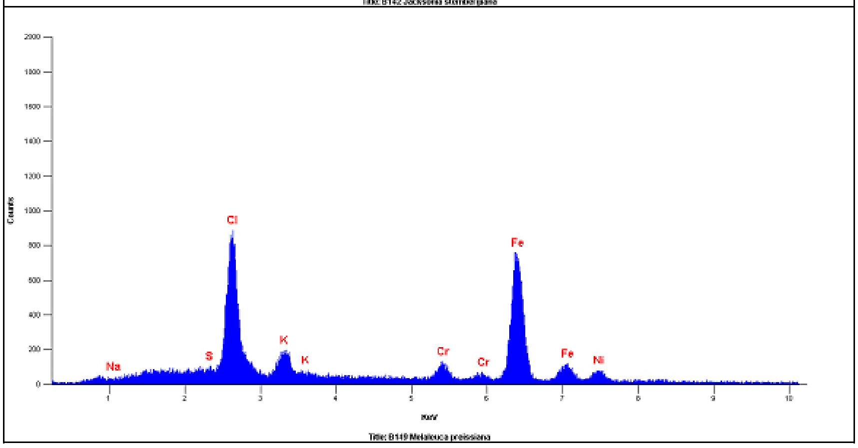
Hakea oleifolia



Jacksonia sternbergiana



Melaleuca preissiana



Senna pleurocarpa

Taxandria juniperina

Trymalium floribundum

Viminaria juncea

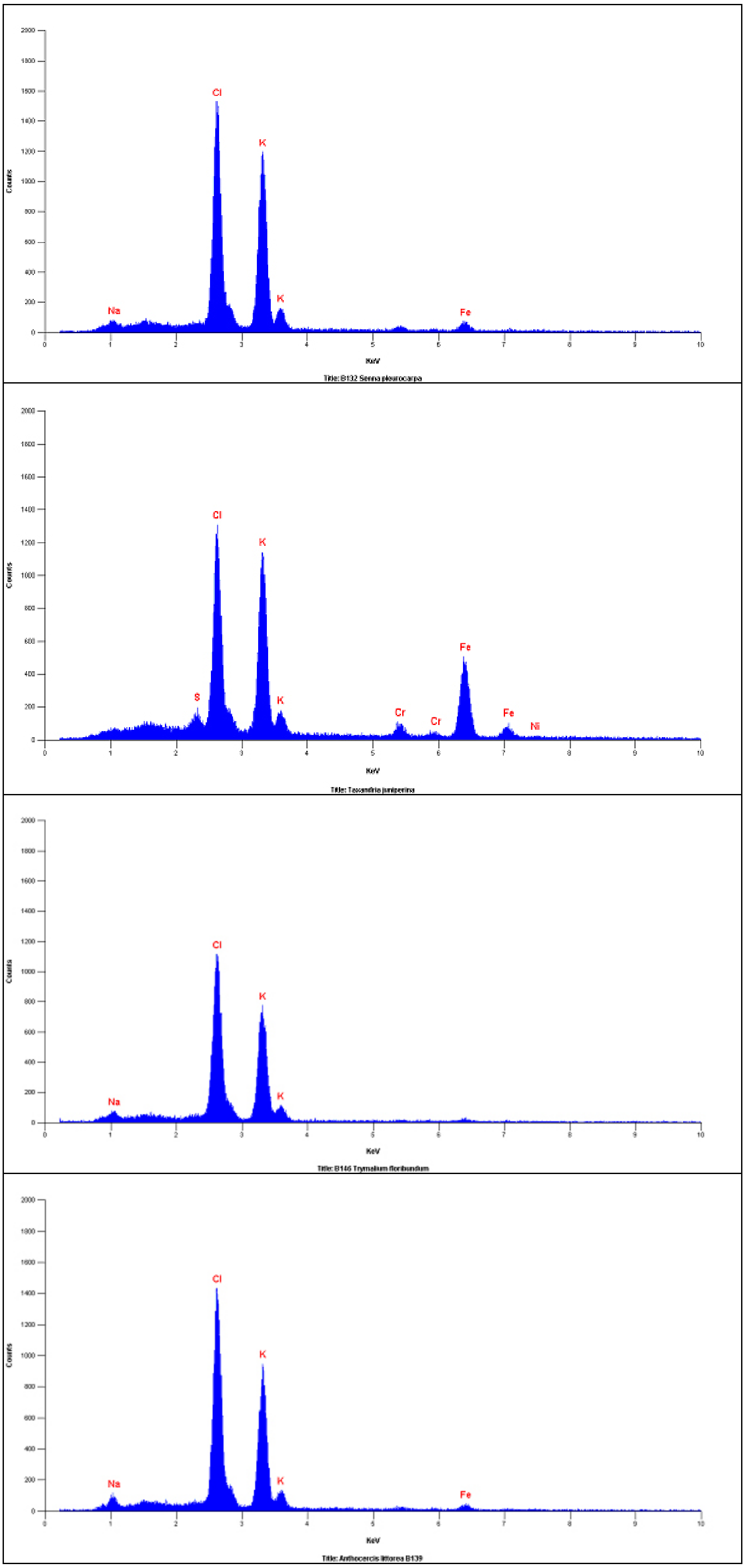


Figure 73. Elemental analysis of fouling deposits for 20 WA species.

6.9 Laboratory testing – charcoal reductant

6.9.1 Introduction

In collaboration with Simcoa Operations Pty. Ltd., the Search Project tested the ash content of a number of tree and shrub species that occur naturally in agricultural areas in southern Western Australia.

This work was performed at Simcoa's laboratories at its Kemerton silicon smelter in southern Western Australia.

6.9.2 Background

Simcoa produces silicon at its smelter at Kemerton, near Bunbury in Western Australia, using quartzite mined near Moora, north of Perth, and charcoal derived from jarrah residues (*Eucalyptus marginata*) from the jarrah forest south of Perth. Sources of jarrah include dead trees and other forest debris, logging residues and sawmill residues.

Simcoa's smelter is located about 300 km from its quartzite mine at Moora, which operates for four to five months each year to provide the annual feedstock requirements of the Kemerton smelter. The smelter location was chosen for its proximity to:

- reliable electricity supply from coal-fired power stations in the Collie area,
- State forest, a source of jarrah wood (feedstock for high quality charcoal),
- supply of natural gas (by pipeline),
- port facilities at Bunbury.

Simcoa makes charcoal in a retort, using 100,000 tonnes per year of air-dried wood blocks. The smelter also uses 30,000 tonnes per year of green wood chip. Both the green wood chips (preferred green to slow the rate of consumption during smelting) and charcoal are consumed in chemical reactions and are not used as a source of energy.

The non-carbon components of the charcoal and green woodchips are contained in the ash, and are incorporated in the final product as impurities. Therefore, wood with low ash content is preferred. Jarrah wood has very low ash content (0.1% to 0.15%) compared to wood from many other species. For example, marri (*Corymbia calophylla*), which is also found in abundance in the jarrah forest, has an ash content of 2.5%, and is unsuitable for large-scale use in silicon smelting. A small proportion (up to 5%) of higher ash content material is often used, such as coal from New Zealand, pine sawmill residues, or blue gum (*Eucalyptus globulus*) residues.

Simcoa produces silicon of high purity (99.5%). Lower grade silicon (99%), resulting from poorer quality charcoal, commands about half the market price of the higher grade product, thus providing a powerful incentive to maintain access to adequate supplies of wood with low ash content.

The components of the ash are also important. Impurities of most concern are iron, phosphorous, titanium, aluminium and calcium.

6.9.3 Market outlook

Silicon production is unlikely to expand in Australia in the near term. Simcoa has not advised of any other deposits being proven up, or of any expansion plans, given the current depressed state of the global silicon market.

Attempts to develop a second Australian silicon project in eastern Australia by Australian Silicon Limited foundered in March 2003 when Portman Limited announced that it would exit its investment in the company, and that. "…recently deteriorating fundamentals in the global silicon market, combined with increasing low-cost Chinese production and the slowdown in Western economies, has depressed prices, resulting in a more subdued outlook… Despite exhaustive efforts to develop the project in four states, market realities - and the lack of availability of competitively-priced electricity supplies - dictate that it can not proceed at this stage". (Portman Limited 2003)

6.9.4 Feedstock specifications

Simcoa's preferred specifications for charcoal feedstock are:

- Moisture content less than 25% (price reduced for wood with a higher moisture content).
- Billets 25 cm long and 2.5 to 12 cm in diameter (blocks down to the size of a cigarette packet acceptable).
- Low ash content.
- Low iron, phosphorous, titanium, aluminium and calcium content in the ash.
- Bark removed (since bark usually has a high ash content, and can block the retort).

6.9.5 Opportunity for charcoal from farm-grown wood

Since future supplies of jarrah are uncertain, as commercial timber usage from State forests becomes more restricted, Simcoa is interested in exploring other potential sources of charcoal feedstock. Farm-grown timber is one option for providing a regular and secure supply of suitable wood. Therefore, growers of 'low-ash' timbers in the agricultural areas inland from Bunbury could supply wood into this market. No economic analysis has been conducted into this potential industry, pending the results of species testing.

Commercial development of a particular species would require further research into genetic and environmental variation in ash content and its mineral components. For example, site conditions, especially fertiliser history, appear to affect the level of mineral contaminants in the ash. Phosphorus levels in the soil are likely to increase phosphorus levels in the ash of some (or all) species. Since phosphorus is a key nutrient required for rapid tree growth, it will be important to select species, or provenances within species, that either:

- store low levels of phosphorus in the wood, or
- can grow well in a low phosphorus environment.

The work done in this project focused on the ash content and components for the species tested. Before any species could be developed for commercial use, further work would be needed on its charcoal - how readily it can be made into charcoal, and the behaviour of the charcoal in silicon smelting.

6.9.6 Simcoa test procedures

Courtesy Kees Visser, Project Metallurgist, Simcoa Operations Pty Ltd

Proximate analysis of the wood samples is conducted using a Leco-601 Thermogravimetric Analyser. The method is based on ASTM D5142 - Standard Test Methods for Proximate Analysis of the Analysis Sample of Coal or Coke by Instrumental Procedures. This test method is used by Simcoa Operations Pty Ltd for the proximate analysis of coal, coke, charcoal and other reductant samples.

The test method determines moisture, volatile matter and ash sequentially. Fixed carbon is a calculated value.

* Moisture is determined by establishing the loss in mass of the analysis specimen when heated under rigidly controlled conditions of temperature and atmosphere.

* Volatile matter is determined by measuring the loss in mass of the dried analysis specimen when heated under rigidly controlled conditions of time, temperature and atmosphere.

* Ash is determined by measuring the mass of the residue remaining after burning the dried analysis specimen under rigidly controlled conditions of temperature, time, and atmosphere.

* Fixed carbon percentage is calculated as 100% - (%volatile matter + %ash)

6.9.6.1 Proximate Test parameters

Moisture

Temperature..... 110 deg C
Time................ Constant weight
Atmosphere...... Nitrogen

Volatile Matter

Temperature..... 950 deg C
Time................ 7 minutes
Atmosphere...... Nitrogen

Ash

Temperature..... 750 deg C
Time................ Constant weight
Atmosphere...... Oxygen

6.9.6.2 Ash analysis

Because the quantity of ash generated from wood samples is generally small, a larger portion of each sample is carbonised and ashed manually at 750 deg C in a muffle furnace to provide an adequate volume of ash for subsequent digestion and analysis.

Approximately 0.1 g of the ash residue is digested (using an in-house method) with hydrofluoric acid on a low heat. Silica is volatilised off as the tetrafluoride. The remaining liquid is 'wet-ashed' with perchloric acid to dissociate any complex fluorides formed. The resultant liquor is diluted and analysed using ICP-AES (Inductively Coupled Plasma - Atomic Emission Spectroscopy). The instrument used is a Perkin Elmer Optime 3300. The instrument reports the concentration of the components of the ash (not the original wood) as oxides.

Typically Simcoa favours wood residues from species that have low ash content and a low concentration of phosphorus, titanium and iron in the wood residue. These impurities will report to the silicon and impact on the quality of the product and potential markets. Other impurities such as aluminium and calcium can be removed by oxidising with air or oxygen during the refining of the silicon prior to casting.

6.9.7 Material collection

Material from suitable species was collected and prepared for laboratory analysis. For each species, stem material was collected from ten different plants, separated into bark and wood, then ground to sawdust consistency. Where applicable, material was collected at the same time, and from the same plants, as wood samples collected for pulp, paper and panel board investigations. Laboratory requirements were for 250 ml of sawdust, plus two sticks 30 to 50 cm in length for each sample to be tested.

Soil samples were collected from near the base of the sampled trees, to allow future correlations to be developed between soil mineral levels and mineral levels in ash.

Since this testing was relatively inexpensive, and required only small amounts of material, most of the species tested elsewhere in the project were also tested for ash content and ash analysis. Testing was concentrated at first on the wood fraction, as this is suitable for making charcoal, and because wood is usually the biomass component with the lowest ash content. Later, more barks were tested, as species with low ash content in the bark could possibly be used without debarking.

6.9.8 Results

Results are presented in Table 39, in which the ash components are expressed as a percentage of the total ash. The same results are also presented in

Table 40, with the ash components expressed as ppm of dry wood or bark (by weight), calculated from Table 39 using the following formula:

Component (ppm wood) = (Component % of ash) x (ash % of wood) x 100

Eucalyptus marginata (jarrah), Simcoa's current feedstock, was not tested in this project, but typical data was provided courtesy of Simcoa for comparison.

A number of species appear to have wood with relatively low ash content. Further work needed on these species to clarify their commercial potential includes:

- wider testing to confirm the original results and to learn more about the effect of site variation on ash content and its constituents,
- trials to test the facility with which the lower ash species can be turned into charcoal, and its performance in smelting,
- growing the better species on farms to learn more about their requirements, and the effect of different silvicultural management on their wood and ash properties.

Table 39. Proximate analysis and ash analysis for some Western Australian woody plants (A. ash components expressed as % of ash).

Species		Percentage of dry wood				A. Ash components expressed as oxides (% of ash)								
		Fixed C	Volatiles	Moisture	Ash	Fe2O3	P2O5	TiO2	Al2O3	CaO	MgO	Na2O	K2O	Total
Eucalyptus marginata	Wood	21.0			0.1	5.15	1.9	0.310	4.89	15.7	7.8	14.7	6.0	56.3
Acacia bartleana Maslin ms	Wood	20.1	79.4	6.9	0.5	0.41	2.9	0.058	0.99	50.2	12.9	0.9	7.4	75.8
Acacia cyclops	Wood	18.0	81.3	6.3	0.7	0.13	1.1	0.001	0.25	50.4	8.2	3.4	7.2	70.7
Acacia cyclops	Bark	25.3	71.8	8.3	2.9	0.83	0.8	0.037	1.62	62.4	3.6	5.5	7.3	82.0
Acacia lasiocalyx	Wood	17.3	82.3	6.7	0.4	0.17	2.5	0.007	0.31	69.3	8.2	1.2	0.8	82.5
Acacia aff. *redolens*	Wood	20.0	79.5	6.6	0.5	0.27	2.7	0.009	0.53	23.5	15.0	5.9	18.1	66.0
Acacia aff. *redolens*	Bark	26.1	71.3	7.6	2.6	0.24	0.3	0.021	0.54	7.4	0.9	1.7	6.5	17.5
Acacia microbotrya	Bark	31.1	66.8	8.0	2.1	0.27	3.2	0.059	0.70	47.7	4.5	2.2	15.8	74.4
Acacia saligna	Wood	19.0	80.2	7.2	0.8	0.16	4.9	0.001	0.24	47.9	14.7	2.6	9.5	80.0
Actinostrobus arenarius	Wood	22.8	76.7	7.5	0.5	0.23	0.9	0.002	0.64	62.0	4.8	4.6	9.2	82.4
Actinostrobus arenarius	Bark	18.2	78.0	7.7	3.8	0.38	0.8	0.061	1.16	67.8	3.1	3.3	3.2	79.8
Adenanthos stictus	Wood	19.7	79.8	6.8	0.5	0.43	1.8	0.001	0.93	29.6	9.3	17.6	13.1	72.8
Adenanthos stictus	Bark	21.5	74.4	7.3	4.1	0.21	0.2	0.053	0.75	57.5	1.0	3.0	3.3	66.0
Agonis flexuosa	Wood	21.0	78.5	6.6	0.5	0.19	3.1	0.001	0.32	26.3	10.2	7.3	21.9	69.3
Agonis flexuosa	Bark	19.8	71.4	8.7	8.8	0.13	0.5	0.022	0.42	68.9	7.4	1.6	2.9	81.7
Alyogyne hakeifolia	Wood	19.0	79.4	7.1	1.6	0.18	6.7	0.015	0.36	51.3	4.4	2.1	7.2	72.3
Alyogyne huegelii	Wood	19.6	79.2	6.8	1.2	0.06	27.2	0.001	0.11	26.4	4.9	3.8	24.2	86.6
Anthocercis littorea	Wood	18.0	81.1	6.9	0.9	0.22	3.8	0.014	0.52	51.9	5.4	3.5	11.6	76.9
Banksia prionotes	Wood	20.6	78.7	7.4	0.7	0.15	3.8	0.001	1.12	9.1	12.2	15.3	17.5	59.1
Banksia prionotes	Bark	24.6	74.2	8.0	1.2	0.19	1.4	0.023	1.60	26.9	19.9	7.2	3.2	60.4
Callitris glaucophylla	Wood	24.0	75.3	7.4	0.7	0.19	2.4	0.004	0.44	33.0	9.4	2.3	25.0	72.7
Callitris glaucophylla	Bark	23.1	74.3	7.9	2.6	0.38	2.3	0.027	1.02	61.9	2.9	1.3	10.7	80.5
Casuarina obesa	Wood	18.4	81.0	7.1	0.6	0.13	4.1	0.001	0.35	61.0	16.6	0.7	0.5	83.3
Codonocarpus cotinifolius	Wood	19.3	79.7	7.9	1.0	0.22	5.1	0.016	0.39	8.0	10.5	8.7	33.9	66.8
Dryandra arborea	Wood	22.3	77.1	7.1	0.6	0.78	2.3	0.064	2.14	13.8	11.6	8.9	27.8	67.4
Dryandra arborea	Bark	26.2	72.3	8.4	1.5	0.65	1.6	0.049	2.12	14.7	8.2	11.0	16.9	55.2
Duboisia hopwoodii	Wood	21.0	78.7	7.2	0.3	0.71	10.7	0.058	1.79	23.9	7.5	4.2	22.5	71.4
Duboisia hopwoodii	Bark	20.4	72.9	7.8	6.7	1.22	1.3	0.099	2.74	44.1	4.3	4.1	10.9	68.8

Species		Percentage of dry wood				A. Ash components expressed as oxides (% of ash)								
		Fixed C	Volatiles	Moisture	Ash	Fe2O3	P2O5	TiO2	Al2O3	CaO	MgO	Na2O	K2O	Total
Eucalyptus accedens	Wood	19.2	80.3	7.8	0.5	0.04	1.4	0.001	0.18	57.8	20.7	1.2	0.4	81.6
Eucalyptus argyphea	Wood	19.4	80.3	7.0	0.3	0.19	0.8	0.001	0.26	61.6	21.0	0.3	0.4	84.6
Eucalyptus leptopoda	Wood	21.8	78.1	7.8	0.1	0.30	1.2	0.001	0.41	47.4	17.3	7.6	9.6	83.9
Eucalyptus leptopoda	Both	22.3	77.3	8.5	0.4	0.06	1.1	0.001	0.26	51.2	14.4	4.5	10.0	81.5
Eucalyptus erythrocorys	Wood	19.2	80.3	7.8	0.5	0.10	6.0	0.001	0.18	49.9	13.0	8.4	7.3	84.9
Eucalyptus erythrocorys	Both	18.3	75.9	7.8	5.8	0.02	0.3	0.001	0.03	71.9	11.6	2.2	1.1	87.2
Eucalyptus globulus	Wood	18.9	80.7	6.1	0.4	0.77	7.7	0.031	0.58	25.5	14.6	3.5	16.4	69.0
Eucalyptus horistes	Wood	17.1	82.6	6.1	0.3	0.58	5.6	0.012	0.87	24.6	21.4	3.8	12.9	69.7
Eucalyptus hypochlamydea	Wood	19.4	80.1	7.2	0.5	0.09	4.1	0.010	0.17	45.7	8.4	4.2	16.4	79.1
Eucalyptus longicornis	Wood	18.3	81.3	7.8	0.4	0.09	1.4	0.006	0.26	32.3	12.0	3.5	17.2	66.8
Eucalyptus loxophl. ssp *liss.*	Wood	16.9	82.6	7.0	0.5	0.12	8.1	0.008	0.12	34.6	11.5	3.3	11.0	68.7
Eucalyptus loxophl. ssp *lox.*	Wood	18.5	81.0	7.6	0.5	0.13	10.9	0.016	0.18	49.8	8.0	3.4	11.0	83.5
Eucalyptus melanoxylon	Wood	17.5	81.8	7.4	0.7	0.08	2.9	0.007	0.40	50.8	8.5	2.8	7.2	72.7
Eucalyptus muellerana	Wood	18.6	81.1	5.9	0.3	0.29	9.1	0.024	0.64	25.7	15.6	6.0	16.1	73.4
Eucalyptus occidentalis	Wood	16.7	82.8	6.2	0.5	1.91	14.7	0.079	2.01	25.0	12.1	6.0	11.4	73.2
Eucalyptus polybractea	Wood	17.7	82.0	6.2	0.3	0.97	4.9	0.096	2.14	48.8	21.0	2.7	1.3	81.8
Eucalyptus rudis	Wood	18.4	80.9	9.7	0.7	0.28	8.6	0.011	0.25	44.8	17.0	2.6	3.9	77.4
Eucalyptus salicola	Wood	19.3	80.2	7.3	0.5	0.10	1.8	0.010	0.31	61.0	9.4	1.9	1.9	76.4
Eucalyptus salmonophloia	Wood	20.2	79.4	8.2	0.4	0.05	2.2	0.001	0.24	40.7	17.8	5.0	11.5	77.4
Eucalyptus salubris	Wood	19.9	78.5	7.0	1.6	0.04	0.7	0.010	0.11	79.1	11.1	1.8	1.8	94.6
Eucalyptus sideroxylon	Wood	19.5	79.8	6.2	0.7	0.14	12.9	0.016	0.27	27.9	13.2	10.9	13.7	79.0
Eucalyptus todtiana	Wood	20.1	79.7	7.3	0.2	0.36	9.8	0.017	0.64	31.2	25.4	7.0	6.8	81.2
Eucalyptus urna	Wood	18.5	81.1	8.1	0.4	0.05	1.0	0.002	0.18	56.0	16.2	2.5	1.3	77.2
Exocarpus sparteus	Wood	20.0	78.6	7.0	1.4	0.45	1.3	0.020	1.09	54.7	6.9	6.1	6.7	77.2
Exocarpus sparteus	Bark	32.1	63.0	9.6	4.9	0.29	0.9	0.032	0.82	38.5	1.5	10.0	17.2	69.2
Grevillea candelabroides	Wood	19.3	80.0	7.9	0.7	0.10	5.7	0.001	0.22	37.7	7.6	7.2	22.2	80.8
Grevillea candelabroides	Bark	22.0	73.7	8.6	4.3	0.10	1.2	0.017	0.31	43.1	2.7	1.7	9.2	58.2
Grevillea leucopteris	Wood	18.1	81.1	6.7	0.8	0.12	5.3	0.001	0.33	25.6	7.9	5.5	22.0	66.7
Gyrostemon ramulosus	Wood	20.9	78.0	7.6	1.1	0.18	6.6	0.012	0.24	14.6	10.0	5.8	27.9	65.3
Hakea oleifolia	Wood	20.1	79.3	6.9	0.6	0.04	1.7	0.007	0.13	29.7	9.7	8.8	11.3	61.3

Species		Percentage of dry wood				A. Ash components expressed as oxides (% of ash)								
		Fixed C	Volatiles	Moisture	Ash	Fe2O3	P2O5	TiO2	Al2O3	CaO	MgO	Na2O	K2O	Total
Hakea oleifolia	Bark	24.5	68.3	9.7	7.2	0.08	0.7	0.019	0.38	34.4	7.3	3.3	3.8	49.8
Jacksonia sternbergiana	Wood	19.9	79.4	7.9	0.7	0.30	10.5	0.010	0.75	55.4	9.3	6.0	2.0	84.3
Kunzea glabrescens	Wood	22.7	76.9	7.3	0.4	0.13	1.9	0.001	0.65	36.6	11.2	13.4	12.6	76.5
Kunzea glabrescens	Bark	20.9	74.9	8.0	4.2	0.06	0.4	0.008	0.21	70.9	3.6	2.7	3.1	81.0
Lambertia inermis	Wood	19.5	80.1	6.3	0.4	0.20	1.4	0.001	0.31	12.7	5.8	14.6	17.1	52.1
Lambertia inermis	Bark	25.8	71.7	8.1	2.5	0.15	0.6	0.006	0.41	5.4	1.7	5.3	4.5	18.0
Melaleuca lateriflora	Wood	20.5	78.4	8.6	1.1	0.12	0.7	0.008	0.11	20.5	8.0	5.7	3.8	38.9
Melaleuca preissiana	Wood	23.2	75.2	7.9	1.6	0.12	6.8	0.001	0.11	4.8	24.3	7.4	17.7	61.2
Melaleuca preissiana	Bark	19.7	78.8	7.2	1.5	0.11	1.4	0.001	0.34	11.7	25.5	9.1	15.4	63.5
Melaleuca rhaphiophylla	Wood	20.4	77.1	7.1	2.5	0.09	1.8	0.001	0.08	6.1	18.1	7.2	8.1	41.4
Melaleuca rhaphiophylla	Bark	17.9	77.7	6.7	4.4	0.39	1.2	0.082	0.84	20.9	8.6	14.4	11.3	57.6
Paraserianthes lophantha	Wood	18.3	81.1	6.7	0.6	0.42	8.1	0.051	0.94	50.6	12.1	3.0	6.4	81.6
Paraserianthes lophantha	Bark	27.7	69.3	9.0	3.0	0.36	4.6	0.027	1.13	34.8	7.5	2.1	19.7	70.2
Pinus brutia	Wood	19.1	80.5	6.4	0.4	0.58	2.1	0.014	0.67	54.0	5.8	2.1	4.2	69.4
Pittosporum angustifolium	Wood	21.3	78.3	7.1	0.4	0.38	8.9	0.018	0.67	44.3	11.2	3.9	10.9	80.3
Pittosporum angustifolium	Bark	18.6	75.8	8.0	5.6	0.42	1.6	0.062	1.67	50.4	4.0	2.1	16.9	77.2
Pittosporum phylliraeoides	Wood	18.4	80.4	7.2	1.2	0.09	2.2	0.010	0.36	36.3	5.3	1.5	25.6	71.3
Senna pleurocarpa	Wood	16.9	82.6	6.4	0.5	0.26	1.4	0.092	1.03	38.3	8.5	8.7	8.2	66.4
Taxandria juniperina	Wood	20.2	78.7	7.6	1.1	0.09	16.5	0.005	0.27	25.7	9.6	9.5	14.5	76.0
Taxandria juniperina	Bark	21.7	75.5	8.4	2.8	0.37	1.0	0.029	0.48	47.0	6.9	8.8	11.2	75.7
Trymalium floribundum	Wood	15.7	83.7	7.0	0.6	0.32	1.3	0.030	1.25	36.4	11.0	3.6	17.6	71.4
Trymalium floribundum	Bark	24.3	71.5	9.3	4.2	0.14	0.6	0.022	0.38	47.4	3.2	4.5	13.4	69.7
Viminaria juncea	Wood	21.4	78.0	7.8	0.6	0.42	1.8	0.115	1.85	42.4	9.7	5.2	4.8	66.4
Mean values	Wood	19.5	79.8	7.2	0.7	0.3	5.0	0.018	0.6	38.3	11.8	5.4	11.9	73.3
	Bark	23.4	72.7	8.2	3.9	0.3	1.3	0.036	0.9	41.1	6.1	5.0	9.8	64.6

Table 40. Proximate analysis and ash analysis for some Western Australian woody plants (B. ash components as % of dry material).

Species		Percentage of dry wood				B. Ash components expressed as oxides (ppm by weight of dry wood or bark)								
		Fixed C	Volatiles	Moisture	Ash	Fe2O3	P2O5	TiO2	Al2O3	CaO	MgO	Na2O	K2O	Total
Eucalyptus marginata	Wood	21.0			0.1	52	19	3	49	157	78	147	60	.06
Acacia bartleana Maslin ms	Wood	20.1	79.4	6.9	0.5	21	146	3	49	2,510	645	47	370	.38
Acacia cyclops	Wood	18.0	81.3	6.3	0.7	9	77	0	18	3,528	575	238	504	.49
Acacia cyclops	Bark	25.3	71.8	8.3	2.9	241	228	11	470	18,096	1,044	1,581	2,111	2.38
Acacia lasiocalyx	Wood	17.3	82.3	6.7	0.4	7	99	0	12	2,772	327	50	34	.33
Acacia aff. *redolens*	Wood	20.0	79.5	6.6	0.5	14	133	0	27	1,175	750	295	905	.33
Acacia aff. *redolens*	Bark	26.1	71.3	7.6	2.6	62	76	5	139	1,924	226	429	1,690	.46
Acacia microbotrya	Bark	31.1	66.8	8.0	2.1	57	672	12	146	10,017	941	456	3,318	1.56
Acacia saligna	Wood	19.0	80.2	7.2	0.8	13	392	0	20	3,832	1,176	208	760	.64
Actinostrobus arenarius	Wood	22.8	76.7	7.5	0.5	11	45	0	32	3,100	239	231	462	.41
Actinostrobus arenarius	Bark	18.2	78.0	7.7	3.8	144	306	23	441	25,764	1,186	1,239	1,220	3.03
Adenanthos stictus	Wood	19.7	79.8	6.8	0.5	21	90	0	46	1,480	466	880	655	.36
Adenanthos stictus	Bark	21.5	74.4	7.3	4.1	86	96	22	307	23,575	426	1,230	1,337	2.71
Agonis flexuosa	Wood	21.0	78.5	6.6	0.5	10	154	0	16	1,315	510	366	1,095	.35
Agonis flexuosa	Bark	19.8	71.4	8.7	8.8	114	408	19	370	60,632	6,494	1,382	2,508	7.19
Alyogyne hakeifolia	Wood	19.0	79.4	7.1	1.6	28	1,067	2	58	8,208	706	333	1,158	1.16
Alyogyne huegelii	Wood	19.6	79.2	6.8	1.2	7	3,264	0	13	3,168	586	454	2,904	1.04
Anthocercis littorea	Wood	18.0	81.1	6.9	0.9	20	342	1	47	4,671	483	316	1,044	.69
Banksia prionotes	Wood	20.6	78.7	7.4	0.7	11	264	0	78	637	854	1,068	1,225	.41
Banksia prionotes	Bark	24.6	74.2	8.0	1.2	23	167	3	192	3,228	2,388	860	384	.72
Callitris glaucophylla	Wood	24.0	75.3	7.4	0.7	13	167	0	31	2,310	655	161	1,750	.51
Callitris glaucophylla	Bark	23.1	74.3	7.9	2.6	99	585	7	265	16,094	759	328	2,782	2.09
Casuarina obesa	Wood	18.4	81.0	7.1	0.6	8	243	0	21	3,660	996	44	28	.50
Codonocarpus cotinifolius	Wood	19.3	79.7	7.9	1.0	22	514	2	39	796	1,050	872	3,390	.67
Dryandra arborea	Wood	22.3	77.1	7.1	0.6	47	139	4	128	828	696	533	1,668	.40
Dryandra arborea	Bark	26.2	72.3	8.4	1.5	97	237	7	318	2,205	1,233	1,650	2,535	.83

Species		Percentage of dry wood				B. Ash components expressed as oxides (ppm by weight of dry wood or bark)								
		Fixed C	Volatiles	Moisture	Ash	Fe_2O_3	P_2O_5	TiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Total
Duboisia hopwoodii	Wood	21.0	78.7	7.2	0.3	21	321	2	54	717	226	127	675	.21
Duboisia hopwoodii	Bark	20.4	72.9	7.8	6.7	817	891	66	1,836	29,547	2,854	2,760	7,303	4.61
Eucalyptus accedens	Wood	19.2	80.3	7.8	0.5	2	69	0	9	2,890	1,035	58	18	.41
Eucalyptus argyphea	Wood	19.4	80.3	7.0	0.3	6	23	0	8	1,848	630	10	12	.25
Eucalyptus leptopoda	Wood	21.8	78.1	7.8	0.1	3	12	0	4	474	173	76	96	.08
Eucalyptus leptopoda	Both	22.3	77.3	8.5	0.4	2	46	0	10	2,048	576	179	400	.33
Eucalyptus erythrocorys	Wood	19.2	80.3	7.8	0.5	5	301	0	9	2,495	650	422	364	.42
Eucalyptus erythrocorys	Both	18.3	75.9	7.8	5.8	12	169	1	16	41,702	6,728	1,282	661	5.06
Eucalyptus globulus	Wood	18.9	80.7	6.1	0.4	31	306	1	23	1,020	584	139	656	.28
Eucalyptus horistes	Wood	17.1	82.6	6.1	0.3	17	167	0	26	738	642	114	387	.21
Eucalyptus hypochlamydea	Wood	19.4	80.1	7.2	0.5	4	207	1	8	2,285	421	208	820	.40
Eucalyptus longicornis	Wood	18.3	81.3	7.8	0.4	4	57	0	10	1,292	480	142	688	.27
Eucalyptus loxophl. ssp liss.	Wood	16.9	82.6	7.0	0.5	6	405	0	6	1,730	575	165	550	.34
Eucalyptus loxophl. ssp lox.	Wood	18.5	81.0	7.6	0.5	7	545	1	9	2,490	402	172	550	.42
Eucalyptus melanoxylon	Wood	17.5	81.8	7.4	0.7	5	204	0	28	3,556	596	198	502	.51
Eucalyptus muellerana	Wood	18.6	81.1	5.9	0.3	9	272	1	19	771	468	179	483	.22
Eucalyptus occidentalis	Wood	16.7	82.8	6.2	0.5	96	735	4	101	1,250	605	299	570	.37
Eucalyptus polybractea	Wood	17.7	82.0	6.2	0.3	29	146	3	64	1,464	630	81	38	.25
Eucalyptus rudis	Wood	18.4	80.9	9.7	0.7	19	600	1	18	3,136	1,190	185	272	.54
Eucalyptus salicola	Wood	19.3	80.2	7.3	0.5	5	92	1	15	3,050	469	95	96	.38
Eucalyptus salmonophloia	Wood	20.2	79.4	8.2	0.4	2	86	0	10	1,628	712	198	460	.31
Eucalyptus salubris	Wood	19.9	78.5	7.0	1.6	6	110	2	18	12,656	1,776	286	280	1.51
Eucalyptus sideroxylon	Wood	19.5	79.8	6.2	0.7	9	903	1	19	1,953	924	763	959	.55
Eucalyptus todtiana	Wood	20.1	79.7	7.3	0.2	7	196	0	13	624	508	140	135	.16
Eucalyptus urna	Wood	18.5	81.1	8.1	0.4	2	38	0	7	2,240	648	101	53	.31
Exocarpus sparteus	Wood	20.0	78.6	7.0	1.4	63	186	3	153	7,658	959	850	938	1.08
Exocarpus sparteus	Bark	32.1	63.0	9.6	4.9	142	432	16	404	18,865	740	4,900	8,428	3.39
Grevillea candelabroides	Wood	19.3	80.0	7.9	0.7	7	398	0	15	2,639	534	507	1,554	.57
Grevillea candelabroides	Bark	22.0	73.7	8.6	4.3	43	499	7	135	18,533	1,157	710	3,935	2.50
Grevillea leucopteris	Wood	18.1	81.1	6.7	0.8	10	420	0	27	2,048	634	441	1,760	.53

Species		Percentage of dry wood				B. Ash components expressed as oxides (ppm by weight of dry wood or bark)								
		Fixed C	Volatiles	Moisture	Ash	Fe2O3	P2O5	TiO2	Al2O3	CaO	MgO	Na2O	K2O	Total
Gyrostemon ramulosus	Wood	20.9	78.0	7.6	1.1	20	726	1	26	1,606	1,095	637	3,069	.72
Hakea oleifolia	Wood	20.1	79.3	6.9	0.6	2	102	0	8	1,782	579	529	675	.37
Hakea oleifolia	Bark	24.5	68.3	9.7	7.2	55	477	14	274	24,768	5,220	2,376	2,700	3.59
Jacksonia sternbergiana	Wood	19.9	79.4	7.9	0.7	21	735	1	53	3,878	652	422	143	.59
Kunzea glabrescens	Wood	22.7	76.9	7.3	0.4	5	76	0	26	1,464	448	536	504	.31
Kunzea glabrescens	Bark	20.9	74.9	8.0	4.2	24	165	3	89	29,778	1,508	1,138	1,298	3.40
Lambertia inermis	Wood	19.5	80.1	6.3	0.4	8	56	0	12	508	233	584	684	.21
Lambertia inermis	Bark	25.8	71.7	8.1	2.5	39	148	2	103	1,343	435	1,318	1,115	.45
Melaleuca lateriflora	Wood	20.5	78.4	8.6	1.1	13	82	1	12	2,255	875	625	422	.43
Melaleuca preissiana	Wood	23.2	75.2	7.9	1.6	19	1,080	0	18	773	3,888	1,184	2,832	.98
Melaleuca preissiana	Bark	19.7	78.8	7.2	1.5	17	203	0	51	1,755	3,825	1,362	2,310	.95
Melaleuca rhaphiophylla	Wood	20.4	77.1	7.1	2.5	21	445	0	19	1,520	4,525	1,800	2,028	1.04
Melaleuca rhaphiophylla	Bark	17.9	77.7	6.7	4.4	170	510	36	371	9,196	3,771	6,336	4,972	2.54
Paraserianthes lophantha	Wood	18.3	81.1	6.7	0.6	25	487	3	56	3,036	726	181	383	.49
Paraserianthes lophantha	Bark	27.7	69.3	9.0	3.0	109	1,374	8	339	10,440	2,238	636	5,910	2.11
Pinus brutia	Wood	19.1	80.5	6.4	0.4	23	82	1	27	2,160	230	85	167	.28
Pittosporum angustifolium	Wood	21.3	78.3	7.1	0.4	15	356	1	27	1,772	448	157	436	.32
Pittosporum angustifolium	Bark	18.6	75.8	8.0	5.6	236	913	35	932	28,224	2,218	1,187	9,464	4.32
Pittosporum phylliraeoides	Wood	18.4	80.4	7.2	1.2	11	259	1	43	4,356	632	179	3,072	.86
Senna pleurocarpa	Wood	16.9	82.6	6.4	0.5	13	71	5	52	1,915	424	434	409	.33
Taxandria juniperina	Wood	20.2	78.7	7.6	1.1	10	1,815	1	29	2,827	1,052	1,042	1,590	.84
Taxandria juniperina	Bark	21.7	75.5	8.4	2.8	104	274	8	133	13,160	1,935	2,450	3,136	2.12
Trymalium floribundum	Wood	15.7	83.7	7.0	0.6	19	76	2	75	2,184	660	214	1,056	.43
Trymalium floribundum	Bark	24.3	71.5	9.3	4.2	60	273	9	160	19,908	1,357	1,894	5,628	2.93
Viminaria juncea	Wood	21.4	78.0	7.8	0.6	25	110	7	111	2,544	584	313	288	.40
Mean values	Wood	19.5	79.8	7.2	0.7	16	359	1	33	2,478	776	368	853	0.49
	Bark	23.4	72.7	8.2	3.9	130	425	15	356	17,479	1,998	1,725	3,528	2.57

6.10 Other products

During the wood coring program (Section 6.3), additional samples were collected from each cored species, for possible later analysis. These further analyses were not intended to be completed within the Search Project, but samples were collected simultaneously with the wood cores so that more information could be found about these species later if required. Collecting additional material from the same plants as those cored enables a more complete picture to be built of the characteristics of individual vouchered plant specimens. Additional samples included bark and foliage.

Bark samples were collected from trees likely to contain high tannin content. They were stored in the same bags as the wood cores, and received the same drying treatment.

Two different foliage samples were collected – one for fodder assessment and one for essential oil analysis.

Samples of foliage for fodder assessment were collected from species that appeared palatable, or were known to be eaten by stock. Foliage samples were stored in paper bags and encouraged to air dry on the field trip, then oven dried at 70 degrees Celsius in the laboratory, as recommended by Tony Schlink, CSIRO Livestock Industries, Floreat Park, Perth.

Samples of foliage for oil assessment were collected from species with aromatic foliage. Samples comprised 3g (fresh weight) of youngest fully expanded leaf. A composite foliage sample was made up of four samples from a single plant, then stored in bottles filled with ethanol. There are two potential tests:
single component tests (e.g. cineole) are relatively cheap and are used to find the proportion of a particular chemical using gas chromatography;
long run tests are used to find all chemicals present in high proportions using gas chromatography. These chemicals are then identified using mass spectrometry.

6.11 Conclusions

Results of the various feedstock testing programs have been encouraging. Despite the speculative nature of much of the material collected, and the limited range of material that could be collected for each species, some good results were achieved at the first attempt, demonstrating that there is considerable promise in the native flora. With targeted selection of the most suitable provenances within the more promising species, and adjustments to processing conditions to suit these new feedstocks, it is likely that these preliminary results can be improved upon.

Further exploration of some of the better prospects, will be carried forward in other projects, especially in association with the Cooperative Research Centre for Plant-based Management of Salinity.

6.12 References

ABARE (2003). Australian commodity statistics 2002. Canberra, Australian Bureau of Agricultural and Resource Economics. 355p.

Anon (not dated). Munsell soil color charts. Regensdorf, Switzerland, GretagMacbeth.

Balodis, V, F Phillips and A Yuritta (1980). "The measurement of basic density of hardwood chips." Appita **33**(4): 291-294.

Boland, D, M Brooker, *et al.* (1984). Forest trees of Australia. 4th ed. Melbourne, Nelson-CSIRO. 687p.

Bootle, KR (1983). Wood in Australia - Types, properties and uses. Sydney, McGraw-Hill.

Brennan, G (1996). Wood density assessments by CALM (1985 to 1995). Department of Conservation and Land Management.

Brennan, GK and P Newby (1992). "Potential of Western Australian Eastern goldfields timbers for high quality wood products." Australian Forestry **55**: 74-79.

Brennan, GK, GR Siemon and J Pitcher (1997). Timber properties and market potential of selected Wheatbelt species. 2. Raspberry jam, brown mallet and York gum. CALM Timber Technology Internal Report. Department of Conservation and Land Management.

Chippendale, G (1973). Eucalypts of the Western Australian goldfields (and the adjacent wheatbelt). Canberra, Australian Government Publishing Service.

CSIRO Energy Technology (2002). Biofuels database. Accessed: http://www.det.csiro.au/science/energyresources/biomass.htm

Dadswell, H (1931). The density of Australian timbers. A preliminary study. Technical Paper No. 2. CSIR Australia Division of Forest Products. Report Technical Paper No. 2.

Energy Research Centre of the Netherlands (ECN) Phyllis. Accessed: 25 September 2004. http://www.ecn.nl/phyllis/

Forest and Wood Products Research and Development Corporation (2003). Australian hardwood drying best practice manual, Australian government.

Hill, P and GK Brennan (2000). "Wood properties of southern gidgee (*Acacia pruinocarpa*) from different sites in the Pilbara and Goldfields regions of Western Australia." CALMScience **3**(3): 317-322.

IEA Bioenergy BioBank. Accessed: 25 September 2004. http://www.ieabioenergy-task32.com/database/biobank.html

Johns, W and K Niazi (1980). "Effect of pH and buffering capacity of wood on the gelation time of urea-formaldehyde resin." Wood and Fibre **12**(4): 255-263.

Kininmonth, J and L Whitehouse (1991). Properties and uses of New Zealand radiata pine. Volume 1 - Wood Properties. Rotorua, New Zealand, Forest Research Institute.

Kornerup, A and JH Wanscher (1978). Methuen handbook of colour. 3rd ed. London, Eyre Methuen. 252p.

Piper, P (2000). Drying gimlet and Goldfields blackbutt timber. Unpublished report. Department of Conservation and Land Management, Forest Products Division.

Piper, P (2001). Drying behaviour and utilisation potential of Preiss's paperbark (*Melaleuca preissiana*). Unpublished report. Forest Products Commission of Western Australia.

Portman Limited (2003). Media release 10 March 2003: Portman posts $3.3 million net annual profit following one-off write-downs. Accessed: 10 March 2003. www.asx.com

Siemon, GR (2001). Utilisation of sawn and round marri timber (*Corymbia calophylla*). Unpublished report. Forest Products Commission WA. Unpublished report.

Siemon, GR and I Kealley (1999). Goldfields timber research report. Report by the research project steering committee. Western Australian Department of Commerce and Trade, Goldfields Esperance Development Commission, Department of Conservation and Land Management, Curtin University Kalgoorlie Campus.

Siemon, GR and J Pitcher (1996). Timber properties and market potential of selected Wheatbelt species. 2. Rock sheoak and swamp sheoak. CALM Timber Technology Internal Report. Department of Conservation and Land Management.

Stamm, AJ (1929). "Density of wood substance, adsorption of wood and permeability of wood." Journal of Physical Chemistry **33**: 398-414.

Standards Association of Australia (1979). Australian Standard AS1301. Basic density of wood chips. Homebush, New South Wales, Standards Association of Australia.

Standards Australia (1986). Australian Standard AS 1301.P414m-1986 : Methods of test for pulp and paper (metric units) - Conditioning of paper for testing. Homebush, New South Wales, Standards Australia.

Standards Australia (1996). Australian Standard AS 2700-1996 : Colour Standards for general purposes. Homebush, New South Wales, Standards Australia.

Standards Australia (1998a). Australian Standard AS/NZS 1301.004s:1998 : Methods of test for pulp and paper - Solubility of wood in boiling water. Homebush, New South Wales, Standards Australia.

Standards Australia (1998b). Australian Standard AS/NZS 1301.415s:1998 : Methods of test for pulp and paper - Standard atmosphere for testing paper and board and procedure for monitoring the atmosphere. Homebush, New South Wales, Standards Australia.

Standards Australia (1998c). Australian Standard AS/NZS 1328.1:1998. Glued laminated structural timber. Part 1. Performance requirements and minimum production requirements. Homebush, New South Wales, Standards Australia.

Standards Australia (1999). Australian Standard AS 2796-1999. Timber-Hardwood-Sawn and milled products Part 2: Grade description. Homebush, New South Wales, Standards Australia.

Standards Australia (2001a). Australian Standard AS/NZS 4266.5(Int):2001 : Reconstituted wood-based panels - Methods of test - Modulus of elasticity in bending and bending strength. Homebush, New South Wales, Standards Australia.

Standards Australia (2001b). Australian Standard AS/NZS 4266.6(Int):2001 : Reconstituted wood-based panels - Methods of test - Tensile strength perpendicular to the plane of the panel (Internal bond strength). Homebush, New South Wales, Standards Australia.

Standards Australia (2001c). Australian Standard AS/NZS 4266.8(Int):2001 : Reconstituted wood-based panels - Methods of test - Swelling in thickness after immersion in water. Homebush, New South Wales, Standards Australia.

Standards Australia (2002). Australian Standard AS/NZS 1301.201s:2002 : Methods of test for pulp and paper - Kappa number of pulp. Homebush, New South Wales, Standards Australia.

Standards Australia (2003). Australian Standard AS 5067-2003 : Timber - Non-structural glued laminated - Performance and production requirements. Homebush, New South Wales, Standards Australia.

University of Technology Vienna BIOBIB. Accessed: 25 September 2004. http://www.vt.tuwien.ac.at/biobib/

Uprichard, J and J Walker (1993). Pulp and paper manufacture. p481-534 *In* Primary wood processing. JCF Walker, Ed. London, Chapman & Hall.

Walker, JCF (1993). Primary Wood Processing. First. London, Chapman & Hall. 595p.

Washusen, R, P Ades, R Evans, J Ilic and P Vinden (2001). "Relationship between density, shrinkage, extractives content and microfibril angle in tension wood from three provenances of 10-year-old *Eucalyptus globulus* Labill." Holzforschung **55**(2): 176-182.

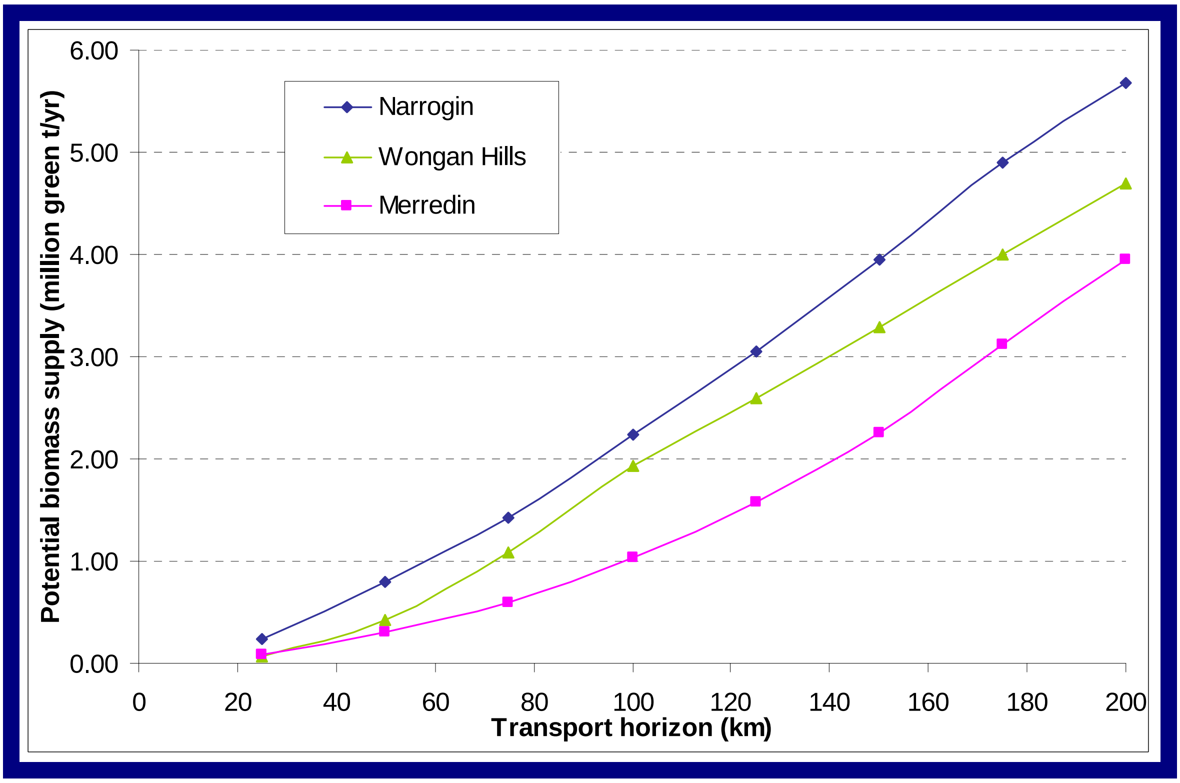
Waterston, GC, Ed. (1997). Australian Timber Seasoning Manual. Launceston, Tasmania, Australian Furniture Research and Development Institute Limited. 206p.

Western Australian Herbarium (1998). FloraBase - Information on the Western Australian flora. Accessed: http://www.calm.wa.gov.au/science/florabase.html

Natural Heritage Trust
Helping Communities Helping Australia
An Australian Government Initiative

Search Project Report

Section 7 – Economic Analysis



Estimate of biomass that could be supplied within various haulage distances from three potential processing centres

Final report for NHT Project 973849

July 2004

Government of Western Australia
Department of Conservation and Land Management
Conserving the nature of WA

Authors

Graeme Olsen[1]
Don Cooper[2]
Dan Huxtable[2]
Jerome Carslake[2]
John Bartle[2]

ISBN No: 0 7307 55509

[1] Olsen & Vickery, PO Box 357 Waroona, Western Australia 6215.

[2] Department of Conservation and Land Management, Locked Bag 104, Bentley Delivery Centre, Western Australia 6983.

Sections in this report

Section 1	Summary
Section 2	Background
Section 3	Search Methodology
Section 4	Product Assessment
Section 5	Species Selection
Section 6	Feedstock Testing
Section 7	Economic Analysis
Section 8	Demonstration and Resource Plantings
Section 9	Propagation Project
Section 10	Project Administration
Appendices	

Contents of this Section

Section 7 Economic Analysis 5

7.1 Introduction 5

7.2 Woody crop yields 6

7.3 Farm-scale economics 15

7.4 Feedstock supply to a processor 43

7.5 GIS Metadata 55

7.6 References 68

Section 7 Economic Analysis

7.1 Introduction

This section presents a preliminary economic analysis of the potential for woody perennial crops and industries in the wheatbelt of Western Australia. It represents the initial stage of work that will be continued in the CRC for Plant-based Management of Dryland Salinity.

The ultimate test of success of a new crop is whether it will be commercially successful for both growers and processors. Failure at either level will preclude its development. However, at the start of new crop development, information is lacking in many key areas. Therefore, one of the first tasks undertaken in assessing any potential new crop should be an economic analysis, to provide an estimate of the likelihood of success based on current knowledge, and to find sensitive parameters to guide research and development.

This study examines the prospects for new tree crop industries from the perspective of both growers and processors. At the farm level, a paddock-scale study was carried out to compare the economics of agriculture incorporating woody perennial crops, with current farming systems based solely on annual plants. To assess the feasibility of supplying a processing plant with raw material, a separate study was undertaken involving estimates of feedstock productivity and available land, from which the supply catchment area and average transport distance required to supply the plant were calculated. Both types of analysis require productivity estimates for woody perennial crops. An updated version of these analyses, which links the farm economics and industry supply sections has been published separately (Cooper *et al.* 2004, submitted).

This section is divided into three parts:

- A methodology for predicting the potential yields for woody crops (7.2).
- A paddock-scale analysis of key economic parameters of woody crops (7.3). This includes calculation of economic parameters to compare different agricultural sequences and layouts, break-even values for various woody crop options, and sensitivity analysis to guide future research.
- An examination of feedstock supply to a processing plant (7.4), calculating the amount of material that may be supplied to three potential processing locations, and on the basis of those amounts, commenting on the types of industries that may be feasible at each location.

7.2 Woody crop yields

7.2.1 Crop archetypes

The analysis presented here is for woody crop archetypes (see Section 2.8.5) rather than particular species. It is assumed that any species chosen as a woody crop will supply material of sufficient quality to warrant the building of a processing facility. Furthermore, it is assumed that chosen species will be well suited to the agricultural environment of south-western Western Australia and will grow quickly. The crop archetypes discussed in this section are described in Table 1. Note that the terms ‘woody crop’ and ‘trees’ are used generically in this section to embrace all archetypes.

Table 1. Woody crop archetypes (see Section 2.8.5 for further information).

Archetype	Description	Layout	Abbreviation
Short-cycle coppice	Long lived species that regenerate strongly from the stump after harvest. Repeated harvests can be sustained on a 2-5 year cycle for many decades.	Belt	C
Short-cycle phase	Species that have rapid initial growth and characteristics favouring establishment by direct seeding. Harvested at age 3-6 years after which the paddock is returned to a period of annual-plant agriculture, thus providing alternating phases of annual and perennial crops.	Block	P
Long-cycle	Long-lived woody species, with tree form and timber suited to high value uses such as cabinet making or flooring. Sawlogs harvested after 20 or more years.	Belt	T-Be
		Block	T-Bl

7.2.2 Productivity estimates

The productivity of a land unit has important ramifications for both industry supply and farm-scale economics. Higher rates of productivity allow an industry to be supplied from a smaller area and improve the likelihood of tree crops being adopted by growers.

Productivity is generally estimated based on measurements of existing crops. However, for potential new industries this isn’t possible. Measurement of trial plots can be used to provide an approximation of yields, but the estimates are site specific. Therefore, in this study we have estimated yields using a physiological relationship between water use and biomass production.

Studies in Western Australia by the Department of Conservation and Land Management (CALM) and Forest Products Commission (FPC) have demonstrated a good regression between the current annual bole volume increment of *Pinus pinaster* and climate wetness index (Equation 1). Additionally, relationships have been derived relating bole volume and above ground biomass for *Pinus pinaster* (Equation 2). These relationships combined with rainfall and evaporation data for each site (Table 2) and an estimate of extra moisture captured (Figure 1) have been used to estimate woody perennial productivity in this analysis.

Error! Objects cannot be created from editing field codes.

Equation 1. Volume increment as a function of climate wetness index (McGrath and Dumbrell, FPC, unpublished data)

$$B = 1.142 * V$$
where :
B = Oven dry biomass
V = Bole volume under bark for 13.4 year old *Pinus pinaster*

Equation 2. Relationship between biomass and bole volume for pines of the average age of the trees from which the regression in Equation 1 was derived (Ritson, FPC, unpublished data).

Table 2. Mean annual rainfall and point potential evaporation at trial sites.

	Kojonup	Jerramungup	Merredin
Mean annual rainfall (mm)	533	442	328
Mean annual evaporation (mm)	1460	1606	2153

Source Bureau of Meteorology (http://www.bom.gov.au/climate/averages/tables/ca_wa_names.shtml). Jerramungup evaporation data was taken from Ongerup, the nearest town with available data.

7.2.3 Key assumptions in productivity estimates

The estimation of woody crop productivity relies on a number of assumptions for both the water to biomass regression and the amount of additional moisture captured by woody perennial crops interspersed with annual plant agriculture. Some of the more important assumptions used in these early development stages of this analytical framework, are discussed below.

7.2.3.1 Key assumptions for water to biomass equation

- It was assumed that current growth rates defined in Equation 1 were in response to water supplied solely from rainfall. The relationship in Equation 1 was derived from trees in extensive plantations, more than 10 years old, where current growth was no longer influenced by initial stored soil water and where the potential for lateral movement of water into the plantation was low (pers. comm. J. McGrath, Aug 2003).
- Water use efficiency of all woody crops is the same as that for the *Pinus pinaster* plots from which Equation 1 was derived.
- Water use efficiency is constant for the life of woody perennials. That is, the amount of water required to produce one unit of biomass is the same for a 10 cm tall seedling as for a 10 metre tall tree. It is assumed that harvest occurs at a relatively young age compared to the potential lifespan of woody plants, thus avoiding the plateau and downward sections of typical growth curves for senescing and old trees.
- The water use efficiency of coppicing plants is assumed to be similar to that of seedlings. However, recent findings suggest that this assumption should be reviewed. Based on experimental data from a site near Kalannie in the northern

wheatbelt, Wildy *et al*. (2003) found that coppice growth of oil mallee (*Eucalyptus kochii subsp. plenissima*) had a higher water use efficiency, and also allocated a higher percentage of biomass production to above ground growth, than seedlings.

- Production of a unit of biomass will require the same amount of water regardless of whether the water is supplied as rainfall or additional captured moisture. In some cases this assumption will underestimate biomass production from additional captured water, because the water use efficiency of rainfall includes losses due to interception and surface evaporation, whereas there may be less loss from other water sources. However, extra energy may be required to extract additional water from these other sources, reducing the efficiency with which additional water is used.

7.2.3.2 Key assumptions relating to water capture by woody perennials

- There are four different conceptual mechanisms by which a permanently planted tree crop area may capture water in addition to rainfall. These may operate alone or in combination depending on soil type and other circumstances (Bartle 1999). They are:
  - Surface runoff can move downslope and infiltrate into the root zone of trees. This can be aided by construction of banks to collect, divert and detain water and thereby increase infiltration in the tree root zone;
  - Shallow subsurface or perched groundwater flows can move downslope and recharge the root zone of trees;
  - Deep groundwater may be extracted by deep roots and replenished by flow within the aquifer;
  - Lateral spread of roots from belts of trees may reach up to 30 m (Sudmeyer 2002) considerably extending their water capture range.

  The first three mechanisms were characterised by Bartle (1999)as ‘water coming to trees’, in presenting a critical review of the George *et al*. (1999) proposition that recharge control would require perennials to influence as much as 70-80% of a catchment.

  Note that depletion of *stored* soil water by a *permanent* stand of trees is not defined as ‘capture’, because it is a once-off source. On the other hand to make this analysis relevant to phase crops, the cycle of depletion of stored soil water by a woody phase crop and its subsequent replenishment during the annual plant phase *is* defined as ‘capture’.

- The percentage capture of excess water increases with the proportion of woody vegetation cover (Equation 3, Figure 1).
- Capture is a multi-stage process:
  - It may involve passive or facilitated transfer of water from an area of surplus to an area with available storage capacity.
  - The water is stored in the soil, either within the existing root zone or in soil volumes later able to be accessed by roots.
  - The soil water store provides a buffer so that the growth response may occur some time after the water enters storage. Capture can be expressed as an average over the lifespan of the woody crop.

7.2.4 Estimation of capture rate

7.2.4.1 Woody crops in belts

For the WA wheatbelt, there are adequate data and models to predict hydrological performance at the catchment scale. There are also good conceptual models of the effect of tree belts on local hydrology (Silberstein *et al.* 2002). However, there are insufficient data from which to predict the water capture rate by tree belts. The lateral flow mechanisms listed in 7.2.3.2 above (surface run-off, perched groundwater, deep groundwater) can be highly variable in time and space, and will require intensive research to collect data on the appropriate scale. The parameters that determine the amount and local distribution of lateral flow include short time-step rainfall intensity and frequency, infiltration rate, vertical and lateral hydraulic conductivities of the various soil horizons, micro-relief of soil surface and perching layers, depth of root penetration, obstruction to root penetration and salinity of groundwater.

The potential for tree roots to provide substantial soil storage volumes and hydraulic gradients to facilitate water capture is indicated in work by Robinson *et al*. (2002). They found that two and four-row mallee belts in Western Australia had exhausted available soil water to the depth of their investigation (10 metres) within seven years of planting. The lateral extent of tree roots was up to 20 metres, depending on soil type. This indicates that belts can provide a large volume sink with large local hydraulic gradients that will facilitate capture of lateral flows that may occur in adjacent cropland, as either surface run-off or lateral flow of perched groundwater. The large local hydraulic gradients that can be generated by trees are in striking contrast to the generally low topographic and regional groundwater gradients of wheatbelt landscapes.

Lateral flows on the surface or in perched systems will be difficult to quantify, as they are transient and generally small, except perhaps during exceptional rainfall events. However, since extra water is a sensitive determinant of yield, it will be important to better quantify lateral flows in future research.

The major form of water capture by tree belts is likely to be via lateral spread of roots into the adjacent unsaturated zone. Trees may capture water from within the root zone of adjacent crops or pastures (in competition with them), or they may capture uncontested sources such as water that infiltrates into the unsaturated soil below the annual plant root depth (‘leakage’), or water from summer rainfall when no annual plants are present.

7.2.4.2 Woody phase crops

The capture of water by phase crops can be estimated from the amount of available stored water in soil profiles. However, the amount captured also depends on the effective depth of roots and the rate of replenishment of the soil profile following the previous phase crop. Data for both these parameters are scarce.

7.2.4.3 Mathematical relationships

A positive relationship was assumed to exist between percentage woody perennial cover and the capture rate of excess water from conventional annual crops. For this study, an estimated exponential relationship between capture and percentage woody cover has been used (Figure 1, Equation 3). The constants for this equation were derived for a hypothetical case in which 50% of the excess water is captured by 10% tree coverage, assuming that water capture is solely by lateral root extension from trees in belts. For trees arranged in 5m wide belts this represents alley widths of 45m with lateral roots capturing all surplus water 11.25m either side of the belts (‘capture width’, Figure 2).

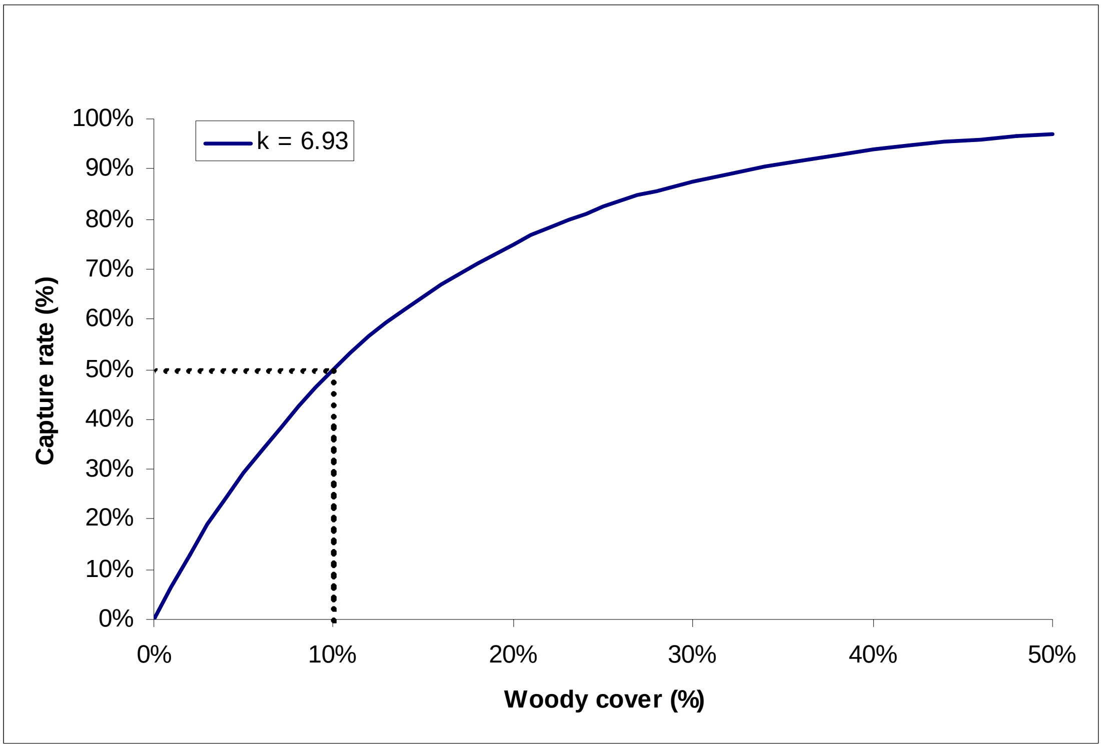


Figure 1. Capture rate of excess water from conventional annual agriculture based on woody cover percentage (derived using Equation 3, k=6.93)

$$C = 1 - e^{-kWc}$$

where :

C = capture rate

k = constant

Wc = Woody cover level

Equation 3. Calculation of capture rate of excess water from annual agriculture by woody perennials, based on percentage woody perennial cover

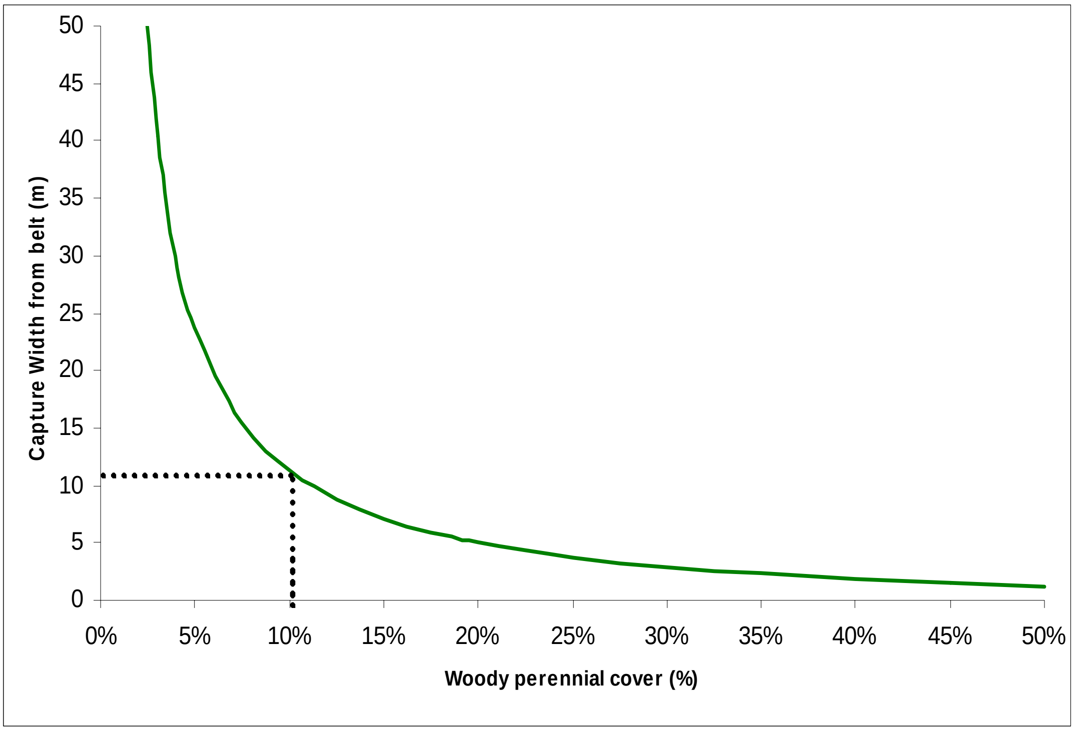


Figure 2. Capture width versus woody perennial cover of 5m tree belts required for 50% capture of excess water from alley

7.2.5 Source of extra water

There are two potential sources of water not utilised by agricultural crops and pastures that may become available to tree crops. They are surface runoff and water leaking past the root zone of annual crops and pastures. The amount of extra water available for tree crops from these sources depends upon rainfall amount and distribution, and soil characteristics such as infiltration rate, surface roughness, slope, unsaturated and saturated hydraulic conductivities through the soil profile, preferred pathways and current soil moisture content.

Hydrologists traditionally define recharge as water that is added to an aquifer (Ghassemi *et al.* 1995). In agricultural terminology, water passing below the root zone is referred to as 'recharge' because it will ultimately end up in an aquifer. However, this 'recharge' component may be intercepted and captured by the deeper root systems of adjacent tree belts before it reaches an aquifer. Likewise, surface run-off available to trees may differ from the run-off measured at a catchment discharge point. Small, local-scale run-off may preferentially infiltrate into the drier soil below tree crops.

In this analysis, it is assumed that all water not used by agricultural crops and pastures is available for capture by woody crops. The terms recharge and run-off are used with the modified meanings outlined above.

Since recharge is dependent upon the amount and distribution of rainfall, annual recharge on a site will vary from year to year. Therefore, it is not surprising that estimates of recharge for an area can be quite different. For example, research carried out by Department of Agriculture near Merredin on deep sands estimated annual recharge under cropping to be 10-15mm, contrasting with 45mm estimated by Asseng et al. (2001) and 100mm modelled by Hatton and Dawes (2000). Measurements of recharge for a period of 22 months, on deep sands at Kalannie, which has a similar annual rainfall to Merredin, suggested that up to one third of rainfall became recharge under pasture (Wildy *et al.* 2003). Recharge rates used in this study are presented in Table 3.

Table 3. Recharge rates for agriculture on sandy surfaced soils.

Kojonup	Jerramungup	Merredin
100 mm	60 mm	30 mm

Source: Don Bennett (WA Department of Agriculture, 2003) except Merredin where the data supplied by Don Bennett and data from Asseng et al. (2001) were averaged.

7.2.6 Estimation of woody yields for different crop types

7.2.6.1 Phase layouts

Biomass yield for woody phase crops was estimated from the total amount of water available, using Equation 1 and Equation 2.

Available water includes rainfall during the phase crop, plus the amount of recharge detained in unsaturated storage during the alternate phase of annual crops and pastures. Capture occurs when this stored soil moisture is subsequently extracted by the phase crop. The maximum soil water storage was calculated for a designated soil profile (Table 4). The actual amount of stored water that a woody phase crop could capture could be less than this maximum, depending on the period between woody phase crops, the recharge rate, and the retention rate of that recharge in the unsaturated zone. It was assumed that the woody phase crop would capture all available stored soil moisture to a depth of eight metres. Therefore, for the purposes of this analysis, the retention rate of water in the unsaturated zone is the same as the capture rate estimated from Figure 1. During the subsequent annual phase the unsaturated soil would refill at the recharge rate multiplied by the retention (or ‘capture’) rate.

There is a trade-off between woody phase crop yield and prevention of recharge to groundwater. If woody phase crops were grown too frequently, available stored water would be reduced. Despite a higher capture rate, yield would decrease. If grown too infrequently the yield would approach a maximum, but the capture rate would be lower and more recharge would be lost to groundwater.

Some experimental work suggests that woody phase crops have considerable ability to dewater unsaturated soil profiles, as assumed in this study. For example, Harper and co-workers demonstrated that two-year-old *Eucalyptus occidentalis* planted at Corrigin had dewatered the top four metres of the soil profile (CALM unpublished data, 2003). Similarly, Smettem *et al*. (1999), found that eight-year-old blue gums utilised all plant-available soil moisture to depths up to nine metres. In the 300-450 mm rainfall zone of the Murray-Darling Basin, Knight et al. (2002) found that four-year-old trees (growing in belts, rather than as phase crops) had removed an additional 600 mm of water from the top 12 m of the profile, compared to annual cropland nearby.

Table 4. Assumptions and estimated yields for phase layouts.

	Kojonup	Jerramungup	Merredin
Sand depth (m)	0.5	0.5	0.5
Sand available moisture (%)	0	0	0
Clay 1 depth (m)	0.3	0.3	0.3
Clay 1 available moisture (%)	0	0	0
Unsaturated clay 2 depth (m)	>10	>10	>10
Clay 2 gravel (%)	30	30	30
Clay 2 available moisture (%)	15	15	15
Dewatered depth (m)	8	8	8
Max available stored soil moisture (mm)	756	756	756
Phase length (years)	4	4	4
Time between phase crops (years)	7	15	26
Woody occupation of total time (%)	36.4%	21.1%	13.3%
Recharge (mm/yr)	100	60	30
Capture Rate (from Figure 1)	92%	84%	60%
Available stored soil moisture (mm)	644	756	468
Mean annual rainfall (mm)	533	442	328
Mean annual evaporation (mm)	1460	1606	2153
Run on – Run off (mm)	0	0	0
Groundwater use (mm)	0	0	0
Ave annual water use (mm)	694	631	445
Biomass production (bone dry t/ha)	**72**	**58**	**28**
Biomass production (green t/ha)	**131**	**106**	**50**

7.2.6.2 Belt layouts

The yield of tree crops in belt layouts was calculated from available moisture using Equation 1 and Equation 2. Rainfall was assumed to be supplemented by capture of excess water through a combination of lateral water movement and lateral extension of roots.

The percentage of the paddock occupied by tree belts was greater on sites with higher rainfall (Table 5) for two reasons. First, recharge under annual plants is greater at higher rainfall. Second, at higher rainfall trees are less dependent on capture of additional moisture to achieve acceptable growth rates, as a higher percentage of their transpiration needs can be met by rainfall. Hence, to control recharge, higher rainfall sites require a greater density of trees than lower rainfall sites. Higher tree density can be achieved by decreasing the spacing between belts.

In contrast, wider belt spacings should be adequate to control recharge at lower rainfall sites. However, increasing belt spacing on lower rainfall sites may also decrease the capture ratio, as the water will take longer to move laterally to the trees, or lateral spread of roots will occupy a smaller proportion of the space between tree belts. Therefore at wider belt spacings, a greater percentage of recharge is likely to move vertically down to become groundwater that may be too saline or deep to be readily captured by tree roots.

Tree belts were set at a width of 10m in this analysis, representing four rows of trees two metres apart with a two metre buffer on either side. Agriculture in the alleys was allocated in 30m increments, to simulate annual cropping machinery passes.

Although belts of trees initially will gain additional growth from the utilisation of available stored soil moisture, this one-off boost was not included in this analysis, as it will not affect the sustainable yield of permanent tree belts.

Table 5. Assumptions and estimated yields for coppice belt and timber belt layouts.

Assumptions	Kojonup	Jerramungup	Merredin
Agricultural passes per alley	1	2	4
Alley width (m)	30	60	120
Tree belt width (m)	10	10	10
Tree belt proportion of paddock (%)	25	14.3	7.7
Excess water (recharge) in alleys (mm/yr)	100	60	30
Capture Rate (from Figure 1)	82%	63%	41%
Annual extra moisture available (mm)	246	227	148
Mean annual rainfall (mm)	533	442	328
Ave annual water use (mm)	780	668	477
Mean annual evaporation (mm)	1460	1606	2153
Harvest period –coppice belts (Yrs)	3	3	3
Harvest period – timber belts (Yrs)	21	24	30
Results – short-cycle coppice belts			
Biomass production (bone dry t/ha)	61	47	23
Biomass production (green t/ha)	111	85	41
Results – long-cycle timber belts			
Sawlog yield (m^3)	225	196	119
Firewood yield (m^3)	150	131	79

7.2.6.3 Timber trees in block layout

The yield for timber blocks was calculated using Equation 1, with rainfall as the only source of water. Timber blocks were assumed to be large enough to negate the effect of run on and run off. Although trees initially will gain additional growth from the utilisation of available stored soil water, this was not considered, as it will not affect the sustainable yield, if the block is subsequently replanted in a second rotation. Also the amount of additional water available would have a relatively small influence over a rotation of 20 years or longer.

Table 6. Estimation of yields for long term blocks.

	Kojonup	Jerramungup	Merredin
Mean annual rainfall (mm)	533	442	328
Mean annual evaporation (mm)	1460	1606	2153
Run on – Run off (mm)	0	0	0
Groundwater use (mm)	0	0	0
Ave annual water use (mm)	533	442	328
Harvest period (Years)	21	24	30
Sawlog yield (m^3)	149	122	74
Firewood yield (m^3)	99	82	49

7.3 Farm-scale economics

7.3.1 Background

7.3.1.1 Study area

Broadscale agriculture is a generic term used here to describe the grazing and cropping activities carried out between the 300mm and 600mm mean annual rainfall isohyets in the 'wheatbelt' of southern Western Australia (Figure 3). This area, mostly of low relief, experiences a typical Mediterranean climate, with cool wet winters, hot dry summers, and relatively low variability between years. Variability in winter rainfall is more pronounced in the drier, eastern part of the wheatbelt, while northern areas are more prone to unseasonable heavy summer rain caused by tropical weather systems. Evaporation increases markedly from south to north.

Crops are sown in late autumn or early winter and are harvested in late spring or early summer. Winter rainfall is the dominant influence on crop yields, with yields depressed by moisture stress in dry years, and by waterlogging in some areas in wet years

Wheat is the main commercial crop. Other crops include canola, lupins, barley and oats. Sheep are the main livestock enterprise, grazing on improved pastures and crop stubbles.

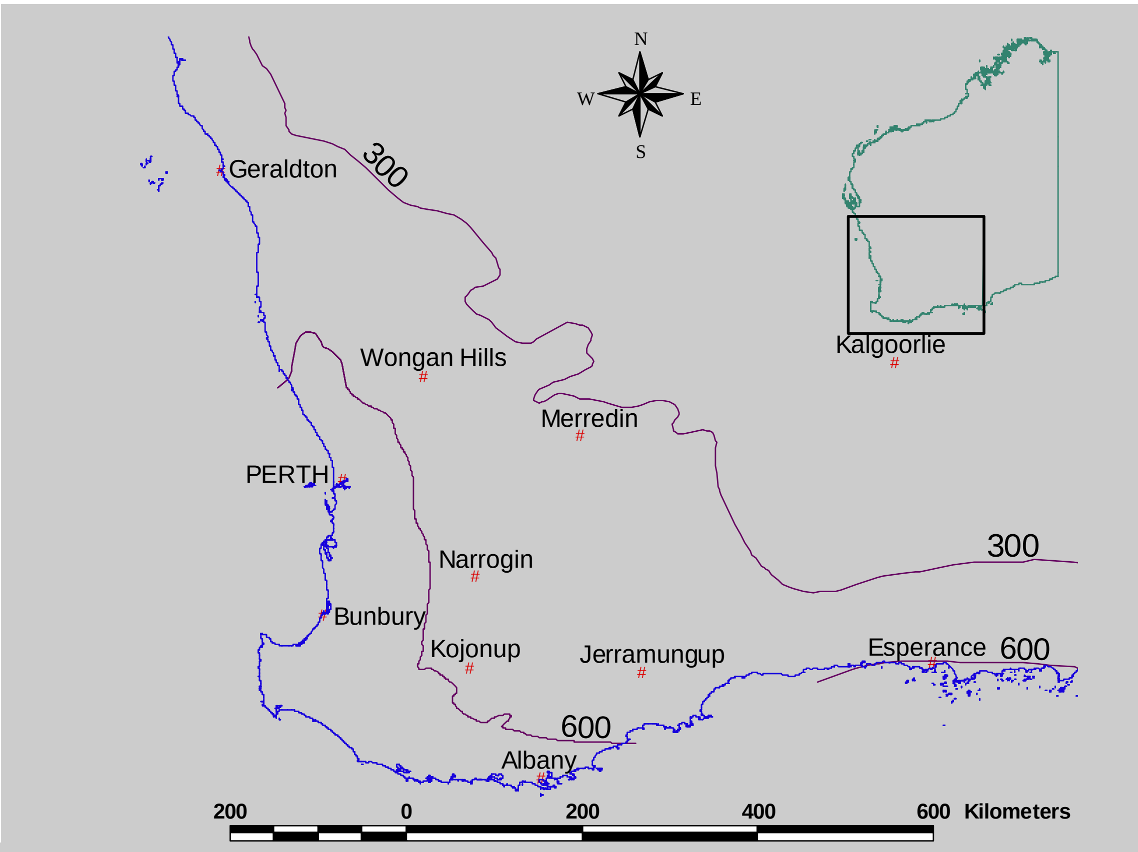


Figure 3. Broadscale agricultural zone for Western Australia, between 300 and 600mm isohyets.

7.3.2 Analysis tool – *Imagine*

7.3.2.1 Description

The Search Project team recognised the importance of early economic analysis at the farm scale, but did not have a suitable tool to facilitate the analysis. The decision was made to develop a Microsoft Excel spreadsheet for the analysis. Concurrently, Dr Amir Abadi now based at the Western Australian Department of Agriculture (WADA) was assessing available agroforestry modelling software as part of RIRDC project UWA 63A. This project aimed to assess the viability of agricultural systems that included current and potential woody perennial crops.

Since the RIRDC project required an economic assessment of similar crops to those the Search Project was investigating, the two projects collaborated to develop an analysis tool called *Imagine*. The Search Project provided most of the programming input to *Imagine* with assistance and guidance from Dr Abadi and funding support from RIRDC project UWA 63A.

Imagine is a Microsoft Excel spreadsheet for Excel 2000 or later that relies heavily on Visual Basic macros. It is a paddock-scale partial budgeting model that computes a number of economic indicators and can carry out sensitivity analysis of single variables. *Imagine* was designed specifically to handle woody crops grown in a variety of layouts within agricultural systems – such as belts, blocks and phase systems.

7.3.2.2 Economic indicators in *Imagine*

Imagine computes several economic indicators and graphs cash flows to enable comparison between alternative projects. An example, for woody coppice crops is shown in Figure 4. The economic indicators calculated in *Imagine* are as follows:

Net Present Value: NPV of the discounted cash flow (Figure 4).

Internal Rate of Return: IRR of the cash flow is the discount rate that returns a NPV of $0.

Benefit:Cost Ratio: Ratio of the NPVs of discounted streams of benefits and costs.

Peak Debt and Time of Peak Debt: The lowest cumulative discounted cash position for the selected sequence and the time that it occurs (Figure 4).

Break-even Time: The time that the discounted cash flow first becomes positive, and the time after which it is always positive (Figure 4).

Average Cash: The average cash value of the cumulative discounted cash flow calculated for the period of analysis and for the year prior to analysis.

NPV Break-even with Agriculture: The time when cumulative discounted cash flow for an agricultural system including woody perennials first matches that of the current agricultural sequence (first break-even), and the time after which it is above current agricultural practice for the rest of the analysis period (last break-even) (Figure 4).

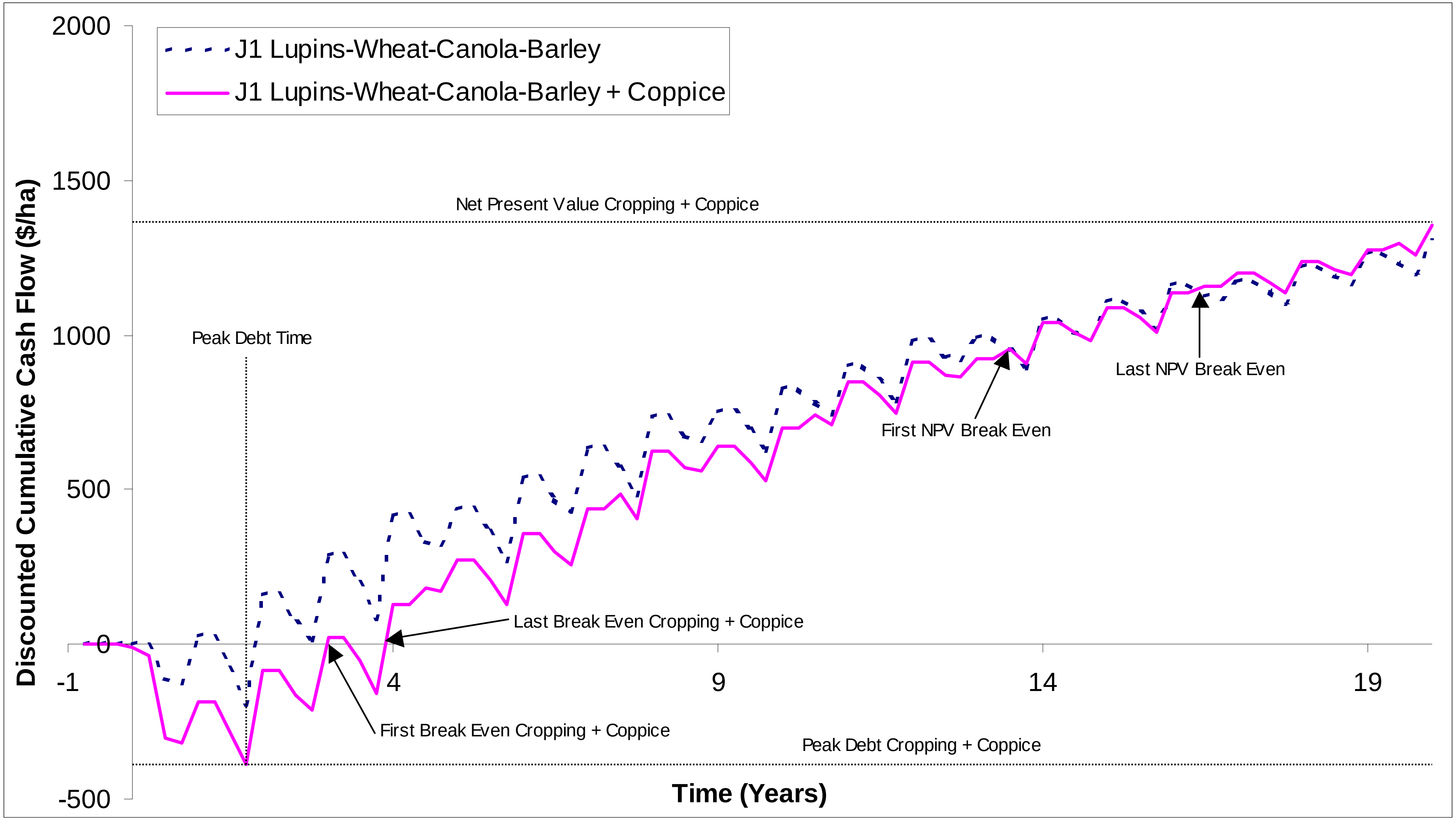


Figure 4. **Pictorial definition of selected economic parameters for a lupin, wheat, canola, barley agricultural rotation and the same agricultural rotation between belts of woody coppice crop.**

7.3.3 Analysis tool - MIDAS

MIDAS (Model of an Integrated Dryland Agricultural System) is a whole-farm, profit maximising linear programming model developed in Western Australia (Kingwell and Pannell 1987). It is designed to find optimal combinations of enterprises to maximise farm profits by analysing interactions between farm enterprises, using detailed biological and economics relationships. A number of regional MIDAS models are maintained by WADA regional agricultural economists.

MIDAS results do not necessarily coincide with average farm profitability, but are more likely to be representative of the top group of farmers, for several reasons (pers. comm. A. Abadi, WADA, 19-5-2003) including:

- MIDAS is an optimisation model that selects the most profitable solution,
- MIDAS assumes the farmer has perfect knowledge and hence can select the optimal solution in advance,
- MIDAS assumes the farmer is highly competent in all aspects of farming, including cropping, livestock, economics and management,
- MIDAS has only limited social and environmental constraints, e.g. soil conservation, and
- MIDAS is an average season model and rotations can be chosen with perfect seasonal knowledge.

7.3.4 Methodology

7.3.4.1 Objective

The objective in this analysis was to assess the economic effects of integrating woody crops with broadscale agriculture. This integration will only occur if several criteria are satisfied. One of the most important criteria is that an agricultural system including woody perennials must give an economic return to the farmer that is competitive with returns from current broadscale agriculture. Hence, the first step in this analysis was to estimate the economic performance of broadscale agriculture, to determine the economic targets that woody perennial crops would need to achieve before they would be likely to be adopted on a large scale.

7.3.4.2 Basis of analysis

All analyses were carried out on the whole agricultural system, to allow interactions between woody and herbaceous components to be included. Also, the success or failure of woody perennials in agriculture is dependent upon the success of integrated agricultural systems as a whole, not just the woody perennial component. Therefore, the economic parameters reported for systems containing coppice belts are for the whole paddock including both coppice belts and broadscale agriculture in the alleys. Similarly, for woody phase crops the economic parameters are calculated over a period that includes both the woody phase crop and the broadscale agriculture phase.

7.3.4.3 Soil type and crop rotations

Based on advice from regional agricultural economists from WADA, a range of crop rotations for broadscale agriculture were chosen from among those commonly grown by farmers. Using MIDAS, WADA economists then determined the optimal agricultural rotations for the soil types best suited to woody perennials. Parameters for the selected crops and pastures were extracted from MIDAS and entered into *Imagine*, which was then used to calculate economic parameters for the optimal agricultural rotations. MIDAS data were available for Merredin in the Eastern Wheatbelt, Jerramungup from the South Coast agricultural region and Kojonup from the Great Southern agricultural region (Figure 3).

The combinations of site, soil type, agricultural sequence and woody crop type that were tested in *Imagine* are shown in Table 7.

Table 7. MIDAS optimal crop rotations and woody crop options for soil types best suited to woody crops.

Site	Soil type	Agricultural sequence	Woody option (Table 1)
Kojonup	**K1** Deep sand (MIDAS code: S3)	**G**: Continuous grazing	a) 10m coppice [**C**] belts with 30m alleys of G
	K2: Sandy loam or loamy sand duplex (MIDAS code: S5)	**5GOB**: Five years grazing, oats, barley	a) Phase [**P**] in rotation with 5GOB b) Timber blocks [**T-Bl**] c) 10m timber belt [**T-Be**] with 30m alleys of 5GOB
Jerramungup	**J1**: Deep sand (MIDAS code: S1)	**LWNB**: Lupins, wheat, canola, barley	a) 10m coppice [**C**] belts with 60m alleys of LWNB
	J2: Duplex (MIDAS code: S3)	**LWNB**: Lupins, wheat, canola, barley	a) Phase [**P**] in rotation with WNBLWNBLWNBLWNB b) Timber blocks [**T-Bl**] c) 10m timber belts [**T-Be**] with 60m alleys of LWNB
Merredin	**M1**: Deep sand (MIDAS code: S2)	**WWL**: Wheat, Wheat, Lupins	a) 10m coppice [**C**] belts with 120m alleys of WWL
	M2: Duplex (MIDAS code: S4)	**W**: Continuous wheat	a) Phase [**P**] followed by 26 years of W
	M3: Medium heavy (MIDAS code: S5)	**W**: Continuous wheat	a) Timber blocks [**T-Bl**] b) 10m timber belts [**T-Be**] with 120m alleys of W

7.3.4.4 Details of belt crop analysis

For woody belt crops the ratio of alleys to belts (Table 5) was chosen as a compromise between water used and growth rates. With wider alleys between the belts there is more excess water available to collect, but the belts capture a lower percentage of this excess. Therefore, each increase in alley width allows the belts to grow faster, but at a lessening marginal rate, and more of the additional excess water escapes the belts and adds to groundwater recharge. To simulate efficient farming practice, alley widths were restricted to multiples of farm machinery width. In this analysis, 30m was used as a standard agricultural machinery width.

7.3.4.5 Details of phase crop analysis

For phase systems, the duration of the agricultural phase (Table 4) was chosen as the number of agricultural rotations that would allow sufficient time to refill the unsaturated soil that is accessible to phase crops. At Merredin the agricultural phase was limited to 30 years, although the unsaturated zone was not completely refilled by that time.

Since the time to refill the unsaturated zone was not necessarily a whole multiple of the annual cropping sequence, the next lowest whole number of rotations was used. Almost refilling the unsaturated soil moisture storage was chosen in preference to allowing it to overfill, as overfilling would be more detrimental from a salinity point of view. At Jerramungup, an incomplete number of rotations (3.75) of broadscale agriculture was used between woody phase crops, with the fourth and final lupin crop omitted, as it is the lowest profit component for broadscale agriculture. Also, lupins are largely included as a break crop, a function fulfilled by the following four-year woody phase crop.

7.3.4.6 Matching woody crop type to soil type

Woody crops were placed on the soil types that offered the best potential for commercial performance. This equates to planting the trees where they have the most potential to use excess water from the landscape, because commercial potential is determined by yield, which in turn is determined by water use (Equation 1).

Belts of coppicing crops were placed on deep sands where the greatest potential exists to capture water, both through better lateral root extent and greater potential for lateral flow. Blocks of phase crops were placed on duplex soils that allow rapid surface infiltration, but have high water storage capacity in the clay horizon.

Blocks and belts of wide-spaced timber trees were placed on good quality duplex or heavier soils that carried larger trees before clearing.

7.3.4.7 Values used in the analysis

Data used in the economic analysis are presented in Table 8 and Table 9. For some parameters the data in these tables is a simplification of *Imagine*'s data entry format, which allows costs and returns to be entered quarterly. For ease of reporting here, the net present value of all costs are reported as single figures for each category.

7.3.4.8 Break-even values

For each major input parameter (Table 10), break-even values were calculated for each combination of woody crop type and location. The 'break-even value' is the value of an input parameter that would give the agricultural system (including woody perennials) the same EAR as broadscale agriculture. The percentage change required in each input parameter to achieve break-even EARs were also calculated, and assessed for feasibility.

Table 8. Assumed and calculated parameter values used for economic analysis of woody crop options.

Location	Kojonup				Jerramungup				Merredin			
Woody Crop Type (Table 1) Soil (Table 7)	C K1	P K2	T-Be K2	T-Bl K2	C J1	P J2	T-Be J2	T-Bl J2	C M1	P M2	T-Be M3	T-Bl M3
Discount Rate	7%	7%	7%	7%	7%	7%	7%	7%	7%	7%	7%	7%
Establishment Cost ($/ha)[1]	1449	342	766	766	1449	342	766	766	1449	342	766	766
Maintenance Cost ($/ha)[1]	278	128	190	190	278	128	196	196	278	128	206	206
Pruning and Thinning Cost ($/ha)[1]			1350	774			1135	709			954	636
Shelter Factor	2%		2%		2%		2%		2%		2%	
Shelter Width (tree heights)	20		20		20		20		20		20	
Competition Factor	20%		20%		20%		20%		20%		20%	
Competition Width (tree heights)	2		2		2		2		2		2	
Temporal Interaction		100%				100%				100%		
Harvest Cost ($/t)	10.00	10.00			10.00	10.00			10.00	10.00		
Other costs at harvest ($/ha)[2]	54.50				54.50				54.50			
Height at harvest (m)[3]	5		15		5		15		5		15	
First harvest age (Years)	5	4	21	21	5	4	24	24	5	4	30	30
Coppice period (Years)	3				3				3			
Transport Distance (km)	50	50			50	50			50	50		
Transport flag fall ($/green t)	2.50	2.50			2.50	2.50			2.50	2.50		
Transport travel cost ($/green t/km)	0.05	0.05			0.05	0.05			0.05	0.05		
Cleanup Cost ($/ha)		250.00				225.00				200.00		
Biomass Yield (green t/ha)	111	131			85	106			41	50		
Biomass Price ($/green t)	30.00	30.00			30.00	30.00			30.00	30.00		
Sawlog Yield (m^3/ha)			225	149			196	122			119	74
Sawlog Price ($/$m^3$)			75.00	75.00			75.00	75.00			75.00	75.00
Firewood Yield (m^3/ha)			150	99			131	82			79	49
Firewood Price ($/$m^3$)			25.00	25.00			25.00	25.00			25.00	25.00

1 Numbers in these categories are not represented by a single figure in *Imagine*, rather these figures are the NPV of all costs in the category
2 Weed and pest control applied to protect coppice regrowth
3 Used in belt layouts to calculate competition and shelter zones
Sawlog data from B Hingston and R Moore (CALM, 2003), yields and pruning regimes modified by D Cooper. Harvest and transport costs from Rick Giles (CALM, 2003)

Table 9. Assumed and calculated parameter values used for economic analysis of broadscale agriculture options.

Location	Kojonup[A]					Jerramungup[AB]								Merredin[A]				
Soil (Table 7)	K1	K2	K2	K2	K2	J1	J1	J1	J1	J2	J2	J2	J2	M1	M1	M1	M2	M3
Crop/Pasture	Pasture	Pasture[1]	Pasture[2]	Oats	Barley	Lupins	Wheat	Canola	Barley	Lupins	Wheat	Canola	Barley	Wheat[3]	Wheat[4]	Lupins	Wheat	Wheat
Weed + pest control ($/ha)	1.23	0.47	0.47	35.92	36.03	33.00	58.00	32.00	44.00	33.00	58.00	32.00	44.00	34.22	34.22	40.52	34.22	34.22
Fertiliser ($/ha)	46.45	34.20	34.20	75.35	95.09	36.00	145.20	90.60	172.50	36.00	76.95	81.50	90.60	57.13	66.34	27.07	66.34	36.46
Seed ($/ha)				9.70	12.56	17.70	12.15	9.00	11.87	17.70	12.15	9.00	11.87	8.00	8.00	13.70	8.00	8.00
Inoculum ($/ha)				2.37	5.49	13.45	4.40		5.40	13.45	4.40		5.40	1.58	1.58	2.37	1.58	1.58
Insurance ($/ha)				3.52	4.04	1.66	3.50	6.50	3.50	1.66	3.50	6.50	3.50	3.07	3.07	2.35	3.45	3.18
Machinery ($/ha)				83.50	72.53	56.40	46.50	69.40	50.00	56.40	46.50	69.40	50.00	60.87	60.87	69.86	60.87	60.87
Labour ($/ha)						7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00					
Price grain 1 ($/t)				130	159	167	165	335	161	167	165	335	161	164	164	159	164	164
Price grain 2 ($/t)					124.48		115		131		115		131					
Price pasture ($/DSE[5])	19.70	19.70	19.70															
Yield grain 1 (t/ha)				3.27	1.96	1.2	2.43	1.20	2.32	1.2	2.01	1.50	1.93	1.68	1.44	1.2	1.5	1.38
Yield grain 2 (t/ha)					0.84		0.26		0.75		0.22		0.62					
Yield pasture (DSE[5]/ha)	13.22	4.62	15.33															
Stubble handling ($/ha)		1.00												3.00	3.00		3.00	3.00

A: Data provided by Felicity Flugge DAWA, 2003
B: Data provided by Mike O'Connell and Felicity Flugge DAWA, 2003
1: First pasture after crop
2: Pasture following pasture
3: Wheat after lupins
4: Wheat following wheat
5: Dry sheep equivalent

7.3.4.9 Sensitivity analysis

Overview

Using *Imagine*, single variable sensitivity analyses were carried out for the more important input parameters in woody crop analysis (Table 10). Sensitivity analysis was not performed for broadscale agriculture because it is already a well-established and well-understood industry, with a long history of development and analysis. However, there is still a wide range of profitability for broadscale agriculture between years and between farmers (Table 11).

Table 10. Parameters and range of values used in woody crop sensitivity analysis.

Variable	Coppice Belts	Phase	Timber Belts	Timber Block
Discount Rate (%)	3.5 - 10.5	3.5 - 10.5	3.5 - 10.5	3.5 - 10.5
Establishment costs [1]	0.5 - 1.5	0.5 - 1.5	0.5 - 1.5	0.5 - 1.5
Maintenance costs [1]	0.5 - 1.5	0.5 - 1.5	0.5 - 1.5	0.5 - 1.5
Pruning/Thinning costs [1]			0.5 - 1.5	0.5 - 1.5
Harvest Costs ($/t)	5 - 15	5 - 15		
Transport Distance (km)	25 – 125	25 - 125		
Interactions	0–1, 0-0.1 [Co, Sh]	0.5 – 1.5 [Y]	0–1, 0-0.1 [Co, Sh]	
Cleanup costs ($/ha) [1]		0.5 – 1.5 [1]	0 – 500	0 – 500
Yields [1, 2]	0.5 - 1.5	0.5 - 1.5	0.5 - 1.5	0.5 - 1.5
Prices [1, 2]	0.5 - 1.5	0.5 - 1.5	0.5 - 1.5	0.5 - 1.5

1 Parameter tested between 0.5 and 1.5 times the value used in the economic analysis

2 Sensitivities for sawlogs and firewood tested separately

Co, Sh: Competition and shelter tested separately between 0 and 100%, and between 0 and 10% respectively

Y: Yield of the following crop tested between 50 and 150%

Table 11. Gross margins of broadscale agriculture for survey respondents (BankWest 1998, 1999, 2000, 2001, 2002).

	Kojonup			Jerramungup			Merredin		
Financial Year	All	Top 25%	Bottom 25%	All	Top 25%	Bottom 25%	All	Top 25%	Bottom 25%
1997/1998	66	126	-7	35	73	1	51	89	9
1998/1999	56	111	1	26	77	-17	29	60	3
1999/2000	65	123	15	36	90	-17	44	77	11
2000/2001	76	118	50	7	43	-28	-2	41	-46
2001/2002	107	260	-23	57	133	-17	53	116	10
5 year Ave	74	148	7	32	83	-16	35	77	-3

In its simplest form, sensitivity analyses can be used to identify parameters that have the greatest effect on the outcome, and therefore need to be measured more accurately. This has great value in an analysis such as this, where the analysis is of conceptual crop types and hence many of the parameter values are estimated, rather than being based on a large body of past measurements. Therefore, this simple level of sensitivity analysis was carried out in this report.

However, a more robust sensitivity analysis will be required further along the industry development pathway, before R&D is commissioned into areas such as plant breeding, development of new machinery or markets, and design of agricultural systems. Future sensitivity analysis will need to extend from investment in R&D to end-point economic parameters. For example, a breeding program costing *w* dollars and taking *x* years, may lead to a change in yield of *y* percent, which in turn will cause a change in an economic parameter of *z*. In this case the relationships between *x* and *w*, and *z* are the important ones. Change in *y* is merely an intermediate link between them. To extend the simple sensitivity analysis carried out in this report, the scope for change in a parameter and the R&D effort (time and money) required to implement that change need to be estimated.

Calculation of sensitivity

Equivalent annual return (EAR) was chosen as the economic output parameter for sensitivity analysis. This is because it can be used to compare between enterprises with different investment time horizons and different investment amounts. It is also less abstract and more readily understood by non-economists than some other measures.

To compare the relative importance of sensitivities of a group of estimated input parameters without knowledge of their relative accuracies, they were first normalised. After normalisation, the change in an economic parameter relative to the percentage change in the input parameters can be compared, to find the input parameters to which the economic measure is most sensitive. (E1, Equation 4). The ratio of sensitivity was chosen in preference to elasticity of sensitivity (E2, Equation 4) to enable comparison of sensitivities between enterprises whilst avoiding the large elasticities that result for enterprises with a mean EAR close to zero.

$$E1 = \frac{(\Delta EAR)}{\left(\frac{\Delta P}{\overline{P}}\right)}$$

$$E2 = \frac{\left(\frac{\Delta EAR}{\overline{EAR}}\right)}{\left(\frac{\Delta P}{\overline{P}}\right)}$$

where:

$E1 =$ Ratio of sensitivity

$E2 =$ Elasticity of sensitivity

$\Delta EAR =$ Change in equivalent annual return

$\overline{EAR} =$ Mean equivalent annual return for the range tested

$\Delta P =$ Change in input parameter

$\overline{P} =$ Mean input parameter for the range tested

Equation 4. Ratio of sensitivity and elasticity of sensitivity.

7.3.5 Results

7.3.5.1 Economic parameters for best guess scenarios

In Table 12 and Table 13 the economic performance of annual cropping cycles, grazing, and four types of woody crop (phase, coppice in belts, timber blocks and timber belts) are presented. The various economic performance indicators can be used to directly compare agricultural sequences including woody crops with typical annual agricultural systems for each soil type, in each location. Each analysis reports the combined economic performance of the woody crop and annual agricultural enterprises that it shares the land with. The one exception is timber block plantings, which occupy the entire site for the duration of the analysis, and therefore have no contribution from annual agriculture.

Examination of economic parameters (Table 12 and Table 13) and cash flow graphs (Figure 5, Figure 6 and Figure 7) demonstrates that agriculture incorporating woody perennials will be economically competitive with broadscale agriculture for some woody options in some locations. Due to the longer harvest intervals and greater planting costs, the initial negative cash flow for all options involving woody crops is greater than for broadscale agriculture, but in some cases this is compensated for by higher future returns.

At Kojonup and Jerramungup, agricultural systems including coppice or phase crops are competitive with conventional broadscale agriculture. They have higher EARs for the analysis period than broadscale agriculture, with NPV overtaking that of broadscale agriculture before the end of the analysis period. However, the cash flow graphs (Figure 5 and Figure 6) and measures designed to quantify cash flow, such as break-even, peak debt and average finance indicate that broadscale agriculture has an advantage in short-term cash flow in each case. Therefore, woody phase or coppice belts at Kojonup and Jerramungup have a higher initial financial hurdle to clear, but over the full course of the analysis period offer greater economic rewards. This suggests that farmers in a weak financial position may not be able to rapidly incorporate large areas of woody perennials into their farming systems, despite the longer term advantages, without outside financial investment or assistance.

At Merredin, including coppice belts in the farming system reduces EAR and NPV slightly to 90% of that provided by broadscale agriculture alone, while including a woody phase crop has a more negative effect, reducing the EAR by almost 40%.

In all regions, the combination of alley farming and timber belts provides 87% to 94% of the EAR and NPV of broadscale agriculture (best results with higher rainfall), but has a much poorer cash flow until the final harvest, and will therefore be difficult to finance on a large scale.

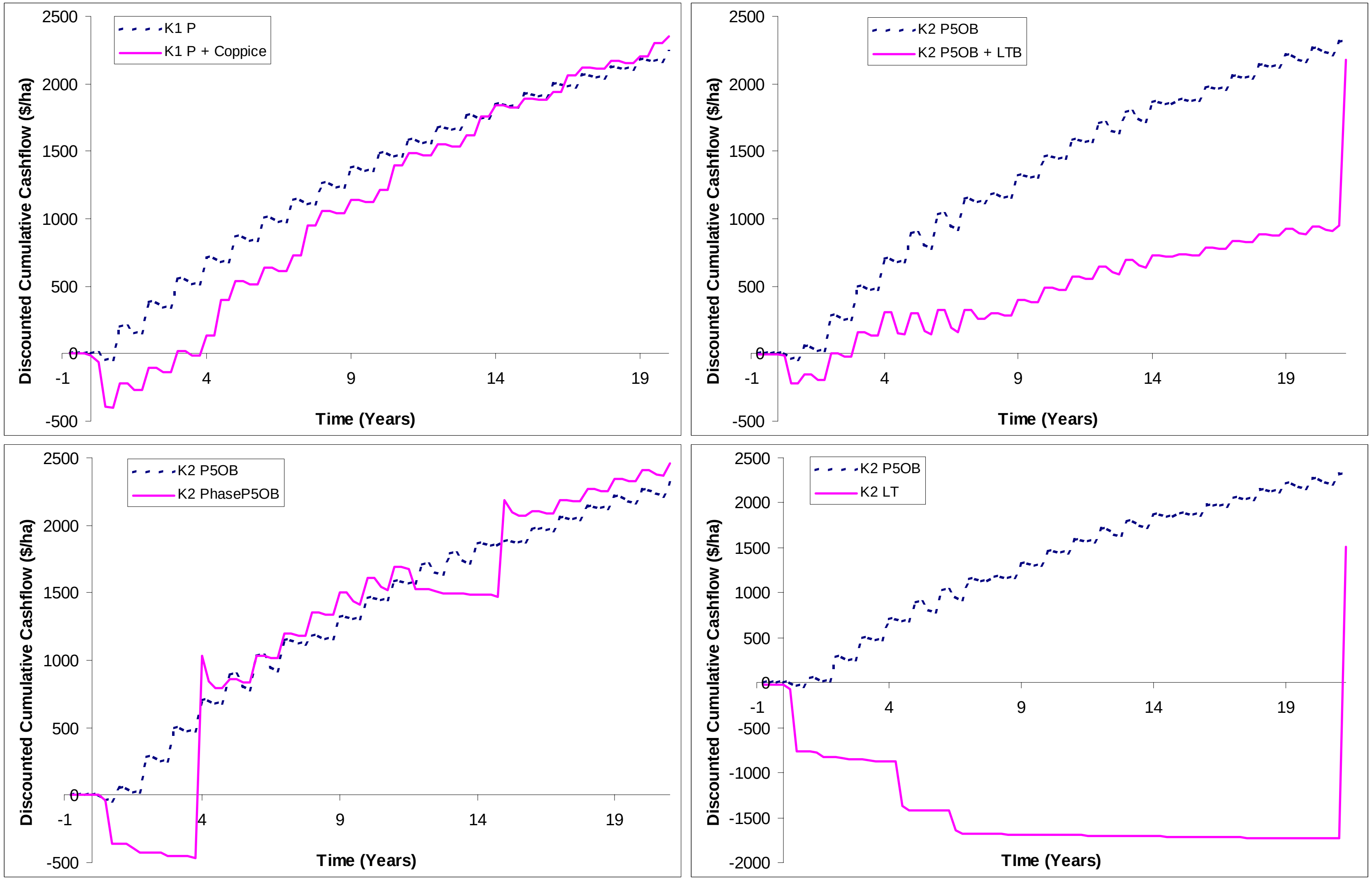
Plantations of timber grown in blocks are not competitive with broadscale agriculture on any economic measurement, with their viability decreasing steeply with rainfall. Compared to broadscale agriculture, timber blocks produce EARs only 66% as high at Kojonup and 30% as high at Jerramungup, while at Merredin they produce a net loss, some 178% lower than returns from cropping.

Table 12. Economic parameters for agricultural sequences including woody crops, sorted by location and soil type. Layouts not including woody perennials are shaded.

Location	Kojonup						Jerramungup						Merredin						
Crop type (Table 7)	G	C	5GOB	P	T-Be	T-Bl	LWNB	C	LWNB	P	T-Be	T-Bl	WWL	C	W	P	W	T-Be	T-Bl
Soil type (Table 7)	K1	K1	K2	K2	K2	K2	J1	J1	J2	J2	J2	J2	M1	M1	M2	M2	M3	M3	M3
Analysis period (Yr)	20	20	21	22	21	21	20	20	24	19	24	24	21	21	30	30	30	30	30
Equivalent annual return ($/ha)	**211**	**222**	**212**	**226**	**200**	**139**	**123**	**128**	**142**	**154**	**133**	**43**	**65**	**59**	**65**	**41**	**76**	**66**	**-59**
Net present value ($/ha)	2237	2355	2309	2501	2179	1511	1307	1358	1633	1592	1529	500	707	642	807	512	944	823	-735
Benefit cost ratio	1.88	1.67	1.96	1.55	1.95	1.87	1.50	1.45	1.67	1.47	1.65	1.30	1.38	1.32	1.35	1.17	1.50	1.44	0.54
Internal rate of return (%)	2883	58.4	895	58.4	58.7	10.7	153	46.2	279	48.3	84.2	8.4	268	52.7	170	18.7	248	82.4	4.5
First break-even (Yr)	1	4	1	4	3	21	1	3	1	4	2	24	1	2	1	4	1	1	-
Last break-even (Yr)	1	4	1	4	3	21	2	4	2	4	2	24	2	4	3	8	2	3	-
Peak debt ($/ha)	-46	-400	-34	-470	-217	-1730	-195	-388	-175	-470	-259	-1671	-127	-230	-136	-470	-107	-158	-1608
Peak debt time (Yr)	0.5	0.75	0.5	3.75	0.5	20.5	1.75	1.75	0.75	3.75	0.75	23.5	0.75	0.75	0.75	3.75	0.75	0.75	29.5
1st NPV break-even with ag (Yr)	n/a	14	n/a	4	-	-	n/a	13.5	n/a	4	-	-	n/a	-	n/a	-	n/a	-	-
Last NPV break-even with ag (Yr)	n/a	17	n/a	15	-	-	n/a	16.5	n/a	4	-	-	n/a	-	n/a	-	n/a	-	-
Average finance ($/ha)	1321	1136	1358	1342	490	-1457	708	616	996	816	581	-1421	410	317	504	196	596	422	-1399
Average pre finance ($/ha)	0	-15	0	0	-21	-84	0	-9	0	0	-12	-84	0	-5	0	0	0	-6	-84

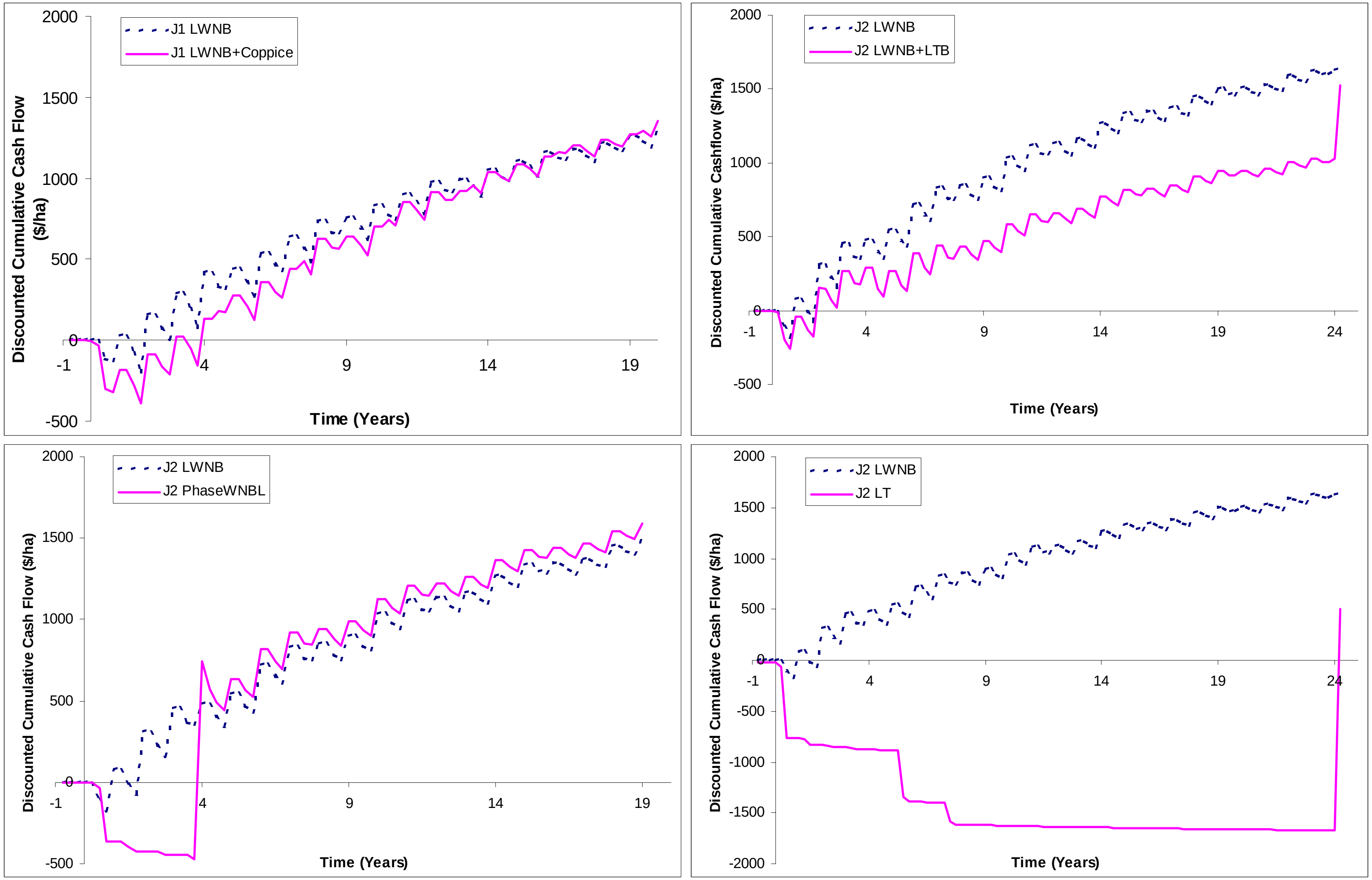
Table 13. Economic parameters at Kojonup, Jerramungup and Merredin for agricultural sequences including woody crops, sorted by woody crop type. Layouts not including woody perennials are shaded.

Crop type (Table 7)	Coppice Belt			Phase (block)			Timber Belt			Timber block			Broadscale Agriculture						
Location	**Koj**	**Jer**	**Mer**	**Koj**	**Jer**	**Mer**	**Koj**	**Jer**	**Mer**	**Koj**	**Jer**	**Mer**	**Koj**		**Jer**		**Mer**		
Soil type (Table 7)	K1	J1	M1	K2	J2	M2	K2	J2	M3	K2	J2	M3	K1	K2	J1	J2	M1	M2	M3
Analysis period (Yr)	20	20	21	22	19	30	21	24	30	21	24	30	20	21	20	24	21	30	30
Equivalent annual return ($/ha)	**222**	**128**	**59**	**226**	**154**	**41**	**200**	**133**	**66**	**139**	**43**	**-59**	**211**	**212**	**123**	**142**	**65**	**65**	**76**
Net present value ($/ha)	2355	1358	642	2501	1592	512	2179	1529	823	1511	500	-735	2237	2309	1307	1633	707	807	944
Benefit cost ratio	1.67	1.45	1.32	1.55	1.47	1.17	1.95	1.65	1.44	1.87	1.30	0.54	1.88	1.96	1.50	1.67	1.38	1.35	1.50
Internal rate of return (%)	58.4	46.2	52.7	58.4	48.3	18.7	58.7	84.2	82.4	10.7	8.4	4.5	2883	895	153	279	268	170	248
First break-even (Yr)	4	3	2	4	4	4	3	2	1	21	24	-	1	1	1	1	1	1	1
Last break-even (Yr)	4	4	4	4	4	8	3	2	3	21	24	-	1	1	2	2	2	3	2
Peak debt ($/ha)	-400	-388	-230	-470	-470	-470	-217	-259	-158	-1730	-1671	-1608	-46	-34	-195	-175	-127	-136	-107
Peak debt time (Yr)	0.75	1.75	0.75	3.75	3.75	3.75	0.5	0.75	0.75	20.5	23.5	29.5	0.5	0.5	1.75	0.75	0.75	0.75	0.75
1st NPV break-even with ag (Yr)	14	13.5	-	4	4	-	-	-	-	-	-	-	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Last NPV break-even with ag (Yr)	17	16.5	-	15	4	-	-	-	-	-	-	-	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Average finance ($/ha)	1136	616	317	1342	816	196	490	581	422	-1457	-1421	-1399	1321	1358	708	996	410	504	596
Average pre finance ($/ha)	-15	-9	-5	0	0	0	-21	-12	-6	-84	-84	-84	0	0	0	0	0	0	0



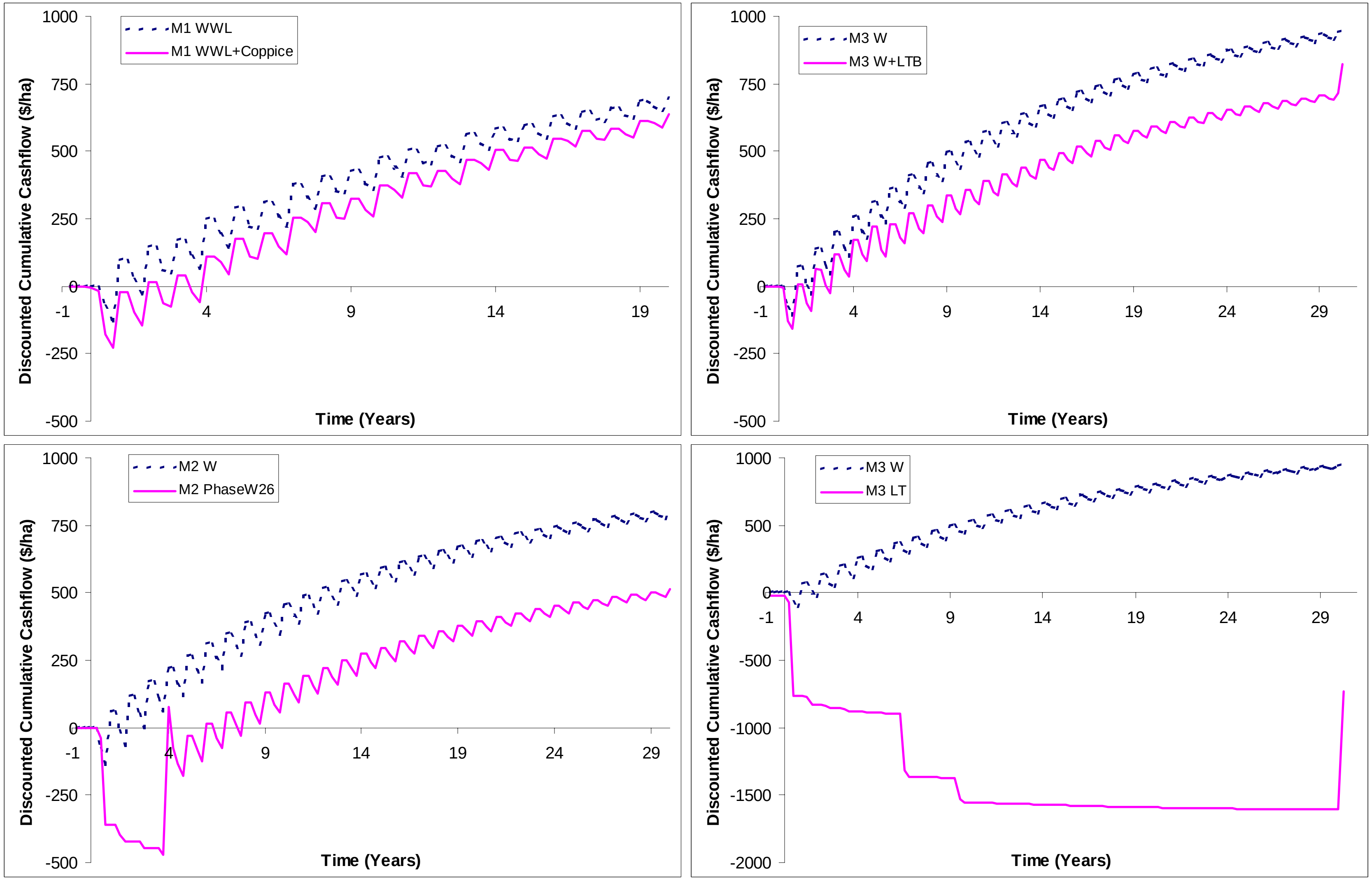
Top left: Coppice crop on deep sand. Top right: Timber belts on duplex soil. Bottom left: Phase crop on duplex soil. Bottom right: Timber block on duplex soil.

Figure 5. Kojonup - Discounted cumulative cash flows of woody options compared with broadscale agriculture.



Top left: Coppice crop on deep sand. Top right: Timber belts on duplex soil. Bottom left: Phase crop on duplex soil. Bottom right: Timber block on duplex soil.

Figure 6. Jerramungup - Discounted cumulative cash flows of woody options compared with broadscale agriculture.



Top left: Coppice crop on deep sand. Top right: Timber belts on medium heavy soil. Bottom left: Phase crop on duplex soil. Bottom right: Timber block on medium heavy soil.

Figure 7. Merredin - Discounted cumulative cash flows of woody options compared with broadscale agriculture.

7.3.5.2 Break-even values for input parameters

Summary

Each input parameter was varied individually (the others being held constant), to find the level of each parameter at which farming systems incorporating woody crops break even with broadscale agriculture (Table 15). For farming systems that exceed the break-even point in this analysis, the difference between these break-even parameter values and the values used in the analysis (Table 8) gives an indication of the susceptibility to adverse changes in each parameter. Conversely, for farming systems that are not competitive under current assumptions, break-even parameter values show how much improvement would be needed in any single parameter to make the system competitive.

The percentage change in each parameter that would move the result to its break-even point was calculated (Table 16). For woody crops that are competitive in this analysis (coppice and phase crops at Kojonup and Jerramungup), only small changes in biomass price (4-5% decline), biomass yield (7-10% decline), or harvest cost (11-16% increase) would reduce their profitability to the break-even level. Conversely, short-cycle coppice and phase crops were not competitive at Merredin, and would need 25-26% improvement in biomass price, or 49-52% improvement in biomass yield to break even.

Long-cycle timber crops were not competitive at any location. However, timber belts would break even at Kojonup if the discount rate were 11% lower, sawlog returns were 13% higher, or if pruning and thinning costs were 39% lower. To break even at Jerramungup the relevant changes would be 17%, 26% and 64% respectively. At Merredin, the prospects for timber belts were even less promising, with the smallest improvement needed to break even being a 46% reduction in discount rate. Timber blocks were the least competitive option. Their best prospects were at Kojonup, where they would break even with a 23% reduction in discount rate or a 30% increase in sawlog returns.

‘Break-even’ parameters of most interest (Table 14) are discussed below.

Table 14. Break-even parameter values of most interest for woody crops.

Woody crop option	Location	Parameter
Coppice and Phase	All locations	Biomass price and yield
Timber Blocks and Belts	Kojonup/Jerramungup	Sawlog price and yield
All woody crops	Kojonup/Jerramungup	Discount Rate
Timber belts	Merredin	Discount rate
Coppice and Phase	Kojonup/Jerramungup	Harvest cost and transport distance
Coppice and Phase	Kojonup/Jerramungup	Establishment Cost
Coppice and Timber Belts	Kojonup/Jerramungup	Shelter and competition
Phase	Kojonup/Jerramungup	Cleanup cost

Prices received

The small changes in biomass price (4-5%) required for woody phase and coppice crops at Kojonup and Jerramungup to fall to break-even, or the 25-26% rise required for these crops to break-even at Merredin, demonstrate the importance of this parameter. Prices received for woody products will be determined by the markets for these products, especially when supplying large-scale industries. Therefore, prices for biomass produced from woody phase crops and coppice crops can be estimated from alternatives such as wood chip from *Pinus* spp. or *Eucalyptus* spp. However, these prices apply only to the wood fraction. For integrated processing of whole biomass, an estimate is also needed of the value of residues. The biomass price used in this analysis was taken from an oil mallee feasibility study (Enecon Pty Ltd 2001), in which biomass was used for three commercial products, activated carbon from wood, eucalyptus from leaves, and electricity generation from all residues.

Future sawlog prices are difficult to predict, due to the longer time until harvest. Timber harvesting from native forests is being reduced in Australia and increasing pressure is being applied to unsustainable logging in tropical forests elsewhere. These factors could decrease the supply of timber, increasing its price, but also increasing substitution with other materials. Hence it is unclear what the future price will be for farm grown sawlogs. Increases of up to 50% of the best guess price may be possible. On the other hand, expansion of plantation forestry in high rainfall zones may increase timber supply and constrain prices.

Yield

Yield calculations, along with the assumptions on which they were based, and other variations in the data are presented in Section 7.2. The closeness of break-even values to the estimates used in the analysis for phase and coppice crops at Kojonup and Jerramungup (7-10% lower), and timber belts at Kojonup (13% higher), suggests that these are critical parameters for these crops at these locations. Yields required for timber blocks to break even at Kojonup (30% increase) and for timber belts to break even at Jerramungup (26% increase) may be more difficult to achieve, while the yield increases required for timber blocks at Jerramungup (64%) and all woody crops at Merredin (49-238%) appear unlikely to be attainable. Further research is required to understand the factors that affect yield, and if possible to improve it, especially at locations where current estimated yields are close to break-even values.

Discount rate

Discount rate is a very difficult parameter to predict. Since it has a great impact on longer-term investments, it is not surprising that the choice of discount rate can make or break all of the woody crop options considered here. For long-cycle trees, farmers may be prepared to apply lower discount rates because of amenity and aesthetic values, which could make long-cycle trees a viable woody crop option. However, this is only likely to apply to small-scale planting. For large-scale planting of tree crops, a high discount rate is more realistic, for two reasons. First, farm economics, rather than amenity and aesthetic values, will determine how the majority of farm land is used, so woody crops will need to compete with other farm and off-farm investment options. And second, because many farmers' ability to plant large areas of woody crops quickly will be restricted by the high establishment costs and the long period between investment and harvest, outside investment is likely to be needed. External investment will only be forthcoming for industries that are attractive in a high discount rate environment.

Harvesting and transport

Harvester technology for short-cycle woody crops is currently under development, and thus the costs presented in this analysis are based on best estimates of future technology. Therefore, the 11-16% increase in harvest cost that would reduce woody phase and coppice crops to break-even status at Jerramungup and Kojonup is worth noting.

Break-even transport distance effectively defines the catchment zone for processing facilities. From this analysis, transport distances up to 70-80 km are profitable for coppice and phase crops at Jerramungup and Kojonup.

Establishment cost

The competitiveness of woody crops is very sensitive to establishment cost, which for short-cycle crops at Kojonup and Jerramungup, need only increase 24-37% for their EARs to be reduced to break-even. This is most significant for phase crops that depend on cheap direct seeding. The success of large-scale direct seeding of woody perennials in the agricultural areas of Western Australia has not been thoroughly tested, so the cost estimates used here may be inaccurate. In contrast, the establishment of coppice crops is better understood due to experience obtained in oil mallee growing, so the likelihood of coppice crop establishment costs being underestimated is low.

Shelter and competition

Shelter has been studied quite extensively for both crops and pastures and has been found to be quite variable, both between sites and between years. Therefore, at Kojonup and Jerramungup respectively, a fall in shelter boost for coppice to 0.8% and 0.9%, or a rise in shelter boost for timber belts to 3.8% and 3.3% may be realistic, and would move those crops to the break-even point.

Anecdotal observations of oil mallees in Western Australia suggest that competition adjacent to belts varies with rainfall. Strong competition has been observed on some sites during dry years, while competition effects are not visible in wet years. For coppice crops, the calculated break-even values for crop and pasture loss within two tree heights of 30% at Jerramungup and 40% at Kojonup may be higher than actual likely losses due to competition, suggesting competition is unlikely to be a critical factor in these circumstances. Soil type will also affect competition. It is expected that the deep sandy soils chosen for this analysis will have lower competition levels than shallow duplex soils with a subsoil that presents difficulty for root penetration, forcing woody crop roots to compete in the annual plant root zone. This variability and uncertainty in the competition effect suggests that this parameter should be studied more closely in relevant circumstances.

Clean-up after phase crops

Stump cleanup following bluegum (*Eucalyptus globulus*) harvesting has proven costly. However, this study assumes that phase crops growing in lower rainfall areas for shorter periods will produce smaller, easier to remove stumps than those found in a typical bluegum plantation. No technical impediments are envisaged in cleaning up rows of four-year-old stumps from woody phase crops. A cleanup cost of approximately $390 per hectare has been flagged as a possible break-even value at Kojonup and Jerramungup.

Table 15. Parameter values at which agricultural systems incorporating woody perennials break even with broadscale agriculture (based on EAR).

Location	Kojonup				Jerramungup				Merredin			
Crop Type	**Coppice**	**Phase**	**Timber Belt**	**Timber Block**	**Coppice**	**Phase**	**Timber Belt**	**Timber Block**	**Coppice**	**Phase**	**Timber Belt**	**Timber Block**
Discount Rate	9.4%	11.0%	6.2%	5.4%	8.4%	11.9%	5.8%	4.4%	1.9%	-3.1%	3.8%	2.0%
Establishment Cost	1924	448	243	-32	1802	469	36	-367	595	47	-799	-912
Maintenance Costs	588	234	-334	-609	506	255	-535	-937	-263	-110	-1364	-1472
Pruning and Thinning Cost			827	-24			406	-424			-611	-1042
Shelter Factor	0.8%		3.8%		0.9%		3.3%		5.9%		5.4%	
Competition Factor	40.4%		12.5%		30.1%		10.7%		-18.8%		-10.8%	
Temporal Interaction		-63.4%				41.0%				268.1%		
Harvest Cost ($/t)	11.51	11.06			11.47	11.57			2.65	2.30		
Transport Distance (km)	79	71			79	81			-97	-104		
Cleanup Cost ($/ha)		391	-2201	-3362		394	-3771	-5847		-194	-12100	-12995
Biomass Yield (green t/ha)	100	122			77	95			61	76		
Biomass Price ($/green t)	28.50	28.94			28.53	28.43			37.35	37.70		
Sawlog Yield (m^3/ha)			254	194			246	200			281	250
Sawlog Price ($/$m^3$)			84.78	97.56			94.20	122.90			176.82	251.07
Firewood Yield (m^3/ha)			238	233			282	316			566	568
Firewood Price ($/$m^3$)			39.71	58.96			53.75	96.28			179.14	288.87

Note, shaded options do not break even with broadscale agriculture under current assumptions. The values in the table for these options are the values to which individual parameters would need to improve to achieve break-even EAR. Conversely, for options that already exceed break-even EAR (unshaded), the parameter values listed here are the values to which individual parameters could deteriorate while still breaking even with broadscale agriculture.

To calculate these values, all parameters except the one being tested were held constant.

Table 16. Percentage change required in parameter values for agricultural systems incorporating woody crops, in order to break even with broadscale agriculture (based on EAR).

Location	Kojonup				Jerramungup				Merredin			
Crop Type	Coppice	Phase	Timber Belt	Timber Block	Coppice	Phase	Timber Belt	Timber Block	Coppice	Phase	Timber Belt	Timber Block
Discount Rate	34%	57%	-11%	-23%	20%	70%	-17%	-37%	-73%	-144%	-46%	-71%
Establishment Cost	33%	31%	-68%	-104%	24%	37%	-95%	-148%	-59%	-86%	-204%	-219%
Maintenance Costs	112%	83%	-361%	-421%	82%	99%	-373%	-578%	-195%	-186%	-762%	-815%
Pruning and Thinning Cost			-39%	-103%			-64%	-160%			-164%	-264%
Shelter Factor	-60%		90%		-55%		65%		195%		170%	
Competition Factor	102%		-38%		51%		-47%		-194%		-154%	
Temporal Interaction		-163%				-59%				168%		
Harvest Cost ($/t)	15%	11%			15%	16%			-74%	-77%		
Transport Distance (km)	58%	42%			58%	62%			-294%	-308%		
Cleanup Cost ($/ha)		56%				75%				-197%		
Biomass Yield (green t/ha)	-8%	-7%			-9%	-10%			49%	52%		
Biomass Price ($/green t)	-5%	-4%			-5%	-5%			25%	26%		
Sawlog Yield (m^3/ha)			13%	30%			26%	64%			136%	238%
Sawlog Price ($/$m^3$)			13%	30%			26%	64%			136%	235%
Firewood Yield (m^3/ha)			59%	135%			115%	285%			616%	1059%
Firewood Price ($/$m^3$)			59%	136%			115%	285%			617%	1055%

Note, shaded options do not break even with broadscale agriculture under current assumptions. The percentages in the table for these options are the percentages by which individual parameters would need to improve to achieve break-even EAR. Conversely, for options that already exceed break-even EAR (unshaded), the percentages shown here are the percentages by which individual parameters could deteriorate while still breaking even with broadscale agriculture.

To calculate these values, all parameters except the one being tested were held constant.

7.3.5.3 Sensitivity of EAR to input parameters

General results

The sensitivity of EAR to changes in input parameters (Table 18) can be used to compare sensitivities between woody crop options and sites. The sensitivities in the table show the increase or decrease (negative numbers) in EAR for a normalised increase in each input parameter. Generally sensitivities are higher where woody crops constitute a higher percentage of land occupation, either spatially or temporally. Similarly, the sensitivities for timber blocks are generally higher than for other woody crop types because they occupy all the land for the full analysis period.

Coppice and phase crops – main results

For coppice and phase crops the two dominant sensitivities for all sites were biomass yield and the price received by growers for biomass, due to their direct influence on revenue (Equation 5). These crops were twice as sensitive to price as they were to yield (Table 17), as half the additional revenue from increased yield is used to pay for harvest and transport.

Harvest cost was the next most sensitive parameter for phase crops at all locations, and for coppice crops at Kojonup and Jerramungup. This was due to the influence of harvest cost on revenue (Equation 5). It can be demonstrated using the same methodology used in Table 17 that EAR is 1.5 times more sensitive to yield than to harvest cost.

$$R = Y * (P - C_{HT})$$

where:

R = Revenue

Y = Yield

P = Price

C_{HT} = Harvest and transport costs

Equation 5. Revenue calculation at harvest

Table 17. Relative sensitivity of return to changes in price and yield, based on Equation 5.

Parameter	Base case	Double yield	Double price
Yield	10	20	10
Price	30	30	60
Harvest + Transport Cost	15	15	15
Return	150	300	450
Change in return	**-**	**150**	**300**

Timber belts and blocks – main results

For timber belts, discount rate is the input parameter to which EAR is most sensitive, due to the long period between expenditure at establishment and return at ultimate harvest. At Kojonup sawlog price and yield are the next most important parameters, followed by competition factor. In this case the sensitivities for price and yield are equal because revenue is simply calculated as yield multiplied by stumpage price, which includes harvest and transport costs (in contrast to Equation 5). At Jerramungup and Merredin, competition and shelter factors have greater relative importance than at Kojonup.

For timber blocks EAR is most sensitive to changes in discount rate, followed by yields and prices for sawlogs. Establishment cost, and thinning and pruning costs are increasingly important for locations with lower yields and longer cycle lengths. The sensitivities for timber blocks are highest at Kojonup where they have the shortest harvest period and highest EAR, and are therefore most affected by changes in input parameters.

Spatial interactions for woody crops in belts

For coppice crops, EAR was almost equally sensitive to competition and shelter at both Jerramungup and Kojonup. This contrasts with the generally higher EAR sensitivities to input parameters at Kojonup than at Jerramungup. Since coppice crops cover a higher percentage of the paddock at Kojonup, due to narrower alley widths, a higher percentage of the alleys are subject to shelter and competition, so sensitivities to shelter and competition would be expected to be higher at Kojonup. This apparent discrepancy is best explained using a simple gross margin equation and the derivation of a simplified sensitivity ratio to competition factor (CF) for CF ranging from 0 to 100 percent (Equation 6). The reason for the unexpected result is that the Kojonup example differs from the Jerramungup example by having pasture in the alleys rather than cropping. Pasture has lower costs and returns associated with it, reducing the sensitivity of the pasture gross margin to changes in yield due to either competition or shelter (Table 19).

In contrast, the EAR for timber belts is much more sensitive to competition at Kojonup than at Jerramungup (Table 19). This is because the timber belts are grown on different soil types than the coppice belts, which affects the relative costs and returns for the agricultural activities in the alleys on both sites, and therefore their sensitivity to competition. At Kojonup, higher quality pasture on duplex soil (K2 for timber belts) can carry more sheep and hence the returns are higher than for deep sands. Furthermore, the pastures are in rotation with barley and oat crops, which both have high returns. In contrast, the costs and returns for duplex soil at Jerramungup (J2 for timber belts) are less than those for deep sands (J1 for coppice belts).

Temporal interactions following phase crops

Following a phase crop, the EAR had a lower sensitivity to temporal interactions at Kojonup than for the other two locations (Table 18). This is partially explained by the lower costs and returns for pasture at Kojonup compared to cropping at Merredin and Jerramungup. Also, only the first year of pasture or the first crop following the woody phase crop was considered in the sensitivity calculations. As the first year of pasture at Kojonup typically has a lower yield than subsequent years (Table 9) the temporal interaction affects only this small yield and hence has a small effect on the performance of the entire system. Conversely, for Jerramungup or Merredin, a wheat crop follows the phase crop, making a greater contribution to overall revenue.

$$GM = \sum_{i=1}^{n} (R_i - C_i) * A_i$$

$$GM = \sum_{i=1}^{n} (P_i * Y_i - C_i) * A_i$$

For a paddock containing alleys of herbaceous agriculture (A) separated by belts of woody perennials (B)

$$GM = (P_A * Y_A - C_A) * A_A + (P_B * Y_B - C_B) * A_B$$

$$GM\ (per\ ha) = \frac{(P_A * Y_A - C_A) * A_A + (P_B * Y_B - C_B) * A_B}{A_A + A_B}$$

$$Y_A = Y_0 * (A_A - 2 * C_F * A_C)$$

$$GM\ (per\ ha) = \frac{(P_A * Y_0 * (A_A - 2 * C_F * A_C) - C_A) + (P_B * Y_B - C_B) * A_B}{A_A + A_B}$$

Testing sensitivity to competition factor between 0 and 100% (mean 50%)

$$SR = \frac{\dfrac{(GM_1 - GM_0)}{(1 - 0)}}{0.5}$$

$$SR = \frac{\left[\dfrac{(P_A * Y_0 * (A_A - 2 * A_C) - C_A) + (P_B * Y_B - C_B) * A_B}{A_A + A_B} - \dfrac{(P_A * Y_0 * A_A - C_A) + (P_B * Y_B - C_B) * A_B}{A_A + A_B}\right]}{2}$$

$$SR = \frac{-P_A * Y_0 * A_C}{A_A + A_B}$$

where :

GM = Gross Margin of a paddock comprising of n agricultural components (n ≥ 1)

R = Return

C = Costs

A = Area

P = Price net of harvest and transport costs

Y = Yield

Y_0 = Yield in the alley with no competition

C_F = Competition factor

A_C = Area subject to competition

SR = Sensitivity Ratio

GM_1 = Gross Margin for competition factor of 100%

GM_0 = Gross Margin for competition factor of 0%

$_i$ = Denotes for component i

$_A$ = Denotes for alley component

$_B$ = Denotes for belt component

Equation 6. Simplified gross margin equation and derivation of simplified sensitivity ratio to competition factor.

.

Table 18. Ratios of sensitivity for woody perennial agricultural systems at Kojonup, Jerramungup and Merredin.

Crop Type	Coppice			Phase			Timber Belt			Timber Block		
Location	Koj	Jer	Mer	Koj	Jer	Mer	Koj	Jer	Mer	Koj	Jer	Mer
Discount Rate	-33	-24	-9	-23	-15	-22	-107	-51	-19	-306	-242	-150
Establishment Cost	-34	-20	-10	-46	-33	-27	-18	-10	-5	-70	-67	-62
Maintenance Cost	-10	-6	-3	-17	-12	-13	-4	-2	-1	-17	-17	-17
Pruning and Thinning Cost							-31	-14	-6	-71	-62	-51
Shelter Factor	20	21	8				34	34	14			
Competition Factor	-27	-24	-8				-69	-49	-16			
Temporal Interaction				9	21	14						
Harvest Cost	-74	-32	-8	-133	-78	-31						
Transport Distance	-19	-12	-3	-50	-29	-12						
Cleanup Cost				-25	-16	-12	-3	-1	0	-4	-3	-3
Biomass Yield	111	49	12	200	117	47						
Biomass Price	223	97	25	400	235	93						
Sawlog Yield							92	35	7	244	154	57
Sawlog Price							92	35	7	244	154	57
Firewood Yield							20	8	2	54	35	13
Firewood Price							20	8	2	54	35	13

Note, the higher the number (either positive or negative), the more sensitive the economic performance is to the particular parameter.

Table 19. Demonstration of sensitivity ratios to competition factor for coppice belts and timber belts at Kojonup and Jerramungup.

	Kojonup (K1 Pasture)	Kojonup (K2 Pasture)	Jerramungup (J1 Wheat)	Jerramungup (J2 Wheat)
Woody crop type	Coppice belts	Timber belts	Coppice belts	Timber belts
Tree Height (m)	2.5	7.5	2.5	7.5
Competition Width (m)	5	15	5	15
Alley Width (m)	30	30	60	60
Belt Width (m)	10	10	10	10
Costs ($/ha) for alley	48	34	277	209
Price for alley	$19.70/DSE net	$19.70/DSE net	$165 & $115/t	$165 & $115/t
Yield for alley	13.2 DSE/ha	15.3 DSE/ha	2.43 & 0.26 t/ha	2.01 & 0.22 t/ha
Gross Margin for alley per ha	$212	$267	$154	$148
Sensitivity Ratio	-32.5	-113	-30.8	-76

Note this table is for demonstration purposes only. The values contained within it are calculated from the simplified Equation 6, not *Imagine*. Therefore, factors not taken into account include discounting, changing tree height and its effect on competition width, and changing crops in the alleys through time.

7.3.6 Key findings

Based on the estimates of parameter values used in this analysis, farming systems that include short-cycle woody crops were economically competitive with broadscale agriculture at Jerramungup and Kojonup, but fell short at Merredin (Table 20). Long-cycle timber crops were not competitive in any of the locations tested, with their competitiveness reducing at lower rainfall. Long-cycle timber crops were much less competitive when grown in blocks than in belts.

Table 20. Percentage change in EAR resulting from inclusion of woody crops in farming systems (relative to broadscale agriculture alone).

Type of woody crop	Kojonup	Jerramungup	Merredin
Coppice in belts	+5%	+4%	-9%
Phase crop	+7%	+8%	-37%
Long-cycle timber belts	-6%	-6%	-13%
Long-cycle timber blocks	-34%	-70%	-177%

Based on data in Table 12.

Break-even analysis showed that the profitability of short-cycle woody crops at Kojonup and Jerramungup would be eroded by small decreases in biomass yield or price, or by small increases in harvest costs. On the other hand, timber belts could become competitive at Kojonup if the discount rate decreased slightly, or if sawlog yield or price increased slightly. A summary of the key break-even parameters is given in Table 21.

The sensitivity of these results to changes in many of the input parameters was tested. Results ranged from low sensitivity for maintenance costs to high sensitivity for product price. The number of highly sensitive parameters and the uncertainty attached to their values suggests that these results should be treated with caution. Further research is required to improve the prospects for woody crops by improving yield and lowering actual costs, and also to improve the accuracy of numbers used in economic analyses.

Table 21. Percentage changes in key parameters needed to change economic analysis to break-even with broadscale agriculture.

Crop type	Parameter	Kojonup	Jerramungup	Merredin
Coppice	Biomass price	-5%	-5%	+25%
	Biomass yield	-8%	-9%	+49%
	Harvest cost	+15%	+15%	-74%
Phase	Biomass price	-4%	-5%	+26%
	Biomass yield	-7%	-10%	+52%
	Harvest cost	+11%	+16%	-77%
Timber belt	Discount rate	-11%	-17%	-46%
	Sawlog yield, price	+13%	+26%	+136%
Timber block	Discount rate	-23%	-37%	-71%
	Sawlog yield, price	+30%	+64%	+238%

Note, shaded options do not break even with broadscale agriculture under current assumptions. The values in the table for these options are the values to which individual parameters would need to improve to achieve break-even EAR. Conversely, for options that already exceed break-even EAR (unshaded), the parameter values listed here are the values to which individual parameters could deteriorate while still breaking even with broadscale agriculture.

To calculate these values, all parameters except the one being tested were held constant.

Based on break-even and sensitivity analyses, the key variables for further research and development are:

- prices received for biomass,
- biomass yields for coppice and phase crops,
- harvest costs for short-cycle crops,
- sawlog yield and price for timber belts (wetter fringes of the wheatbelt only),
- choice of discount rate that will be applied by farmers and external investors when assessing investment in large-scale integration of woody perennials into agriculture, and
- establishment costs, especially for phase crops, which are dependent upon direct seeding.

A second tier of potential research topics includes competition and shelter factors for belt crops. These parameters may influence the break-even economics of woody crops in some circumstances, but are not as sensitive as the key parameters listed above.

The differences in results between the three regions tested here suggest that these results should not be applied outside those regions. To assess the prospects for woody crops in other regions, separate analyses are needed.

Although Merredin was not as economically attractive as the other locations in this analysis, continued investigation of woody crops in drier areas is justified because:

- some woody options could break even with broadscale agriculture with modest improvements in yield or price, two of the recommended areas for further research,
- Merredin is representative of a large potential planting area for woody perennials, and
- Merredin is representative of an area at risk from salinity, but with few other salinity management options.

Although none of the farming systems incorporating timber trees had EARs as high as broadscale agriculture, trees in belts at Kojonup were closest to breaking even. In drier regions, and at plantation densities, the EAR for timber trees declined steeply. Even if EARs could be improved, large scale planting of timber trees may not occur unless the break-even point were exceeded by an amount sufficient to offset the higher cash investment required. Additionally, the long delay between investment and return makes it more likely that external investment would be required, and thus a higher discount rate may need to be applied, further undermining the EAR of long-cycle timber crops. If timber trees are to be developed further in the 300-600 mm mean annual rainfall zone, then discount rates, sawlog prices, and yields in belt layouts are the recommended topics for research. The most promising targets would be trees grown in belts, along the wetter fringes of the zone.

7.3.7 Direct versus indirect returns

In this study, the economic performance of tree crops was investigated to determine their likelihood of commercial success, which is a measure of their ability to deliver direct benefits. Indirect benefits were not included in the analysis. The current level of non-commercial tree planting in agricultural areas demonstrates that indirect benefits alone are not sufficient to encourage tree planting on the scale needed to have a significant effect on large environmental problems such as salinity. Nevertheless, indirect benefits are important factors in influencing farmer decisions to plant species with commercial potential, as demonstrated by oil mallee plantings in Western Australia. Although oil mallees are not yet commercial, the current attempt to make them commercial, combined with indirect returns, have inspired over 900 farmers to plant a total of more than 20 million mallees over a period of eight years (Bartle and Shea 2002). Indirect benefits are also important from a broader perspective that includes the public benefit of salinity management and biodiversity protection.

Indirect returns were not considered in this analysis for a number of reasons:

- The value of indirect benefits is very uncertain.
- Many remain speculative and may not come into effect. Examples include ecosystem service payments related to salinity, biodiversity or greenhouse gases.
- Payments for indirect benefits such as ecosystem services may be insecure and unstable, as they will be dependent on government policy decisions, and will not be determined by free markets.
- The returns that farmers can secure from indirect benefits are unclear, both for benefits that accrue directly on the farm (shade, shelter, and in some cases, salinity) and benefits that accrue to society as a whole.
- It is likely that most ecosystem service benefits provided by woody crops (such as salinity control and biodiversity protection) would have only a low value per hectare of woody crop. In most circumstances, payments for these benefits would be unlikely to be sufficient to make a large difference to he economic performance of woody crops (Pannell 2004).

Although indirect benefits were not considered in this analysis, the results can be used to calculate the returns that would be needed from indirect benefits to convert some marginal or unprofitable alternatives into profitable ones that can compete with current cropping and grazing systems.

7.4 Feedstock supply to a processor

7.4.1 Factors relevant to feedstock supply

7.4.1.1 Feedstock quantity

A key issue for establishing a new processing plant is whether it can be supplied with sufficient feedstock at its required price. This ultimately depends on whether enough material can be grown, at an acceptable cost within a feasible transport distance of the proposed plant location. Key determining factors at each location are climatic conditions, the distribution of suitable soil types, and the level of adoption by farmers.

The amount of feedstock required is determined by the type and scale of processing industry, and the biomass component required (Table 22). Woody crops produce a variety of components, including wood, bark, leaf and twig. For some processing plants, not all of this will be suitable feedstock, so the total amount of biomass to be grown will be the feedstock requirement of the processing plant divided by the extractable percentage of the required component within the total biomass. For example, if 25% of biomass grown is woodchip of a suitable quality to supply a factory requiring 100,000t of wood chip per year, then 400,000t of biomass needs to be grown.

Table 22. Typical annual feedstock requirements for potential woody crop industries.

Product	Typical feedstock requirement		Reference
	At the plant	Green biomass (kt)	
Electricity from biomass	10 kt dry biomass	18	(Hague *et al.* in prep.)
Wood plastic composites	5 kt dry wood	36	(Hague *et al.* in prep.)
Electricity from pyrolysis	40 kt dry biomass	73	(Hague *et al.* in prep.)
Integrated tree processing	100 kt green biomass	100	(Enecon Pty Ltd 2001)
Ethanol from biomass	165 kt dry biomass	300	(Hague *et al.* in prep.)
Panel Products	200 kt dry wood	1,450	(Hague *et al.* in prep.)
Methanol from biomass	1,600 kt dry biomass	2,900	(Hague *et al.* in prep.)
Kraft pulp	2,500 kt green wood	10,000	(Hague and Clark 2003)

Assumptions: Biomass is 45% moisture (fresh weight basis); wood component is 25% of biomass.

7.4.1.2 Area of farmland required

The amount of feedstock required by a processing facility will be the major determinant of the area of tree crops needed to supply it. However, the relationship between feedstock requirement and land requirement is complex. In drier regions, the total land area required is increased by the integrated nature of tree crops, grown either spatially in belts, or temporally as phase crops. For example, as shown earlier, tree belts at Merredin would occupy only 7.7% of the suitable soil types (Table 5), with agricultural alleys occupying the remaining 92.3%. Therefore, the total land area required would be 13 times greater than that required for the tree belts alone. Similarly, in an area in which stored soil moisture is replenished at 30mm per annum, phase crops would be present only 12% of the time (Table 4) and the total land area required would be eight times that planted at any one time during the project life.

Other feedstock supply considerations include crop type, species, and soil and climatic requirements. Woody crops are likely to be targeted at soil types where they can grow well, and reduce recharge. Soil types that will not suit woody crops include shallow soils, heavy clay soils and saline soils. Furthermore, different tree crops may have different soil preferences. Once the amount of each soil type has been identified, its availability has to be assessed. Land may be unavailable for many reasons. It may have infrastructure built on it, such as roads or houses, or it may already be vegetated, or the farmer may choose not to grow tree crops.

In summary, factors that affect the area required to supply a processing plant include:

- amount and type of material required by the processing plant (Table 22),
- distribution and availability of suitable soil types,
- tree crop type, and productivity on the available land,
- integration of the tree crop into farming systems, and
- uptake level by farmers.

The effect of these factors on the area required is shown in a hypothetical example (Table 23). Based on the assumptions used in this example, a total of 866,000 hectares would be needed to supply 100,000 tonnes of biomass per year, from a woody crop of 20,000 hectares dispersed within farming systems.

Table 23. Sample calculation of the total land area required to supply a hypothetical processing plant with chipped wood from a low rainfall area.

Parameter	Value
Wood chip required (t/annum)	**100,000**
Wood chip as a % of biomass	25%
Biomass required (t/annum)	400,000
Harvest frequency (years)	3
Biomass yield per harvest (t)	60
Area of woody crop needed (ha)	**20,000**
Percentage of farmed area planted [1]	7.7%
Suitable soil type (% in landscape - assumed)	67%
Arable percentage of suitable soil type (assumed)	90%
Adoption rate (assumed)	50%
Available suitable soil type (67% x 90% x 50%)	30%
Total land area needed to supply wood chips (ha)	**866,623**

1 Woody crop percentage for Merredin (Table 5) is used here as an example.

7.4.1.3 Transport distance

The average transport distance to supply a processing plant is dependent upon the area from which the material is collected, the shape of that area, the location of the plant within the area and the shape of the road network.

Many simple studies assume a circular collection area, with the plant located at the centre of the circle and a radial road network. This methodology effectively calculates the minimum transport horizon. The circle method is most suited to plantations in highly productive areas. In places where productivity is lower and tree crops have to be integrated with agriculture, the circle required is large and the method error prone.

A circular transport horizon assumes that there are no barriers to production in any direction. However, for large supply areas, barriers include soil distribution, climatic conditions and geographic features. Similarly, placing the processing plant in the middle of the circle assumes that there are no restrictions on placing the industry. Once a suitable growing area has been identified in the wheatbelt the placement of the processing plant will be heavily influenced by existing infrastructure, including roads, electricity and water supplies, towns and perhaps rail. Therefore, the industry will probably be placed in a large rural town close to the centre of the catchment area. Finally, the road network in the wheatbelt of Western Australia is strongly rectilinear (Figure 8), running north-south and east-west, with only a few radial roads linking towns, rather than all roads radiating out from towns as per the radial transport model.

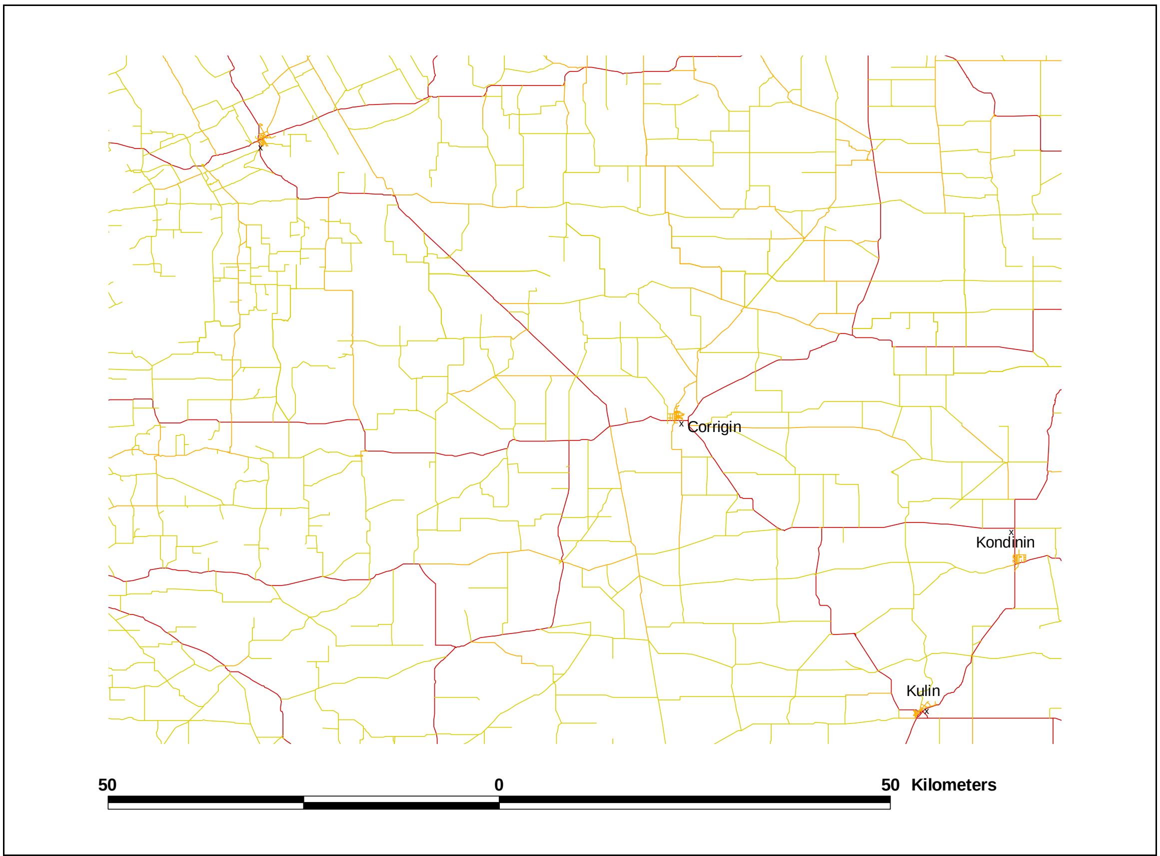


Figure 8. Road layout around Corrigin, Western Australia.

Two options exist to overcome the deficiencies of circular model. First, transport distances could be estimated using a rectilinear model. In this case all travel is assumed to be either north-south or east-west. For large areas, this method can also have linear barriers to represent the limit of suitable climate or geography, and the processing plant can be placed off-centre if required. Alternatively, if sufficient information were available on the distribution of woody crops, a GIS system could be used to calculate exact transport distances. The simpler, rectilinear transport model was used in this study, due to insufficient data being available to run a complete GIS analysis at this early stage of woody crop development.

7.4.2 Methodology used in this study

The aim of this study was to develop a method for investigating the potential for woody crops (especially short-cycle woody crops) to supply processing industries of various size with their required amounts of feedstock. Narrogin, Wongan Hills and Merredin, three regional centres in Western Australia, were used as case studies (Table 24).

Table 24. Towns used in biomass supply analysis.

Town	Region
Narrogin	Upper Great Southern
Wongan Hills	Central Wheatbelt
Merredin	Eastern Wheatbelt

Sites suitable for tree crops were selected based on climate and soil types. Three rainfall zones and three ‘point potential evaporation’ zones (Table 25) were used to define nine climatic zones (Table 26). Soil types were classified as either suitable or unsuitable for trees by Harper (2003, CALM unpublished data) based on an analysis of “Soil groups of Western Australia” (Schoknecht 2002).

Table 25. Rainfall and point potential evaporation zones for supply analysis.

Zone	Range (mm)
Low rainfall	300-400
Medium rainfall	400-500
High rainfall	500-600
Low evaporation	<1600
Medium evaporation	1600-2000
High evaporation	>2000

Point potential evaporation is one of three evaporation measures provided by the Bureau of Meteorology, and is equivalent to pan evaporation in an otherwise water-free environment. It is a measure that assumes the evaporating water source is small enough not to influence local conditions.

The total amount of biomass that could be supplied to the three potential processing centres was calculated by multiplying productivity rates by available areas. Productivity (Table 26) was calculated for each climate zone based on its median rainfall and point potential evaporation, the woody perennial percentage cover used for woody belt crops (Table 5), and a biomass conversion relationship (Equation 1 and Equation 2).

Available areas were calculated using ArcView 3.2 GIS using the UTM, MGA zone 50 projection and GDA 94 datum. Metadata for all datasets are provided in Section 7.5.

Available area was calculated in 25km transport distance increments, with the area defined by the transport horizon cropped by:

- coastline (Figure 9),
- freehold land (Figure 10, Figure 11),
- 300-600 mm isohyets,
- climatic zones (Table 25, Figure 12), and
- land suitable for trees (excluding unsuitable soils and land occupied by infrastructure and native vegetation).

In order to compare the amounts of material that can be supplied to potential processing plants with the amount of material needed (Table 22), some assumptions were needed. It was assumed that biomass can be partitioned into 25% wood chip, 25% leaf material and 50% small sticks, twigs, bark and fines, and that all fresh material has a moisture content of 45% (as a percentage of its fresh weight).

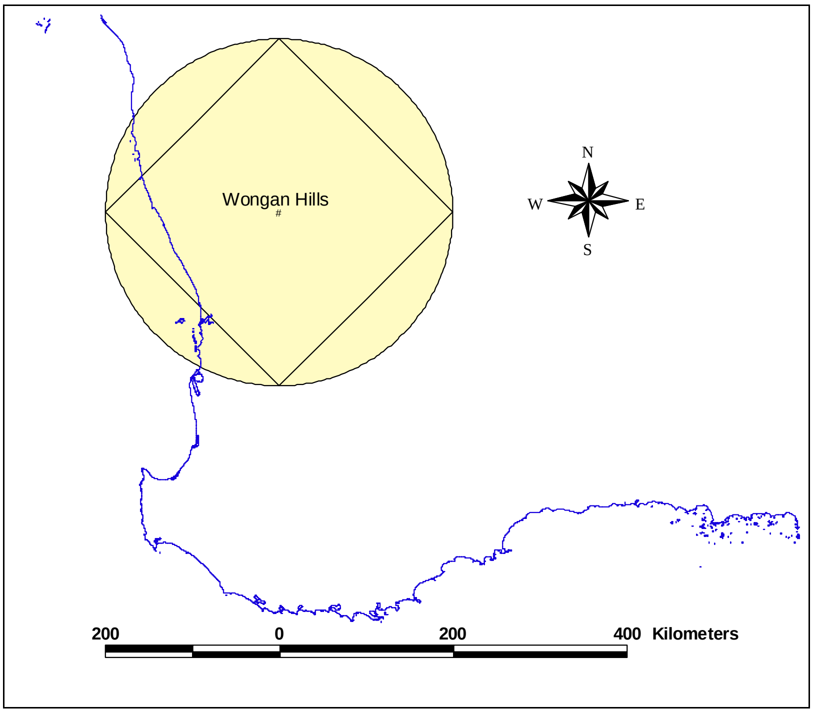


Figure 9. 200 km radial and rectilinear transport horizons around Wongan Hills, plus the WA coastline.

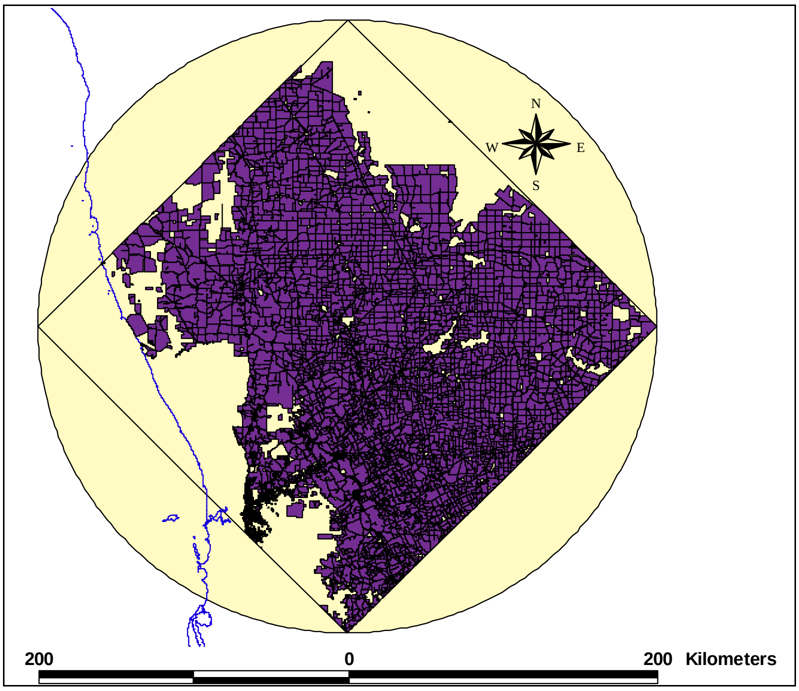


Figure 10. Freehold land within a 200km rectilinear transport distance of Wongan Hills.

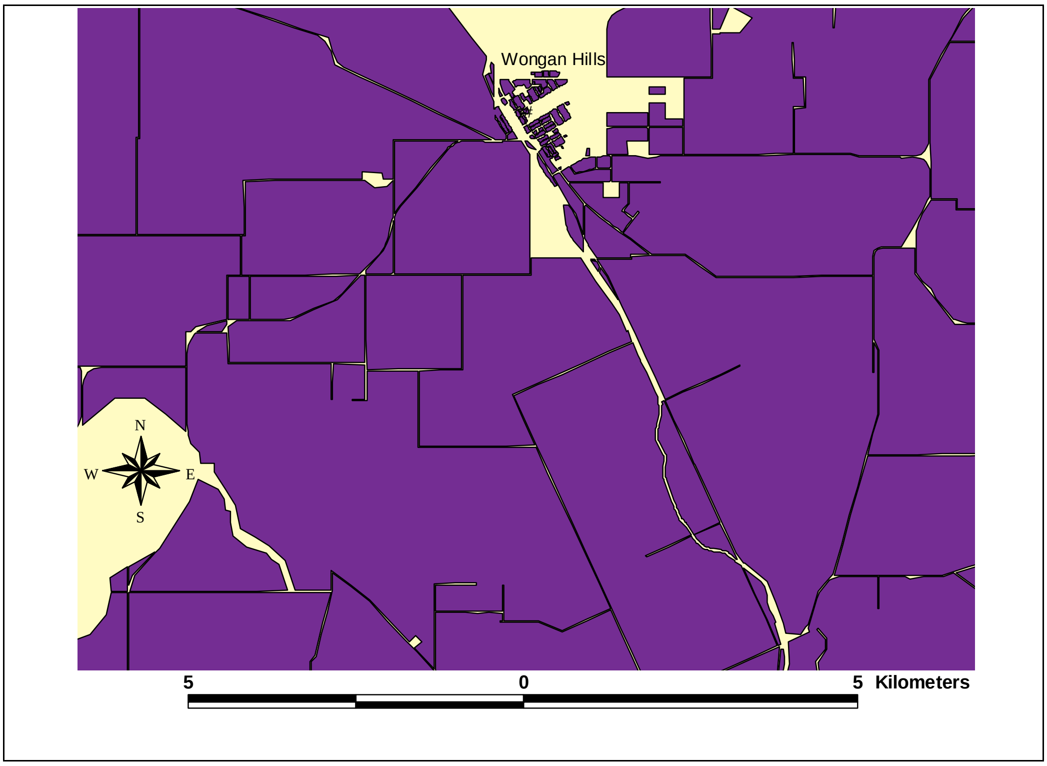


Figure 11. Close-up of freehold land, excluding roads, shire and other public land.

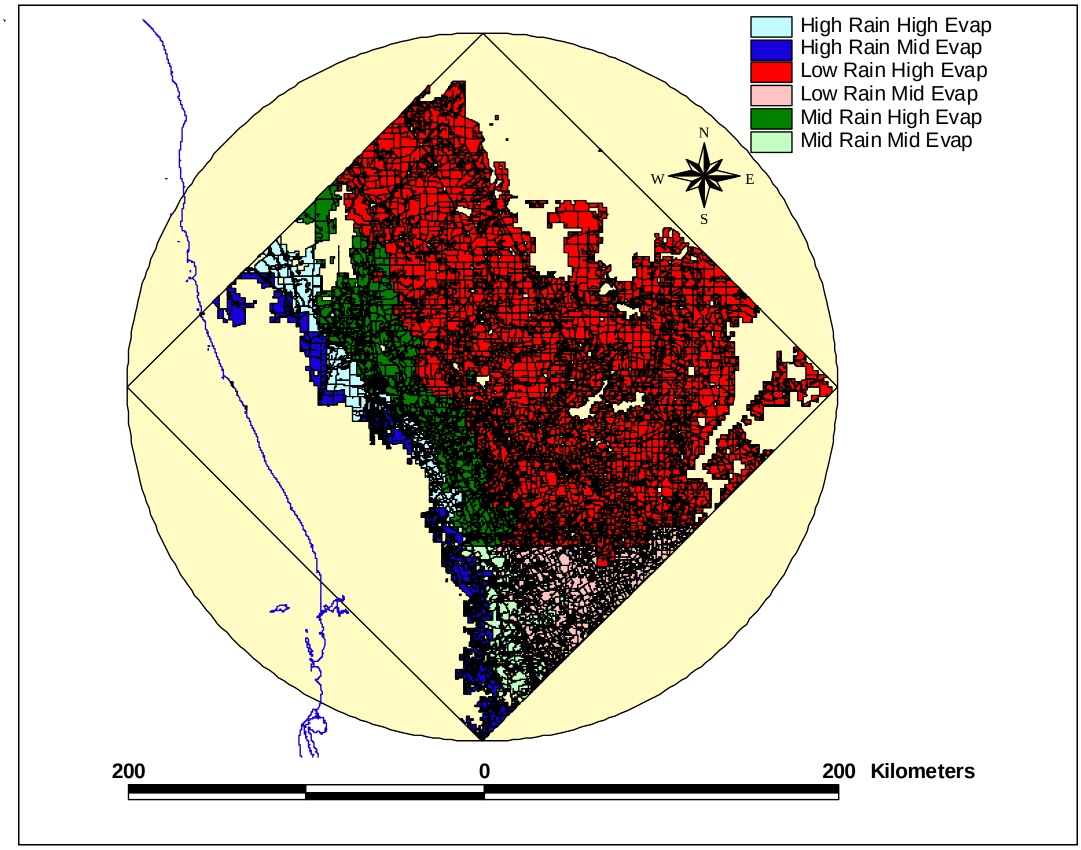


Figure 12. Climatic zones for freehold land within a 200km rectilinear transport distance of Wongan Hills.

Table 26. Calculation of productivity for woody perennials on soils suited to trees, for each climatic zone.

Climate zone	High Rain Low Evap	High Rain Mid Evap	High Rain High Evap	Mid Rain Low Evap	Mid Rain Mid Evap	Mid Rain High Evap	Low Rain Low Evap	Low Rain Mid Evap	Low Rain High Evap
Mean Annual Rainfall - MAR (mm/yr) [A]	550	550	550	450	450	450	350	350	350
Potential Evaporation - PE (mm/yr) [A]	1500	1800	2100	1500	1800	2100	1500	1800	2100
Leakage (mm/yr) [B]	100	100	100	60	60	60	30	30	30
Capture rate (%) [C]	82%	82%	82%	63%	63%	63%	41%	41%	41%
Tree planting area / total area (%) [C]	25.0%	25.0%	25.0%	14.3%	14.3%	14.3%	7.7%	7.7%	7.7%
Extra water (mm/yr) [C]	247	247	247	226	226	226	149	149	149
Total Water (W) = MAR + Extra water (mm/yr)	797	797	797	676	676	676	499	499	499
Climate Wetness Index W/PE	0.531	0.443	0.380	0.451	0.376	0.322	0.333	0.277	0.238
Annual volume increment (m^3/ha/yr) [D]	17.8	14.6	12.3	14.9	12.1	10.2	10.6	8.6	7.2
Biomass dry weight (t/ha/yr) [1]	**20.3**	**16.6**	**14.0**	**17.0**	**13.9**	**11.7**	**12.1**	**9.8**	**8.2**
Moisture content (% of fresh weight) [E]	45%	45%	45%	45%	45%	45%	45%	45%	45%
Biomass Wet (t/ha/yr)	36.9	30.2	25.5	30.8	25.2	21.2	22.0	17.8	14.9
Land unavailable (%) [E]	10%	10%	10%	10%	10%	10%	10%	10%	10%
Farmer uptake (%) [E]	100%	100%	100%	100%	100%	100%	100%	100%	100%
Biomass wet weight / total ha (t/ha/yr) [2]	**8.30**	**6.80**	**5.74**	**3.97**	**3.24**	**2.73**	**1.52**	**1.24**	**1.03**

1 Weight of dry biomass produced each year from each hectare of tree crop.
2 Weight of fresh biomass produced each year from each hectare of suitable soil devoted to farming systems that include tree crops (averaged over entire farming system).

A Approximate mid-points for each climate zone (Table 25).
B From Table 3.
C From Table 5.
D Calculated using Equation 1and Equation 2.
E Assumptions.

7.4.3 Results

7.4.3.1 Land area and biomass production

The percentage of land suited to farming systems that include woody crops ranged from 53% to 66% for short transport horizons (50 km or less), but dropped to 39% to 45% for the 200km transport horizon (Table 27). At longer transport horizons a higher percentage of the land was unavailable because it was outside the 300 mm to 600 mm MAR zone. For example, a transport distance of 200km to the west of Narrogin and Wongan Hills takes in large areas of higher rainfall country and the ocean, while a transport distance of 200 km east of Merredin and Wongan Hills includes large areas of pastoral country.

The total area suited to woody crops was similar for each transport horizon around the three potential processing sites tested here (Figure 13). However, the climatic zones that the land is spread across vary greatly for the three centres (Figure 15). This results in large differences in the amount of biomass that can be supplied to each processing centre (Figure 14). For example, at a maximum transport distance of 100km, Narrogin could be supplied with more than double the biomass that Merredin could receive (Table 28), from only 25% more suitable land (Table 27).

Table 27. Freehold land available within 25km increment transport horizons, restricted to target climate zone, and soils suited to woody crops.

Transport horizon	25	50	75	100	125	150	175	200
Total land (000 ha)	**125**	**500**	**1,125**	**2,000**	**3,125**	**4,500**	**6,125**	**8,000**
Narrogin								
On land (%)	100%	100%	100%	100%	100%	100%	99%	96%
Freehold Land (FL) (%)	91%	89%	91%	88%	83%	81%	78%	76%
FL + climate (%)	91%	89%	88%	82%	77%	74%	71%	67%
FL + climate + soil (%)	66%	66%	63%	58%	55%	52%	49%	45%
FL + climate + soil (000 ha)	83	329	710	1,169	1,719	2,320	2,971	3,568
Wongan Hills								
On land (%)	100%	100%	100%	100%	100%	100%	96%	94%
Freehold land (FL) (%)	93%	96%	95%	93%	90%	84%	77%	70%
FL + climate (%)	93%	96%	95%	91%	83%	75%	67%	61%
FL + climate + soil (%)	53%	60%	57%	56%	52%	48%	43%	39%
FL + climate + soil (000 ha)	66	301	646	1,113	1,636	2,138	2,614	3,083
Merredin								
On land (%)	100%	100%	100%	100%	100%	100%	100%	100%
Freehold Land (FL) (%)	92%	93%	93%	93%	91%	85%	79%	73%
FL + climate (%)	87%	86%	81%	83%	81%	77%	72%	67%
FL + climate + soil (%)	61%	53%	47%	46%	45%	44%	42%	40%
FL + climate + soil (000 ha)	76	266	526	920	1,402	1,975	2,583	3,190

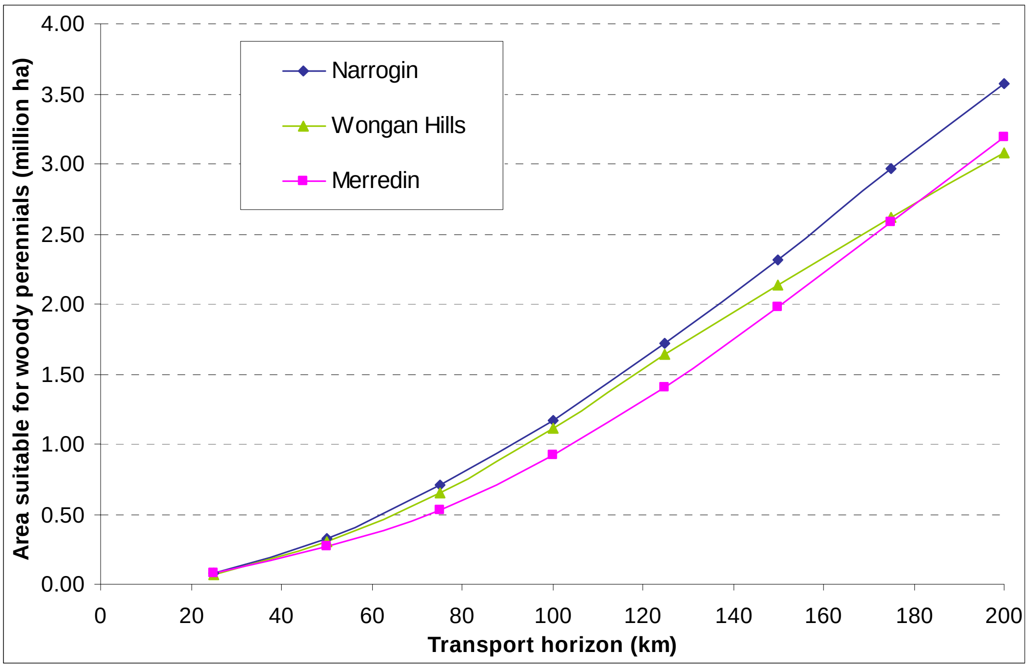


Figure 13. Land area available at different distances from three potential processing sites.

Figure 14. Potential green biomass supply (000s t/annum) for regional processing centres, in 25km transport horizon increments.

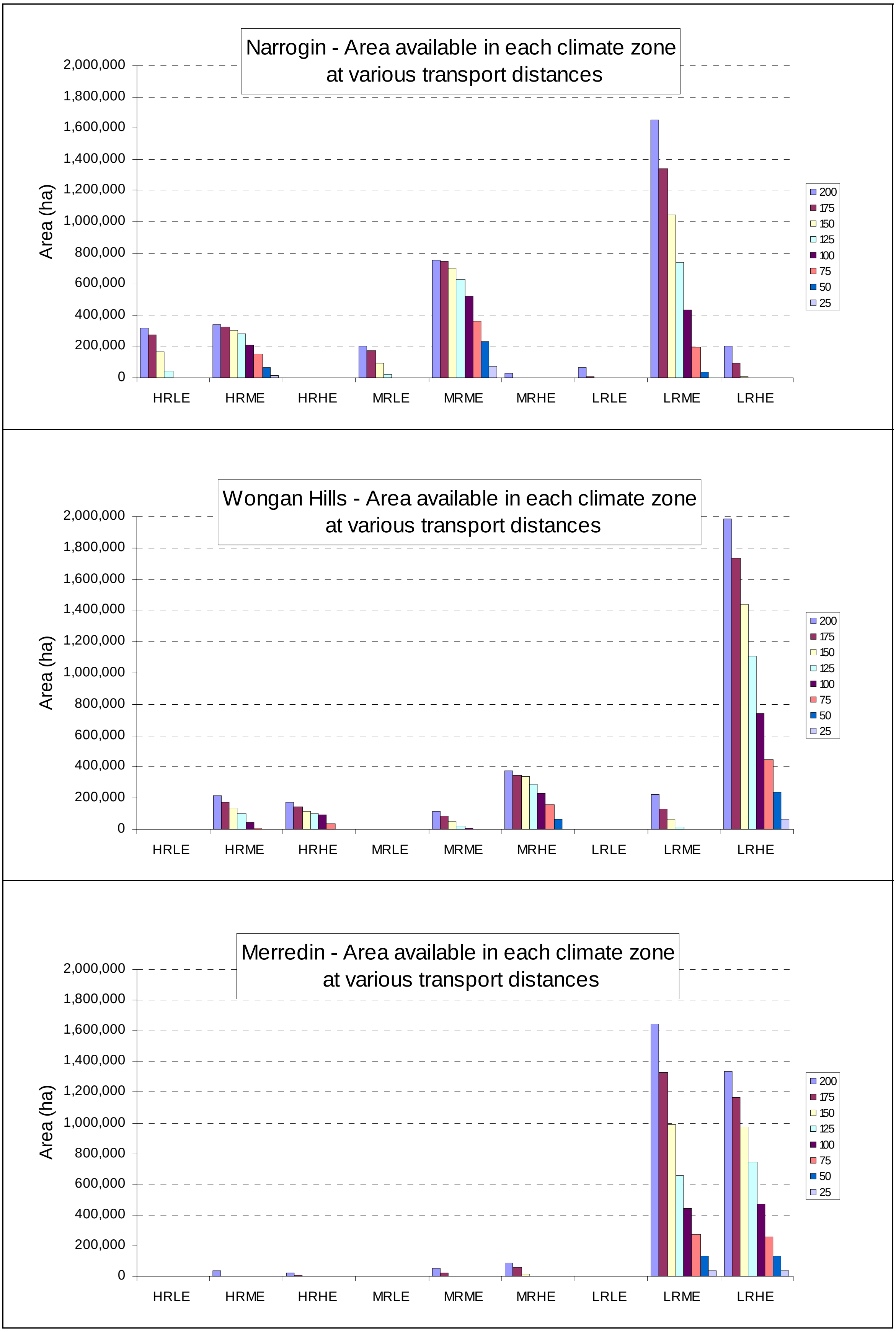


Figure 15. Land available in each climate zone at various transport distances from three regional centres (25km increments).

7.4.3.2 Industry scale

Most of the industries considered in this analysis are small and could be supplied with their feedstock requirements from transport horizons of less than 50km (Table 28, Table 29). The three exceptions are panel products, methanol and Kraft pulp. Of these, panel products and methanol could be supplied at larger transport distances at all three locations, but Kraft pulp appeared to be out of reach.

However, the economics of growing these crops also needs to be considered. Based on the break-even transport horizons in Table 15, returns from farming systems incorporating short-cycle woody crops are likely to fall below those for conventional agriculture at transport horizons of 100 km or more. The effect of this commercial constraint is to limit the tonnage of biomass that could be supplied to a processor. Combining this constraint with the estimated profitability of woody crops, based on estimates of economic parameters for woody crops at Merredin (Table 12), leads to the conclusion that an industry with feedstock requirements as large as panel board manufacture is unlikely to be feasible in low rainfall areas, under current assumptions, although it could be feasible in higher rainfall areas, such as Narrogin.

Table 28. Potential green biomass supply ('000 t/annum) for regional processing centres, in 25km transport horizon increments.

Transport Distance (km)	25	50	75	100	125	150	175	200
Narrogin	233	797	1,425	2,230	3,043	3,953	4,895	5,684
Wongan Hills	74	421	1,091	1,940	2,594	3,289	3,997	4,689
Merredin	86	301	597	1,039	1,579	2,260	3,115	3,958

Table 29. Transport horizon in 25 km increments required to supply woody perennial based industries.

Product	Biomass Feedstock ('000 t green)	Narrogin	Wongan Hills	Merredin
Electricity from biomass	18	25	25	25
Electricity from pyrolysis	73	25	25	25
Wood plastic composites	36	25	25	25
Integrated tree processing	100	25	50	50
Ethanol from biomass	300	50	50	50
Panel Products	1,450	75[1]	100	125
Methanol from biomass	2,900	125	150	175
Kraft pulp mill	10,000	-	-	-

1 The 75km transport distance can supply 98% of the material required

These results do not rule out the potential for large-scale industries to use woody material grown in the wheatbelt, for two reasons. First, the calculations used here are based on assumptions that require further testing and refinement. Second, the wheatbelt may not need to supply 100% of the feedstock for larger industries. Some larger industries may be co-supplied with material from higher rainfall areas. For example, a large plantation blue gum (*Eucalyptus globulus*) industry has developed in areas with a mean annual rainfall exceeding 600 mm, with current chipping and export facilities based at Albany and Bunbury. If a Kraft pulp mill is established to utilise material from these two areas it may also accept material grown in adjacent parts of the wheatbelt. In this case, the siting of such a pulp mill would be crucial to the prospects of partially supplying it with wheatbelt material. To attract investment to a suitable site on the edge of the wheatbelt, the material produced there would need to be lower priced, or higher quality than material available in the high rainfall zone near the coast.

Industry size is an important determinant of the scale of environmental benefits that could flow from new industries based on woody crops. Large industries are likely to be complex to establish, but could have a large regional effect on environmental issues such as salinity, erosion and biodiversity conservation. Conversely, industries with smaller feedstock requirements could be supplied by fewer farmers within smaller transport horizons. Smaller industries may be simpler to establish, but would have more localised environmental effects. Many small industries would need to be established to provide regional scale environmental benefits.

7.4.3.3 Final comments

In conclusion, note that these results are very speculative, and are presented here as a demonstration of the type of analysis that is possible using this method. They are not intended to be firm findings. This method is the first step towards developing a cohesive and realistic analytical technique for linking water available in the paddock to the market requirements of industries of various scale.

Further development of this method is planned within the Cooperative Research Centre for Plant-based Management of Dryland Salinity, to refine the method, validate the assumptions, and improve the quality of the data used, to allow more accurate assessments to be made of the potential for different scale industries based on woody crops to develop in the wheatbelt.

7.5 GIS Metadata

7.5.1 Western Australian Coastline

Dataset

Custodian

Department of Conservation and Land Management

Jurisdiction

Western Australia

Description

Abstract

West Australian coastline as collected by the Digital Acquisition Program (DAP) and AUSLIG.

Geographic Extent

Western Australia

Attribute List:	**Attribute Name**	**Attribute Description**
	source	Character string describing data source.

***source* Values**	***source*Name**	***Source*Description**
	dap	Coastline as collected by DAP
	auslig	Coastline as collected by AUSLIG
	par129	Border between WA and SA

Data Currency

Beginning Date: Unknown
Ending Date: Current
Metadata Date: 27/9/01

Dataset Status

Progress

Complete

Maintenance and Update Frequency

As required

Format

Stored Data Format: Digital
Available Formats: Arc/Info

Data Quality

Lineage

Original topographic file obtained from DOLA. Ground features verified, modified and value added in conjunction with 1:25 000 orthophotographs. Map sheets compiled on appropriate DGN file levels to produce a file which covered the three forest regions. This file then converted into Arc/Info format. The DAP data was then combined with AUSLIG's coastline which was collected at 1:250 000.

Positional Accuracy

DAP positional accuracy (85% of points are +/- 12.5m from the true position and, generally, the remainder should be no worse than +/- 50m from the true position). AUSLIG unknown.

Logical Consistency

All line work is clean

Completeness

Complete

Contact Information

Organisation:	Department of Conservation and Land Management
Position:	Spatial Database Administrator
Person:	Steve Jones
Address:	17 Dick Perry Ave, Technology Park, Western Precinct
City:	Kensington WA 6151
Telephone:	(08) 9334 0350
Fax:	(08) 9334 0357
Email:	stevenj@calm.wa.gov.au

7.5.2 Spatial Cadastral Database (SCDB)

Custodian Details

Land Administration (Agency), Department of Western Australia

Abstract

The SCDB is an integrated database comprising of a number of datasets (layers)of digital spatial data, defining all Crown and Freehold land parcels within the State as well as subsidiary survey network control. Includes an integrated administrative boundaries dataset and a lodged layer containing recent surveys.

Search

BOUNDARIES Administrative, LAND Cadastre, LAND Ownership

Currency and Status

Beginning Date: 01/01/1982
Ending Date: Not Known
Metadata Date: 08/03/2001
Progress: Complete
Maintenance & Update Frequency: Daily

Native Format

DB2 tables on the mainframe, SDE in Oracle database on Client Server

Available Format Types

Arc/Info Export Files
Arc/Info Shape Files
IGDS - Intergraph Design file
Norm2 via Land Information Access system
On line file transfer for Government Agencies.
Hardcopy

Access Constraints

No restrictions, except most of the recently captured administrative boundaries are not yet available in NORM2 digital extracts.

Lineage

This dataset was originally digitised from the largest scale Public Plans available. Selected areas are now spatially upgraded to survey accuracy. The dataset is maintained and updated from directly from accurate survey information lodged in digital form.

Positional Accuracy

Upgraded data +/- 0.01m to +/- 0.25m in urban regions. +/-1m to +/-10m in rural areas. Digitised data +/-1mm at source map scale.

Attribute Accuracy

95%accurate

Logical Consistency

Digitally correct, data has been processed to remove digital errors.

Completeness

Digitised dataset is complete. Spatial upgrade is proceeding and is 58.5% complete as at 1/2/2001.

Additional Metadata

Christmas and Cocos Islands are also included in the dataset.

Contact Persons

Department of Land Administration (Agency)
Product Consultant, Land Enquiry Centre
PO Box 2222
Midland WA Australia 6936
Ph: 08 9273 7341
Fax: 08 9273 7655
email: lec@dola.wa.gov.au

7.5.3 Mean Monthly and/or Mean Annual Rainfall Data (Base Climatological Data Sets)

CUSTODIAN

Bureau of Meteorology (Australia)

JURISDICTION

Australia

ABSTRACT

Mean monthly and mean annual rainfall grids. The grids, which have been smoothed by a one-pass 13-point box binomial smoother, show the raw rainfall values across Australia. The mean data are based on the standard 30-year period 1961-1990. See LINEAGE below for more information.

SEARCH WORDS

Gridded, spline, analyses, climatology, rainfall. meteorology

GEOGRAPHIC EXTENT NAME(S)

Australia

BEGINNING DATE

N/A

ENDING DATE

N/A

PROGRESS

Completed

MAINTENANCE AND UPDATE FREQUENCY

10+ years

STORED DATA FORMAT

Arc/Info grids – all Australia

AVAILABLE FORMAT TYPE(S)

ASCII grid-point, Arc/Info grid export, 3-column (longitude, latitude, value) text

ACCESS CONSTRAINTS

Commonwealth of Australia copyright applies (see RESTRICTIONS ON USE below)

LINEAGE

Gridded data were generated using the ANU (Australian National University) 3-D Spline (surface fitting algorithm). As part of the 3-D analysis process a 0.025 degree resolution digital elevation model (DEM) was used. Approximately 6000 rainfall stations were used in the analysis. All input station data underwent a high degree of quality control before analysis, and conform to WMO (World Meteorological Organisation) standards for data quality.

POSITIONAL ACCURACY

Better than 0.02 (approximately 2km) degrees

ATTRIBUTE ACCURACY

80% of data have an associated quantitative uncertainty of 5%; uncertainty of remainder is within 15%

LOGICAL CONSISTENCY

N/A

COMPLETENESS

No missing data

CONTACT ORGANISATION

Bureau of Meteorology

CONTACT POSITION

Superintendent National Climate Centre

CONTACT PERSON

As above

MAIL ADDRESS

PO BOX 1289K, Melbourne 3001, Australia

SUBURB OR PLACE OR LOCALITY

Melbourne

STATE OR LOCALITY

Victoria

COUNTRY

Australia

POSTCODE

3001

TELEPHONE

(03) 9669 4086

FACSIMILE

(03) 9669 4678

ELECTRONIC MAIL ADDRESS

webclim@bom.gov.au

METADATA DATE

December, 1999

ADDITIONAL METADATA

Supersedes maps printed in: Climatic Atlas of Australia (Australian Government Printing Service, 1975)

Gridded maximum and minimum temperature datasets are also available.

ATTRIBUTES

Grid/s provides rainfall values for all Australia on a grid-cell by grid-cell basis

SCALE/RESOLUTION

0.025 degrees (i.e. based on 0.025 x 0.025 degree gridded data)

RESTRICTIONS ON USE

Copyright for any data supplied by the Bureau of Meteorology is held in the Commonwealth and the purchaser shall give acknowledgement of the source in reference to the data. Apart from dealings under the Copyright Act 1968, the purchaser shall not reproduce (electronically or otherwise), modify or supply (by sale or otherwise) these data without written permission from the supplier.

SIZE OF DATASETS

20-30 Mb

PRICE and ACCESS

$22 per grid or $275 per set of 13 grids (monthly and annual) in standard output format

Electronic download (fast) or CD-ROM

7.5.4 Mean Monthly and/or Mean Annual Evapotranspiration Data (Base Climatological Data Sets)

CUSTODIAN

Bureau of Meteorology (Australia)

JURISDICTION

Australia

ABSTRACT

Mean monthly and mean annual Areal Actual, Areal Potential and Point Potential evapotranspiration (ET) grids. The grids show the ET values across Australia. The mean data are based on the standard 30-year period 1961-1990. See LINEAGE below for more information.

SEARCH WORDS

gridded, spline, analyses, climatology, evapotranspiration, hydrology, meteorology

GEOGRAPHIC EXTENT NAME(S)

Australia

BEGINNING DATE

N/A

ENDING DATE

N/A

PROGRESS

Completed

MAINTENANCE AND UPDATE FREQUENCY

10+ years

STORED DATA FORMAT

Arc/Info grids – all Australia

AVAILABLE FORMAT TYPE(S)

ASCII grid-point, Arc/Info grid export, 3-column (longitude, latitude, value) text

ACCESS CONSTRAINTS

Commonwealth of Australia copyright applies (see RESTRICTIONS ON USE below)

LINEAGE

Gridded data were generated using the ANU (Australian National University) 3-D Spline (surface fitting algorithm). As part of the 3-D analysis process a 0.1 degree resolution digital elevation model (DEM) was used. Approximately 700 stations were used in the analysis. All input station data underwent a high degree of quality control before analysis, and conform to WMO (World Meteorological Organisation) standards for data quality. The definitions of Areal Actual, Areal Potential and Point Potential ET are as follows:

Areal Actual ET is the ET that actually takes place, under the condition of existing water supply, from an area so large that the effects of any upwind boundary transitions are negligible and local variations are integrated to an areal average.

Areal Potential ET is the ET that would take place, under the condition of unlimited water supply, from an area so large that the effects of any upwind boundary transitions are negligible and local variations are integrated to an areal average.

Point Potential ET is the ET that would take place, under the condition of unlimited water supply, from an area so small that the local ET effects do not alter local airmass properties. It is assumed that latent and sensible heat transfers within the height of measurement are through convection only.

The above definitions are based on those given by Morton (1983), but we have used the term areal potential ET for Morton's wet-environment ET and the term point potential ET for Morton's potential ET.

Morton, F.I. (1983). Operational estimates of areal evapotranspiration and their significance to the science and practice of hydrology. Journal of Hydrology, 66: 1-76.

POSITIONAL ACCURACY

Better than 0.05 (approximately 5km) degrees

ATTRIBUTE ACCURACY

80% of data have an associated quantitative uncertainty of 5%; uncertainty of remainder is within 15%

LOGICAL CONSISTENCY

N/A

COMPLETENESS

No missing data

CONTACT ORGANISATION

Bureau of Meteorology

MAIL ADDRESS

PO BOX 1289K, Melbourne 3001, Australia

SUBURB OR PLACE OR LOCALITY

Melbourne

STATE OR LOCALITY

Victoria

COUNTRY

Australia

POSTCODE

3001

TELEPHONE

(03) 9669 4082

FACSIMILE

(03) 9669 4515

ELECTRONIC MAIL ADDRESS

webclim@bom.gov.au

METADATA DATE

December, 1999

ADDITIONAL METADATA

Supersedes (evaporation) maps printed in: Climatic Atlas of Australia (Australian Government Printing Service, 1975).

Gridded rainfall, maximum and minimum temperature datasets are also available.

ATTRIBUTES

Grid/s provides ET values for all Australia on a grid-cell by grid-cell basis

SCALE/RESOLUTION

0.1 degrees (i.e. based on 0.1 x 0.1 degree gridded data)

RESTRICTIONS ON USE

Copyright for any data supplied by the Bureau of Meteorology is held in the Commonwealth and the purchaser shall give acknowledgement of the source in reference to the data. Apart from dealings under the Copyright Act 1968, the purchaser shall not reproduce (electronically or otherwise), modify or supply (by sale or otherwise) these data without written permission from the supplier.

SIZE OF DATASETS

Approx. 600 Kb per grid

7.5.5 Soil-landscape Systems of the South West of Western Australia

Custodian

Agriculture WA

Abstract

Soil-landscape systems mapping of the South West of Western Australia, Agriculture Western Australia, Version 3, Oct. 2001.

Publication Scale

1:500, 000

This map is derived from detailed soil-landscape mapping at various scales covering the agricultural area of Western Australia.

Geographic Extent

South west of WA.

Beginning Date

01-11-2001

Ending Date

Current

Update Frequency

Maintenance & Update Frequency As required

Stored Data Formats

Arc coverage

Available Data Formats

Shape file

Access Constraint

Subject to data licensing agreement.

Lineage

Data compiled from more detailed (1:25,000 - 1:250, 000) soil-landscape mapping. The Intergraph MGE merge process was used to create system polygons from subsystem and phase level mapping. The data was then weeded using the MGE Line Weeder process with a 10 m weeding tolerance. Soil survey was carried out according to the standards set in "Australian Soil and Land Survey - Guidelines for Conducting Surveys", Gunn et al., CSIRO, 1988.

Coverage Attributes:

Attribute name	Description
MSLINK	Link to Agwa graphics in GeoMedia
MAPID	
MAPPING_UN	Map unit code

SOIL_AREA	

Associates tables

systems_v3_desc.txt	Mapping unit descriptions
MANUALNov01.pdf	Land evaluation standards for land resource mapping
SYSTEMS_V3_calm_qua.xls	Associated information for land resource mapping.

MANUALNov01.pdf and SYSTEMS_V3_calm_qua.xls can be found on CD 497 in the CD library.

Attributes

systems_v3_desc.txt

Attribute name	Description
MAP_UNIT	Map unit code
MU_RANK	Map unit rank
MU_NAME	Map unit name
MU_STATUS	Map unit status
MU_SUM_DESC	Map unit summary description – combines and summarizes landform, geology, soils and vegetation data.
MU_LFORM	Map unit land form data - detailed
MU_GEOL	Map unit geology data - detailed
MU_SOIL	Map unit soil data - detailed
MU_VEG	Map unit vegetation data - detailed
MU_LOCAT	Map unit location
EXTRACTED	Date of extraction

Projection

None

Datum

GDA 94

Positional Accuracy

+ or - 250 m

Attribute Accuracy

Mapping is at the system level of the Agriculture WA soil-landscape mapping hierarchy. Good accuracy for the scale of mapping.

Logical Consistency

Clean linework and one label per polygon. Data checked using Mappa MDL Application and Intergraph MGE GIS software.

Completeness

Agricultural area of Western Australia.

Contact Organisation

CALM

Contact Person

Steve Jones

Address

Department of Conservation and Land Management, Locked Bag 104, BENTLEY DELIVERY CENTRE WA 6983

Telephone

(08) 9334 0350

Facsimile

(08) 9367 9357

Email Address

stevenj@calm.wa.gov.au

Metadata Date

01-11-2001(from AgWA)

7.6 References

Asseng, S, I Fillery, F Dunin, B Keating and H Meinke (2001). "Potential deep drainage under wheat crops in a Mediterranean climate. I. Temporal and spatial variability." Aust. J. Agric. Res. **52**(1): 45-56.

BankWest (1998). BankWest benchmarks 1997/1998. BankWest Agribusiness Centre, Bank of Western Australia.

BankWest (1999). BankWest benchmarks 1998/1999. BankWest Agribusiness Centre, Bank of Western Australia.

BankWest (2000). BankWest benchmarks 1999/2000. BankWest Agribusiness Centre, Bank of Western Australia.

BankWest (2001). BankWest benchmarks 2000/2001. BankWest Agribusiness Centre, Bank of Western Australia.

BankWest (2002). BankWest benchmarks 2001/2002. BankWest Agribusiness Centre, Bank of Western Australia.

Bartle, J (1999). The new hydrology: new challenges for landcare and tree crops. State Landcare Conference, Esperance Civic Centre, Western Australia.

Bartle, J and S Shea (2002). Development of mallee as a large-scale crop for the wheatbelt of WA. Australian Forest Growers 2002 National Conference: Private Forestry - Sustainable accountable and profitable, Albany, WA, Australia.

Cooper, D, G Olsen and J Bartle (2004). Capture of agricultural surplus water determines the productivity and scale of new woody crop industries. Salinity solutions - working with science and society, Capital Theatre, Bendigo Performing Arts Centre, Bendigo, Victoria, Australia.

Cooper, D, G Olsen and J Bartle (submitted). "Capture of agricultural surplus water determines the productivity and scale of new dryland woody crop industries." Australian Journal of Experimental Agriculture.

Enecon Pty Ltd (2001). Integrated tree processing of mallee eucalypts. Rural Industries Research and Development Corporation. Report 01/160. 81p.

George, RJ, RA Nulsen, R Ferdowsian and G Raper (1999). "Interactions between trees and groundwaters in recharge and discharge areas - A survey of Western Australian sites." Agricultural Water Management **39**: 91-113.

Ghassemi, F, A Jakeman and H Nix (1995). Glossary. p516 *In* Salinisation of land and water resources. Sydney, NSW, Australia, University of New South Wales Press Ltd.

Hague, J and N Clark (2003). An overview of the pulp and paper industry. CSIRO Forestry and Forest Products. Report 1344 for WA Department of CALM. 25p.

Hague, J, G Freischmidt, S Pongracic and P Fung (in prep.). Six Best Bet Products from Agroforestry Biomass Grown in Low Rainfall Areas. Project No. CSF-60A. Rural Industries Research and Development Corporation.

Hatton, TJ and WR Dawes (2000). Biophysical simulation and interpretation of phase farming with trees. p13-19 *In* Phase farming with trees: a scoping study of its potential for salinity control, soil quality enhancement and farm income improvement in dryland areas of southern Australia. RJ Harper, TJ Hatton, DS Crombie*et al*, Eds. Canberra, ACT, Australia, Rural Industries Research and Development Corporation.

Kingwell, RS and DJ Pannell (1987). MIDAS, A Bioeconomic Model of a Dryland Farm System. Wageningen, Netherlands, Pudoc. 207p.

Knight, A, K Blott, M Portelli and C Hignett (2002). "Use of tree and shrub belts to control leakage in three dryland cropping environments." Australian Journal of Agricultural Research **53**: 571-586.

Pannell, DJ (2004). Enhancing the environmental benefits of agroforestry through government policy mechanismsAgroforestry for Natural Resource Management, (forthcoming). I Nuberg, Ed., Draft version currently available online at: http://www.general.uwa.edu.au/u/dpannell/dp0404.htm.

Robinson, N, RJ Harper, KRJ Smettem, R Archibald, A Stilwell and Y Oliver (2002). Recharge reduction on degraded agricultural soils with agroforestry systems. 17th World Congress of Soil Science 14-21 August 2002, Bangkok, Thailand.

Schoknecht, N (2002). Soil groups of Western Australia. Department of Agriculture, Government of Western Australia. Report Technical Report 246. 122p.

Silberstein, RP, RA Vertessy, D McJannet and TJ Hatton (2002). Tree belts on hillslopes. p57-76 *In* Trees, water and salt: an Australian guide to using trees for healthy catchments and productive farms. RA Vertessy, RJ Stirzaker and A Sarre, Eds. Canberra, Australian Capital Territory, Joint Venture Agroforestry Program.

Smettem, KRJ, P Farrington, M Rivasborge, RJ Harper, DS Crombie and D Williamson (1999). Defining soil constraints to blue gum water use, growth and survival for managing groundwater recharge. Land and Water Resources Research and Development Corporation. Report Grant UWA 15, Final Report.

Sudmeyer, R (2002). Tree root morphology in alley systems. RIRDC/L&W Australia/FWPRDC Joint Venture Agroforestry Program. Report RIRDC Publication No 02/024.

Wildy, D, J Pate and J Bartle (2003). Silviculture and water use of short-rotation mallee eucalypts. RIRDC/Land & water Australia/FWPRDC/MDBC Joint Venture Agroforestry Program. Report RIRDC Publication No 03/033.

Natural Heritage Trust
Helping Communities Helping Australia
An Australian Government Initiative

Search Project Report

Section 8 – Demonstration and Resource Plantings

Dan Huxtable with nine-month-old *Viminaria juncea* at Blake's property, Katanning.

Final report for NHT Project 973849

July 2004

Government of Western Australia
Department of Conservation and Land Management
Conserving the nature of WA

Authors

Graeme Olsen[1]
Don Cooper[2]
Dan Huxtable[2]
Jerome Carslake[2]
John Bartle[2]

Photographs: Unless stated otherwise, all photographs were taken by Graeme Olsen.

ISBN No: 0 7307 55509

[1] Olsen & Vickery, PO Box 357 Waroona, Western Australia 6215.

[2] Department of Conservation and Land Management, Locked Bag 104, Bentley Delivery Centre, Western Australia 6983.

Sections in this report

Section 1	Summary
Section 2	Background
Section 3	Search Methodology
Section 4	Product Assessment
Section 5	Species Selection
Section 6	Feedstock Testing
Section 7	Economic Analysis
Section 8	Demonstration and Resource Plantings
Section 9	Propagation Project
Section 10	Project Administration
Appendices	

Contents of this Section

Section 8 Demonstration And Resource Plantings 5

8.1 Background.. 5

8.2 Demonstration plantings.. 6

8.3 Resource plantings.. 38

8.4 References 48

Section 8 Demonstration And Resource Plantings

8.1 Background

The third objective of the Search Project, partly funded by the Natural Heritage Trust's Bushcare Program, was to explore the industry potential of native woody perennial plant species by undertaking large-scale planting of selected species on farm land. The intention was to benefit from farmer innovation and experience, and test new species for their commercial suitability. The species to explore were selected in the first two sections of the Search Project.

This objective had two parts:

- to establish a preliminary selection of subjectively chosen species in **demonstration** trials, and
- to plan and commence building new biomass industries, by developing a planted **resource**, utilising best practice and planting design for highly prospective species.

To meet the first part of this objective, a large suite of demonstration plantings was established in the early stages of the Search project, in 2000 and 2001, followed by a smaller number of plantings in later years.

Work on the second part of the objective - larger scale development plantings that could contribute to the development of a pre-commercial resource of promising species - started in 2001 and expanded in 2002 and 2003.

In the following pages, the work performed on each part of the objective is described sequentially, from the first plantings in 2000 through to those established in 2003.

A summary of 'demonstration' and 'resource' plantings is contained in Table 1.

Table 1. Summary of demonstration and resource plantings.

Year	Demonstration planting sites	Resource plantings		
		Seedlings planted	Taxa	Participating landholders
2000	75	-	-	-
2001	20	100,000	8	17
2002	4	1,901,000	27	161
2003	8	4,316,000	136	475
Overall	**107**	**6,317,000**	**158**	**610**

Work in both planting programs was made more difficult by the annual funding timetable and associated negotiations coinciding with the planning for seed collection and nursery orders.

8.2 Demonstration plantings

8.2.1 Overview

Demonstration plantings provided an opportunity to fast-track the process of industry development, by generating information on the field performance of prospective species concurrently with detailed investigation of their other attributes, such as their suitability as feedstocks for particular products. A disadvantage of this approach was that species selected for demonstration plantings would not necessarily turn out to be the most prospective when their feedstock attributes were tested. However, even though many of the species used in these plantings may not be selected for further commercial development, they still provide useful general information about propagation techniques, site selection, appropriate layouts, and plant productivity and water use.

Because of the initial uncertainty about which species were most prospective, a wide range of genera and species were included in the early plantings. As the project progressed, a number of additional demonstration plantings were established, using updated species lists as new information became available.

8.2.2 2000 demonstration planting

8.2.2.1 Species selected in 2000

A panel of experts and experienced revegetation practitioners selected species to plant in the year 2000 demonstration plantings. Three different categories of species were included, based on crop archetypes (see Section 2.8.5). They were:

- **Short-cycle Phase** (or "**seeder**") species - typically fast growing, obligate seeders without the ability to resprout if the above ground part of the plant is removed.
- **Short-cycle Coppice** (or "**sprouter**") species - capable of coppicing, or re-sprouting if the above ground part of the plant is removed.
- **Long-cycle Timber** species - likely to be suited to long, conventional harvest cycles for solid wood products.

In total, 46 species from 12 genera were selected for the year 2000 plantings, including 18 **phase** (or "seeder") species, 15 **coppice** (or "sprouter") species and 14 **timber** species (Table 2, Table 3 and Table 4. *Eucalyptus camaldulensis* was used in both coppice and long-cycle plantings.

For very diverse species, such as *Acacia acuminata*, *A. microbotrya*, *A. saligna*, *Melaleuca acuminata, M. lateriflora and M. uncinata*, several sub-species, or other distinct forms were included. As well, up to three different provenances of each species or form were tested. The combination of species, sub-species, forms and provenances gave a total of 137 separate entities to plant.

Table 2. Phase species included in demonstration plantings - 2000.

Phase species	Provenances
Acacia acuminata (broad phyllode form)	3
Acacia acuminata (narrow phyllode form)	3
Acacia acuminata subsp. *Oldfieldii*	2
Acacia anthochaera	3
Acacia coolgardiensis subsp. *effusa*	3
Acacia inceana subsp. *Conformis*	3
Acacia redolens	1
Acacia resinimarginea	3
Alyogyne huegelii	2
Codonocarpus cotinifolius	3
Dodonaea viscosa	3
Gyrostemon ramulosus	2
Hakea francisiana	3
Hakea laurina	3
Hakea minyma	1
Hakea multilineata	3
Hakea petiolaris	3
Xylomelum angustifolium	3

Table 3. Coppice species included in demonstration plantings - 2000.

Coppice species	Provenances
Acacia cyclops	1
Acacia microbotrya var. *borealis*	3
Acacia microbotrya var. *microbotrya*	3
Acacia murrayana	3
Acacia rostellifera	1
Acacia saligna (Coastal form)	3
Acacia saligna (Wheatbelt form)	3
Acacia victoriae	3
Eucalyptus angustissima	1
Eucalyptus camaldulensis	3
Eucalyptus horistes	1
Eucalyptus loxophleba subsp. *lissophloia*	1
Melaleuca acuminata subsp. *acuminata*	3
Melaleuca acuminata subsp. *websteri*	3
Melaleuca lanceolata	3
Melaleuca lateriflora subsp. *lateriflora*	3
Melaleuca lateriflora subsp. *acutifolia*	2
Melaleuca uncinata – Variant 6 Wongan Hills	3
Melaleuca uncinata – Variant 9 Southern Laterite	3
Melaleuca vinnula	3

Table 4. Timber species included in demonstration plantings - 2000.

Timber species	Provenances
Acacia pruinocarpa	3
Allocasuarina huegeliana	3
Casuarina obesa	2
Eucalyptus astringens	3
Eucalyptus brockwayi	3
Eucalyptus camaldulensis	3
Eucalyptus capillosa	2
Eucalyptus kondininensis	3
Eucalyptus longicornis	3
Eucalyptus occidentalis	2
Eucalyptus ornata	2
Eucalyptus salmonophloia	3
Eucalyptus salubris	3
Eucalyptus urna	3

8.2.2.2 Sites chosen in 2000

Planting sites were selected in each of the four Interim Biogeographic Regionalisation of Australia (IBRA) regions (Thackway and Cresswell 1995) encompassing the WA wheatbelt (Figure 1) - Geraldton Sandplains (GS), Avon Wheatbelt (AW), Mallee (MAL) and Esperance Plains (ESP). Avon Wheatbelt was subdivided into northern (NAW) and southern (SAW) sub-regions due to its size and geomorphic variability.

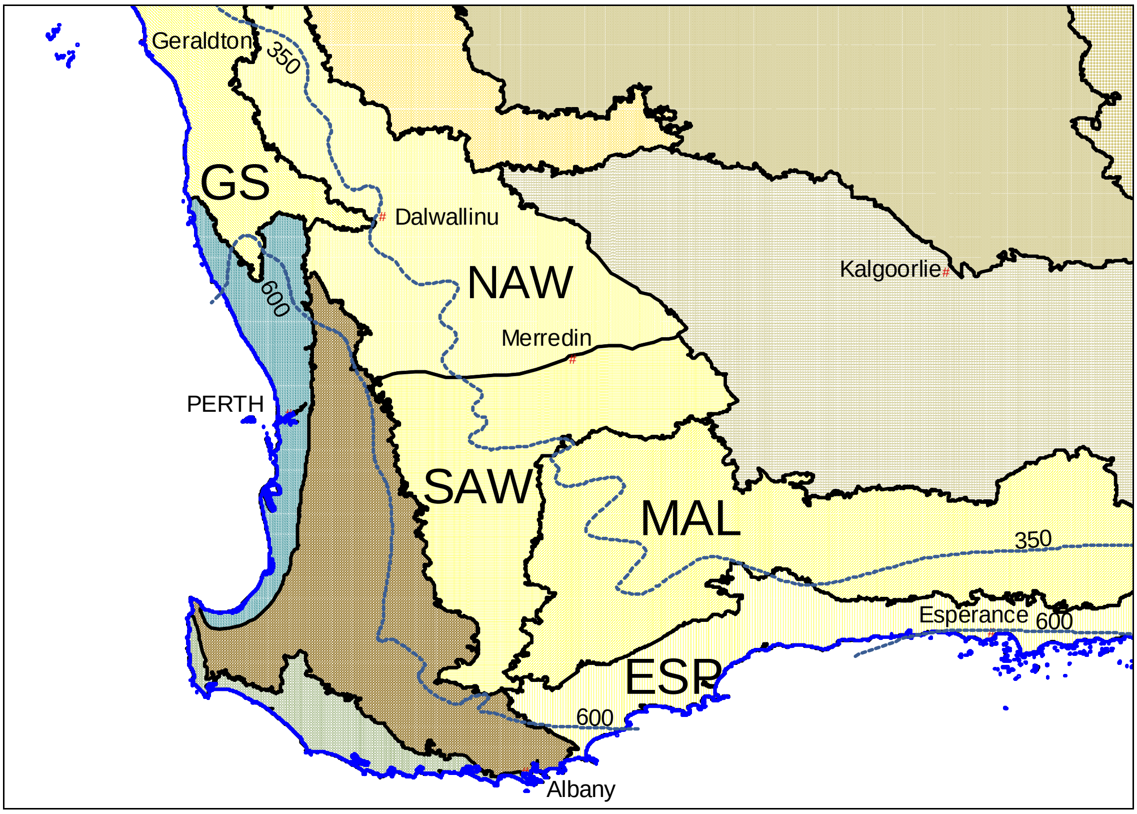


Figure 1. Interim Biogeographic Regionalisation of Australia (IBRA) bioregions encompassing the Western Australian wheatbelt.

Within each bioregion, five site categories were chosen, to represent the range of landscape types found in the Western Australia wheatbelt. Two site categories were high in the landscape (light soil and heavy soil), and three were low in the landscape (light soil, heavy soil, and saline/seepage areas).

Landowners were approached by project staff and district landcare coordinators to find a range of suitable sites. These were inspected in the first quarter of 2000, after which 75 sites were selected on 30 farms. Representative sites were found for each combination of plant type, site and IBRA region (Table 5), giving a wide coverage across the wheatbelt zone of south western Australia (Figure 2).

Table 5. Categories of demonstration site established in 2000.

IBRA Region	Site Category	Species Category		
		Phase (P)	Coppice (C)	Timber (T)
Geraldton Sandplains (GS)	Upslope Light (UL)	GS UL P	GS UL C	GS UL T
	Upslope Heavy (UH)	GS UH P	GS UH C	GS UH T
	Downslope Light (DL)	GS DL P	GS DL C	GS DL T
	Downslope Heavy (DH)	GS DH P	GS DH C	GS DH T
	Seepage/Salt (SS)	GS SS P	GS SS C	GS SS T
Avon Wheatbelt North (AN)	Upslope Light (UL)	AN UL P	AN UL C	AN UL T
	Upslope Heavy (UH)	AN UH P	AN UH C	AN UH T
	Downslope Light (DL)	AN DL P	AN DL C	AN DL T
	Downslope Heavy (DH)	AN DH P	AN DH C	AN DH T
	Seepage/Salt (SS)	AN SS P	AN SS C	AN SS T
Avon Wheatbelt South (AS)	Upslope Light (UL)	AS UL P	AS UL C	AS UL T
	Upslope Heavy (UH)	AS UH P	AS UH C	AS UH T
	Downslope Light (DL)	AS DL P	AS DL C	AS DL T
	Downslope Heavy (DH)	AS DH P	AS DH C	AS DH T
	Seepage/Salt (SS)	AS SS P	AS SS C	AS SS T
Mallee (ML)	Upslope Light (UL)	ML UL P	ML UL C	ML UL T
	Upslope Heavy (UH)	ML UH P	ML UH C	ML UH T
	Downslope Light (DL)	ML DL P	ML DL C	ML DL T
	Downslope Heavy (DH)	ML DH P	ML DH C	ML DH T
	Seepage/Salt (SS)	ML SS P	ML SS C	ML SS T
Esperance Plains (ES)	Upslope Light (UL)	ES UL P	ES UL C	ES UL T
	Upslope Heavy (UH)	ES UH P	ES UH C	ES UH T
	Downslope Light (DL)	ES DL P	ES DL C	ES DL T
	Downslope Heavy (DH)	ES DH P	ES DH C	ES DH T
	Seepage/Salt (SS)	ES SS P	ES SS C	ES SS T

(green)	Biomass yield measured in 2003.
(orange)	Not measured in 2003 due to poor seedling survival.

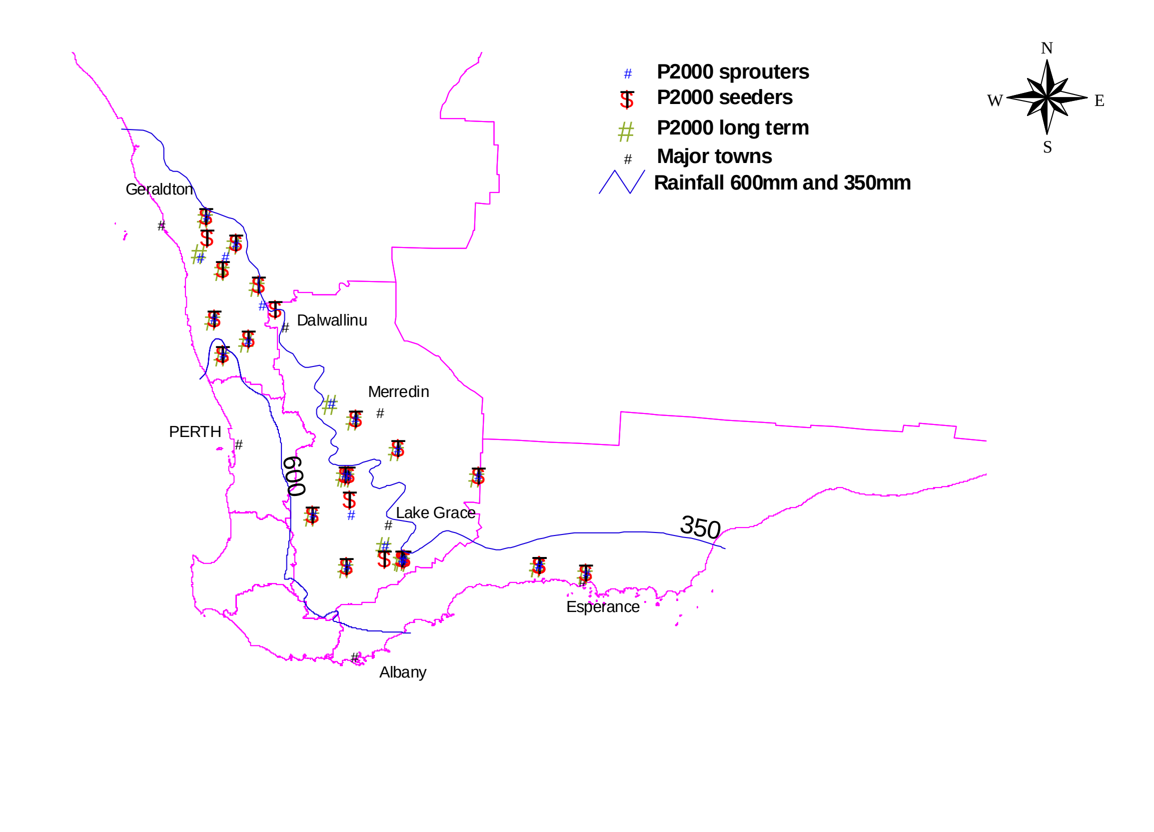


Figure 2. **Demonstration sites established in 2000.**

8.2.2.3 Plant establishment in 2000

Seed for the demonstration plantings was collected from wild populations between September 1999 and January 2000. Specimen information from FloraBase (Western Australian Herbarium 1998) was used to help find suitable populations from which to collect seed. Vouchers were collected from all plant specimens that were sampled and were lodged with the WA Herbarium. Seed was used to produce containerised seedlings at CALM's Narrogin nursery, which is experienced in the propagation of species not yet in common use.

Planting configurations amenable to quantitative assessment were developed for each category of plant type. In all cases, a randomised block design with 3 replications was used. "Phase" species were planted in blocks of 56 plants at a spacing of 3 metres between rows and 1.5 metres within rows. "Coppice" species were planted in a "hedgerow" configuration, consisting of 20 plants arranged in two rows spaced 2 metres apart, with seedlings planted 1.5 metres apart within the row. A distance of 5 metres separated each twin row hedge. "Timber" species were planted in three-row blocks of 30 plants at a spacing of 3 metres between rows and 2 metres within rows.

Participating landowners assisted with establishment by undertaking ground preparation and weed control. Ground preparation methods were dictated by the availability of equipment, but in most cases consisted of constructing rip lines to a depth of 400-600 mm. In some cases, the lines were also mounded. The seedlings were planted by hand between June and July 2000. All plots were labelled with engraved aluminium tags attached to steel posts.

8.2.2.4 Monitoring results from 2000 plantings

The performance of the demonstration plantings was monitored during the course of the project. Initial survival assessments were conducted in summer 2000/01. There was considerable variation in survival across sites and in some cases seedling deaths were significant. Factors contributing to seedling mortality included below average winter rainfall, a locust plague in spring 2000 and very small or poor quality seedlings for some species.

There was little or no prior experience in nursery production methods for many of the species selected for these plantings. Challenges included germinating the seed effectively and applying a suitable growing regime to produce seedlings of a desirable size by the planting season. Some species were not sown as early as desired due to late delivery of seed. Better seedling quality was attained for species that are more commonly grown, such as those in the *Eucalyptus* genus. The lower than expected seedling survival affected subsequent monitoring and evaluation of the 2000 demonstration plantings.

Plots were measured in winter 2002, at age 2 years. Individual tree heights were measured in plots with an average height greater than 1.3m, while an average tree height was estimated for the remainder. Sites where seedling deaths had been extensive (greater than approximately 50% for many species) were excluded from monitoring.

In winter 2003, selected plots were re-measured (Table 5). For plots with an average height greater than 1.5m, individual tree heights were measured, as well as crown width. Two width measurements were made parallel and perpendicular to the direction of the rip lines respectively. For plots with an average height less than 1.5m, estimates of the average or “typical” plant height and crown width were recorded.

Crown volume index (CVI)

Monitoring data collected in 2003 was analysed to provide an assessment of species performance across different site types. Plant height and width measurements were multiplied to calculate crown volume indices (CVI) for each measured plant, which were then averaged for each measured plot (Table 6, Table 8 and Table 10). CVI provides an estimate of above ground biomass yield. Each plot was given a ranking, based on its mean plant CVI. These rankings were averaged across sites to identify strongly performing species, and across species to identify the best sites.

Site productivity index (SPI)

A site productivity index (SPI) was also calculated by multiplying the plot mean CVI by the number of stems per square metre originally planted and then multiplying this figure by the percentage seedling survival in the plot (Table 6, Table 8 and Table 10). The SPI rankings of different species across different sites were then compared.

SPI is a better measure of plot productivity than CVI, as it allows for the effect of seedling survival percentage on plot biomass. It is assumed that seedlings that survived in plots with low overall survival had greater access to moisture and nutrients, allowing them to produce more biomass per plant.

Analysis of variance

A two way analysis of variance (ANOVA) of site and taxon mean SPIs was also performed on measurements from coppice and timber plots. The results of these analyses were compared with the CVI and SPI rankings. The resolution of the ANOVA was constrained by several factors. First, for some demonstration plantings only one of the several available replicates was measured. Some plots had been destroyed by locust attack or stock that had breached fences. Second, because many taxa were not planted on every demonstration site, yields had to be estimated for sites on which particular taxa were not planted, using SPI means from sites where they had been planted. This had the effect of smoothing out potential differences in a species performance on different sites. However, the results of the ANOVA were similar to those produced by the qualitative ranking methods (Table 7, Table 9, Table 11 and Table 12). Importantly, the strongest performing cluster of species in the ANOVA coincided with the best species identified using the qualitative ranking methods.

Figure 3. 3¾-year-old *Acacia saligna* at Blake's, Katanning.

Figure 4. 3¾-year-old *Hakea francisiana* and melaleucas at Blake's, Katanning.

Table 6. Coppice species planted 2000 - Site Productivity Index (SPI) and Crown Volume Index (CVI). Data collected winter 2003.

Coppice species	Mean SPI (m^3/m^2)	Mean CVI (m^3/plant)	Rank SPI	Rank CVI
A. saligna (wheatbelt) P3	1.546	10.558	1	1
A. saligna (wheatbelt) P2	1.101	8.554	2	2
E. camaldulensis P1	1.079	6.740	3	4
E. camaldulensis P2	1.037	6.879	4	3
A. saligna (wheatbelt) P1	0.909	6.403	5	5
E. loxophleba subsp. *lissophloia*	0.724	4.706	6	7
A. saligna (coastal) P1	0.627	4.814	7	6
A. microbotrya var. *borealis P1*	0.600	3.738	8	8
A. microbotrya var. *borealis* P3	0.513	3.188	9	10
A. saligna (coastal) P3	0.490	3.360	10	9
A. microbotrya var. *borealis* P2	0.435	3.076	11	11
E. camaldulensis P3	0.272	1.896	12	13
M. lateriflora subsp. *lateriflora* P1	0.265	1.557	13	16
A. microbotrya var. *microbotrya* P2	0.240	2.411	14	12
A. microbotrya var. *microbotrya* P3	0.236	1.772	15	15
M. lanceolata P2	0.206	1.302	16	18
M. lateriflora var. *acutifolia* P1	0.205	1.233	17	19
M. lateriflora var. *acutifolia* P2	0.204	1.139	18	21
M. uncinata variant6 P3	0.195	1.821	19	14
M. acuminata var. *websteri* P3	0.165	1.043	20	23
M. lanceolata P1	0.163	1.102	21	22
A. victoriae P3	0.157	0.925	22	24
A. murrayana P1	0.146	1.186	23	20
M. lanceolata P?	0.144	0.918	24	26
E. horistes	0.131	0.881	25	27
A. murrayana P2	0.110	0.924	26	25
M. uncinata variant 6 P2	0.104	0.793	27	30
M. lateriflora subsp. *lateriflora* P3	0.101	0.845	28	28
A. microbotrya var. *microbotrya* P1	0.098	0.738	29	31
A. murrayana P3	0.088	1.342	30	17
A. saligna (coastal) P2	0.086	0.795	31	29
M. lateriflora subsp. *lateriflora* P2	0.079	0.591	32	33
M. vinnula P2	0.077	0.475	33	37
E. angustissima	0.071	0.605	34	32
M. acuminata var. *websteri* P1	0.069	0.490	35	36
M. uncinata variant 6 P1	0.069	0.443	36	38
M. acuminata var. *websteri* P2	0.067	0.515	37	35
A. victoriae P2	0.066	0.545	38	34
M. vinnula P1	0.066	0.442	39	39
M. uncinata variant 9 P2	0.058	0.402	40	40
M. vinnula P3	0.047	0.373	41	41
M. uncinata variant 9 P3	0.045	0.362	42	42
M. uncinata variant 9 P1	0.024	0.167	43	43
A. victoriae P1	0.005	0.089	44	44

No data was available for Acacia cyclops, A. rostellifera or Melaleuca acuminata subsp acuminata.

Table 7. Coppice species planted 2000 - Analysis of variance of mean site and taxon Site Productivity Indices (SPI). Data collected winter 2003.

Coppice species	Mean SPI ANOVA (m^3/m^2)	Std Error	Rank
A. saligna (wheatbelt) P3	1.141	0.1197	**1**
A. saligna (wheatbelt) P2	1.091	0.1197	**2**
E. camaldulensis P1	1.079	0.1051	**3**
E. camaldulensis P2	1.067	0.1197	**4**
A. saligna (wheatbelt) P1	0.899	0.1197	**5**
E. loxophleba lissophloia	0.724	0.1051	**6**
A. saligna(coastal) P1	0.661	0.2263	**7**
A. microbotrya var. *borealis* P1	0.632	0.1424	**8**
A. microbotrya var. *borealis* P3	0.545	0.1424	**9**
A. saligna (coastal) P3	0.525	0.2263	**10**
A. microbotrya var. *borealis* P2	0.420	0.1297	**11**
A. microbotrya var. *microbotrya* P3	0.402	0.2262	**12**
E. camaldulensis P3	0.358	0.1422	**13**
A. microbotrya var. *microbotrya* P2	0.311	0.1593	**14**
M. lateriflora P1	0.295	0.1848	**15**
A. microbotrya var. *microbotrya* P1	0.264	0.2262	**16**
E. angustissima	0.264	0.3207	**17**
A. murrayana P1	0.239	0.3199	**18**
M. lateriflora var. *acutifolia* P1	0.236	0.1118	**19**
M. uncinata variant 6 P3	0.225	0.1197	**20**
M. lanceolata P2	0.224	0.1118	**21**
A. murrayana P2	0.219	0.1843	**22**
M. lateriflora var. *acutifolia* P2	0.207	0.1117	**23**
M. lanceolata P1	0.163	0.1051	**24**
A. victoriae P3	0.158	0.1845	**25**
M. lanceolata P?	0.144	0.1051	**26**
M. vinnula P2	0.138	0.1296	**27**
M. acuminata var. *websteri* P3	0.136	0.1051	**28**
M. lateriflora P3	0.131	0.1848	**29**
A. saligna (coastal) P2	0.121	0.2263	**30**
E. horistes	0.116	0.1297	**31**
M. lateriflora P2	0.109	0.1848	**32**
M. uncinata variant 6 P1	0.108	0.1197	**33**
M. uncinata variant 6 P2	0.104	0.1051	**34**
A. murrayana P3	0.101	0.2261	**35**
M. uncinata variant 9 P2	0.090	0.1118	**36**
M. acuminata websteri P2	0.085	0.1118	**37**
M. uncinata variant 9 P3	0.076	0.1118	**38**
M. acuminata var. *websteri* P1	0.069	0.1051	**39**
M. vinnula P1	0.062	0.1117	**40**
M. vinnula P3	0.047	0.1051	**41**
M. uncinata variant 9 P1	0.038	0.1198	**42**
A. victoriae P1	0.015	0.1424	**43**
A. victoriae P2	-0.013	0.1424	**44**

No data was available for Acacia cyclops, A. rostellifera or A. acuminata subsp. acuminata.

Table 8. Timber species planted 2000 - Site Productivity Index (SPI) and Crown Volume Index (CVI). Data collected winter 2003.

Timber species	Mean SPI (m^3/m^2)	Mean CVI (m^3/plant)	Rank Mean SPI	Rank Mean CVI
C. obesa P1	0.881	5.495	1	3
E. camaldulensis P3	0.842	6.193	2	1
E. camaldulensis P1	0.746	5.638	3	2
E. camaldulensis P2	0.660	5.412	4	4
C. obesa P2	0.633	4.961	5	5
E. occidentalis P1	0.596	4.791	6	7
E. occidentalis P2	0.558	4.794	7	6
E. astringens P2	0.433	3.712	8	9
E. astringens P3	0.427	3.302	9	12
E. ornata P1	0.424	3.946	10	8
E. kondininensis P3	0.393	2.873	11	17
E. capillosa P2	0.364	3.578	12	11
E. capillosa P1	0.354	2.877	13	16
A. huegeliana P2	0.343	2.955	14	15
E. kondininensis P2	0.328	2.673	15	19
E. ornata P2	0.325	3.587	16	10
A. huegeliana P1	0.306	3.163	17	13
E. astringens P1	0.302	2.865	18	18
E. longicornis P2	0.290	1.960	19	27
A. huegeliana P3	0.284	2.493	20	20
E. salubris P1	0.283	1.982	21	26
E. urna P2	0.261	2.379	22	22
E. longicornis P3	0.250	2.379	23	21
E. urna P1	0.235	2.001	24	25
E. urna P3	0.235	3.048	25	14
E. longicornis P1	0.225	1.776	26	30
E. kondininensis P1	0.207	2.035	27	23
E. salubris P2	0.204	1.780	28	29
E. brockwayi P1	0.187	1.951	29	28
E. brockwayi P3	0.176	2.027	30	24
E. salmonophloia P2	0.165	1.383	31	31
E. salubris P3	0.150	1.172	32	33
E. brockwayi P2	0.119	1.270	33	32
E. salmonophloia P3	0.096	0.857	34	34
E. salmonophloia P1	0.083	0.636	35	35

No data was available for *Acacia pruinocarpa*.

Table 9. Timber species planted 2000 - Analysis of variance of mean site and taxon Site Productivity Indices (SPI). Data collected winter 2003.

Timber species	Mean SPI ANOVA (m^3/m^2)	Std Error	Rank
C. obesa P1	0.770	0.1487	1
E. camaldulensis P3	0.731	0.1487	2
E. camaldulensis P1	0.635	0.1487	3
E. occidentalis P1	0.596	0.1033	4
E. occidentalis P2	0.558	0.1033	5
E. camaldulensis P2	0.549	0.1487	6
C. obesa P2	0.522	0.1487	7
E. astringens P2	0.484	0.1282	8
E. astringens P3	0.477	0.1282	9
E. ornata P1	0.475	0.1282	10
E. salubris P1	0.444	0.1824	11
E. capillosa P2	0.415	0.1282	12
E. capillosa P1	0.405	0.1282	13
E. kondininensis P3	0.393	0.1033	14
E. ornata P2	0.376	0.1282	15
E. salubris P2	0.366	0.1824	16
E. astringens P1	0.353	0.1282	17
A. huegeliana P2	0.343	0.1033	18
E. kondininensis P2	0.328	0.1033	19
E. salmonophloia P2	0.327	0.1824	20
E. urna P2	0.312	0.1282	21
E. salubris P3	0.312	0.1824	22
E. brockwayi P1	0.298	0.1487	23
E. longicornis P2	0.288	0.1136	24
E. brockwayi P3	0.287	0.1487	25
E. urna P3	0.286	0.1282	26
E. urna P1	0.286	0.1282	27
A. huegeliana P3	0.261	0.1136	28
E. salmonophloia P3	0.258	0.1824	29
E. longicornis P3	0.248	0.1136	30
E. salmonophloia P1	0.245	0.1824	31
E. brockwayi P2	0.230	0.1487	32
A. huegeliana P1	0.226	0.1277	33
E. longicornis P1	0.223	0.1136	34
E. kondininensis P1	0.207	0.1033	35
A. pruinocarpa P1, P2, P3	No Data	No Data	-

Table 10. Phase species planted 2000 - Site Productivity Index (SPI) and Crown Volume Index (CVI). Data collected winter 2003.

Phase species	Mean SPI (m^3/m^2)	Mean CVI (m^3/plant)	Rank Mean SPI	Rank Mean CVI
Acacia saligna (coastal) M3 – 2001	0.627	6.706	**1**	1
Acacia saligna (coastal) M1 – 2001	0.378	5.304	**2**	2
Acacia anthochaera P2	0.308	2.686	**3**	6
A. acuminata (narrow phyllode) P3	0.293	1.990	**4**	9
Hakea francisiana P1	0.260	2.971	**5**	4
Acacia anthochaera P3	0.259	1.978	**6**	10
Hakea francisiana P3	0.238	3.124	**7**	3
Hakea petiolaris P1	0.228	1.857	**8**	13
Hakea multilineata P1	0.208	1.626	**9**	16
Hakea multilineata P2	0.195	2.017	**10**	8
Hakea petiolaris P2	0.188	1.738	**11**	15
Acacia anthochaera P1	0.158	1.288	**12**	19
A. acuminata (narrow phyllode) P1	0.152	1.062	**13**	22
A. acuminata (narrow phyllode) P2	0.135	1.623	**14**	17
Hakea multilineata P3	0.134	1.609	**15**	18
Hakea petiolaris P3	0.130	1.901	**16**	12
A. acuminata subsp. *oldfieldii* P2	0.124	2.100	**17**	7
A. acuminata (broad phyllode) P3	0.113	1.800	**18**	14
Dodonaea viscosa P3	0.104	0.648	**19**	26
A. acuminata (broad phyllode) P1	0.086	1.166	**20**	20
Acacia inceana subsp. *conformis* P3	0.078	0.571	**21**	30
Hakea francisiana P2	0.069	2.847	**22**	5
Acacia inceana subsp. *conformis* P2	0.064	0.296	**23**	32
Hakea minyma	0.049	0.824	**24**	23
A. acuminata subsp. *oldfieldii* P1	0.044	0.582	**25**	29
Dodonaea viscosa P2	0.042	0.618	**26**	27
Acacia inceana subsp. *conformis* P1	0.033	0.594	**27**	28
Acacia resinimarginea P3	0.026	1.120	**28**	21
Dodonaea viscosa P1	0.021	0.818	**29**	24
Gyrostemon ramulosus P2	0.008	1.975	**30**	11
A. coolgardiensis subsp. effusa P1	0.007	0.213	**31**	33
Acacia resinimarginea P1	0.005	0.740	**32**	25
Xylomelum angustifolium P1	0.002	0.317	**33**	31
Gyrostemon ramulosus P1	0.001	0.070	**34**	34
A. acuminata (broad phyllode) P2	-	No Data	-	-
A. coolgardiensis subsp. effusa P2, P3	-	No Data	-	-
Acacia redolens	-	No Data	-	-
Acacia resinimarginea P2	-	No Data	-	-
Alyogyne huegelii P1, P2	-	No Data	-	-
Brachychiton gregorii P1, P2, P3	-	No Data	-	-
Codonocarpus cotinifolius P1, P2, P3	-	No Data	-	-
Hakea laurina P1, P2, P3	-	No Data	-	-
Hakea suberea	-	No Data	-	-
Xylomelum angustifolium P2, P3	-	No Data	-	-

Note: Shaded species (*A. saligna*), planted a year later, in 2001 as an infill species, is reported here for comparison.

Results – coppice species

See Table 6 and Table 7. Two species were consistently the strongest performers across a range of sites: *Acacia saligna* (wheatbelt provenances 1, 2 and 3) and *Eucalyptus camaldulensis* (provenances 1 and 2). For both these species, plot mean CVIs were as high as 20 m^3/plant range on the most productive site. The next highest ranking taxa included *Eucalyptus loxophleba* subsp. *lissophloia*, *Acacia microbotrya* var. *borealis* (provenances 1, 2 and 3) and *Acacia saligna* (coastal provenances 1 and 3). Collectively, these 11 taxa accounted for 72% of the total biomass of 558m^3 from coppice plots used in this analysis. *Melaleuca* species consistently grew slowly and were consequently ranked low.

Results - timber species

See Table 8 and Table 9. The better performing species in the timber plantings had biomass yields comparable with those in the coppice plantings. Two species were consistently strong performers across a range of sites: *Eucalyptus camaldulensis* (provenances 1, 2 and 3) and *Eucalyptus occidentalis* (provenances 1 and 2). For both these species, mean CVIs were as high as 8-10 m^3/plant on better sites. *Casuarina obesa* provenances 1 and 2 were not widely planted but produced very high yields on one site, with mean CVIs of 10-12 m^3/plant. Collectively, these 7 taxa accounted for 35% of the total biomass of 105m^3 from timber plots used in this analysis. Other species that performed well were *Eucalyptus astringens* (provenances 2 and 3) and *Eucalyptus ornata* (provenance 1).

Results – phase species

See Table 10. The overall performance of the phase species was poor in comparison with species used in the coppice and timber demonstrations. The superior performance of *Acacia saligna* (coastal form), which was used to infill some failed plots in 2001, highlights this observation. The *Acacia saligna* seedlings were the largest plants in the analysis despite being twelve months younger.

Of the phase species planted in 2000, *Hakea francisiana* consistently had the largest plot average CVIs, in the 2.8-3.1 m^3/plant range. However, survival percentages for this species were often poor resulting in slightly lower SPI rankings. Other highly ranked species, for both SPI and CVI values, included *Acacia anthochaera*, *Hakea multilineata* and *Acacia acuminata* (narrow leaf form).

Since many phase species were either absent or poorly represented in the sites that were measured, no conclusions can be made on the performance of these species. Poor seedling quality may have contributed to an undeserved negative bias against some of the less commonly cultivated genera. For example, the few individuals of *Gyrostemon ramulosus* and *Codonocarpus cotinifolius* that survived the establishment phase have grown well, suggesting that high biomass yields may be possible from these species.

Site variation

Variation in mean biomass production between sites was considerable (Table 11 and Table 12). An assortment of factors such as rainfall, soil type, soil moisture storage, seedling quality, site preparation method, locust attack and effectiveness of weed control may have affected how different species performed. There was some evidence that specific taxa preferred particular site types, particularly for a number of the timber species. However, many species tended to maintain their relative ranking across different sites (Table 15 and Table 16). No detailed investigations of the soil profile at the demonstration sites were made. However the more productive sites would be expected to have relatively deep soil profiles with an abundance of plant-available water. Rainfall data for nearby towns was obtained from the Bureau of Meteorology and compared with the site rankings (Table 17). The tentative conclusion from this assessment is that sites with light textured soil and higher annual rainfall tended to produce greater biomass than sites with heavy textured soil and lower annual rainfall.

Table 11. Performance of coppice species on different sites, using ANOVA analysis.

Site Name	Mean SPI (m^3/m^2)	Standard Error	Rank
AN DL C	0.569	0.0712	1
AS DH C	0.462	0.0686	2
AS SS C	0.450	0.0687	3
AN UH C	0.387	0.0613	4
AS UL C	0.343	0.0624	5
GS SS C	0.289	0.0675	6
GS UH C	0.225	0.0563	7
ML SS C	0.126	0.0650	8
AS UH C	0.016	0.0564	9
MEAN	**0.3184**		

Table 12. Performance of timber species on different sites, using ANOVA results.

Site Name	Mean SPI (m^3/m^2)	Std Error	Rank
AS SS T	0.800	0.0709	1
GS SS T	0.514	0.0532	2
AS UL T	0.374	0.0594	3
AN DH T	0.270	0.0502	4
AS UH T	0.176	0.0479	5
ML SS T	0.172	0.0709	6
MEAN	**0.384**		

Other observations

The ability to compare the performance of different species and sites was compromised to some extent by the wide variation in seedling survival between plots. Despite this limitation, the application of the various analytical methods described above did allow strongly and poorly performing species to be separated.

Biomass production in the WA wheatbelt is limited by moisture availability on most sites. The ability of plants to access and rapidly utilise soil moisture is of critical importance for the development of profitable biomass industries. In this respect, the outstanding species in the demonstration plantings provide an initial glimpse of the potential for rapid conversion of moisture into woody biomass. The genetic resource within strongly performing species such as *Acacia saligna* and *Eucalyptus camaldulensis* is likely to be important for future plant crop development.

Table 13. Relative performance of measured coppice and timber demonstration sites. Data collected winter 2003.

Site	Mean SPI (m^3/m^2)	Mean CVI (m^3)	Mean SPI from ANOVA (m^3/m^2)	Std Error	Rank SPI	Rank CVI	Rank ANOVA
AS SS T	0.846	6.359	0.800	0.0709	1	1	1
AN DL C	0.725	4.863	0.569	0.0712	2	2	2
GS SS T	0.543	4.223	0.514	0.0532	3	3	3
AS DH C	0.514	3.088	0.462	0.0686	4	6	4
AS SS C	0.488	3.179	0.450	0.0687	5	5	5
AN UH C	0.370	2.473	0.387	0.0613	6	7	6
AS UL T	0.352	3.860	0.374	0.0594	7	4	7
GS SS C	0.333	2.411	0.289	0.0675	8	8	9
AS UL C	0.303	2.231	0.343	0.0624	9	9	8
AN DH T	0.236	1.830	0.270	0.0502	10	11	10
ML SS T	0.217	1.882	0.172	0.0709	11	10	13
GS UH C	0.176	1.307	0.225	0.0563	12	13	11
ML SS C	0.140	1.118	0.126	0.0650	13	14	14
AS UH T	0.138	1.440	0.176	0.0479	14	12	12
AS UH C	0.045	0.442	0.016	0.0564	15	15	15

Table 14. Relative performance of measured phase demonstration sites. Data collected winter 2003.

Site Name	Mean SPI (m^3/m^2)	Mean CVI (m^3)	Rank SPI	Rank CVI
GS SS P	0.326	2.843	1	1
AS SS P	0.228	2.359	2	2
GS UH P	0.213	2.079	3	3
AS UL P	0.077	2.003	4	4
AN DH P	0.046	0.694	5	5

Figure 5. 2-year-old *Allocasuarina huegeliana* at Johnson's, Dandaragan. (Photo: Jerome Carslake)

Table 15. Variation in coppice species rankings across measured demonstration sites.

Coppice species	Site Rank / Mean SPI Rank	1 AN DL	2 AS DH	3 AS SS	4 AN UH	5 GS SS	6 AS UL	7 GS UH	8 ML SS	9 AS UH
A. saligna(wheatbelt) P3	1	1	3	1	6	3			9	17
A. saligna (wheatbelt) P2	2	4	2	2	1	5			2	12
E. camaldulensis P1	3	2	4	3	7	2	3	1	5	5
E. camaldulensis P2	4	3		6		1	1	2	1	2
A. saligna (wheatbelt) P1	5	5	1	4	10	4			14	15
E. loxophleba lissophloia	6	6	7	5	5	6	2	3	8	1
A. saligna (coastal) P1	7						6	5		
A. microbotrya var. *borealis* P1	8		5		8		5	8		3
A. microbotrya var. *borealis* P3	9		6		3		7	6		8
A. saligna (coastal) P3	10						4	17		
A. microbotrya var. *borealis* P2	11	8	8		2		17	10		7
E. camaldulensis P3	12			7			15	4	10	11
M. lateriflora P1	13			9		11			6	
A. microbotrya var. *microbotrya* P2	14		18			7		12		6
A. microbotrya var. *microbotrya* P3	15					8				18
M. lanceolata P2	16	7		8	26	17	14	11	3	13
M. lateriflora var. *acutifolia* P1	17		14	11	9	14	13	19	11	4
M. lateriflora var. *acutifolia* P2	18	10	16	12	4	13		23	12	22
M. uncinata variant 6 P3	19	18		14		15		20	27	24
M. acuminata var. *websteri* P3	20	11	10	21	11	18	16	14	13	20
M. lanceolata P1	21	9	9	13	25	10	10		7	32
A. victoriae P3	22				12			34		
A. murrayana P1	23							13		
M. lanceolata P???	24	12	13	10	24	16	18	22	4	9
E. horistes	25	21	12				9	7		14
A. murrayana P2	26				18			9		16
M. uncinata variant 6 P2	27	13	15	19	13	26	19	29	19	31
M. lateriflora P3	28			18		12			18	
A. microbotrya var. *microbotrya* P1	29					9				26
A. murrayana P3	30				21			16		
A. saligna (coastal) P2	31						12	24		
M. lateriflora P2	32			16		20			20	
M. vinnula P2	33			17	14		23	30	28	28
E. angustissima	34								16	
M. acuminata var. *websteri* P1	35	20	11	23	27	21	24	18	15	21
M. uncinata variant 6 P1	36	16			15	25	11	27	21	10
M. acuminata var. *websteri* P2	37	14		25	20	23	20	15	17	19
A. victoriae P2	38	22	22		19		8	32		
M. vinnula P1	39	15	20	20	16		26	26	25	23
M. uncinata variant 9 P2	40		17	15	23	19	25	25	22	25
M. vinnula P3	41	17	21	24	17	22		28	24	30
M. uncinata variant 9 P3	42		19	22	22	24	21	31	23	29
M. uncinata variant 9 P1	43	19	23		28		22	21	26	27
A. victoriae P1	44	23					27	33		33

Highest ranking – 1 to 5 (pink) Next highest ranking – 6 to 10 (blue)

Table 16. Variation in timber species rankings across measured sites.

	Site Rank	1	2	3	4	5	6
Timber	**Mean SPI Rank**	**AS SS**	**GS SS**	**AS UL**	**AN DH**	**ML SS**	**AS UH**
C. obesa P1	1	1	16			4	
E. camaldulensis P3	2	3	3			15	
E. camaldulensis P1	3	6	2			12	
E. camaldulensis P2	4	7	4			10	
C. obesa P2	5	2	23			3	
E. occidentalis P1	6	4	8	3	13	2	3
E. occidentalis P2	7	9	1	11	18	1	5
E. astringens P2	8		12	4	15		2
E. astringens P3	9		9	5	12		7
E. ornata P1	10		6	8	10		26
E. kondininensis P3	11	12	11	7	8	9	13
E. capillosa P2	12		22	1	4		9
E. capillosa P1	13		15	2	19		11
A. huegeliana P2	14	5	5	20	28	14	29
E. kondininensis P2	15	8	14	17	17	5	6
E. ornata P2	16		7	14	25		20
A. huegeliana P1	17	10	13	19		16	
E. astringens P1	18		17	9	16		1
E. longicornis P2	19	14	20		2	7	15
A. huegeliana P3	20	11	10	20		13	28
E. salubris P1	21				6		8
E. urna P2	22		19	13	1		16
E. longicornis P3	23	15	21		9	6	18
E. urna P3	24		25	12	11		4
E. urna P1	25		24	10	3		22
E. longicornis P1	26	13	26		5	8	25
E. kondininensis P1	27	16	18	18	20	11	12
E. salubris P2	28				7		19
E. brockwayi P1	29			6	27		27
E. brockwayi P3	30			16	14		21
E. salmonophloia P2	31				22		10
E. salubris P3	32				21		14
E. brockwayi P2	33			15	26		17
E. salmonophloia P3	34				23		23
E. salmonophloia P1	35				24		24

Highest ranking – 1 to 5	(pink)	Next highest ranking – 6 to 10	(blue)

Table 17. Rainfall recorded near coppice and timber demonstration sites monitored in 2003.

Mean SPI Rank	Mean SPI (m^3/m^2)	Site Name	1998	1999	2000	2001	2002	2003 (Jan-Aug)	Mean (1998-2002)	Long term mean
1	0.846	AS SS T	-	404	289	416	377	300	357	370
2	0.725	AN DL C	356	649	328	332	226	332	371	333
3	0.543	GS SS T	566	808	587	518	533	543	593	-
4	0.514	AS DH C	502	533	453	383	351	368	431	468
5	0.488	AS SS C	-	404	289	416	377	300	357	370
6	0.370	AN UH C	343	521	339	266	227	249	367	367
7	0.352	AS UL T	339	399	422	319	261	361	371	369
8	0.333	GS SS C	566	808	587	518	533	543	593	-
9	0.303	AS UL C	339	399	422	319	261	361	350	369
10	0.236	AN DH T	-	-	293	-	190	-	242	293
11	0.217	ML SS T	320	359	256	328	171	228	277	316
12	0.176	GS UH C	582	897	529	546	425	388	561	638
13	0.140	ML SS C	320	359	256	328	171	228	277	316
14	0.138	AS UH T	339	399	422	319	261	361	350	369
15	0.045	AS UH C	339	399	422	319	261	361	350	369

Figure 6. Left: 2-year-old *Eucalyptus camaldulensis*, Doley's Coorow. Right: 2-year-old *Codonocarpus cotinifolius*, Kenworthy's, Arrino. (Photos: Jerome Carslake)

Figure 7. 2-year-old *Gyrostemon ramulosus* at Grieves', Mingenew. (Photo Jerome Carslake)

Figure 8. 3-year-old *Gyrostemon ramulosus* at Grieves', Mingenew. (Photo Jerome Carslake)

8.2.3 2001 demonstration planting

8.2.3.1 Species selected in 2001

Species from two genera were used in the 2001 demonstration plantings: *Acacia* and *Melaleuca*. A suite of sites was established for each genus, to expand on the 2000 demonstration plantings, but a number of new species were also added. Since there were no results available from product testing to guide species selection at this time, species were selected on the basis of their growth characteristics.

Eleven *Acacia* demonstration sites were established to provide information on species performance and biomass yield. Fourteen of the most prospective taxa, with up to three provenances of each, were included in these plantings (Table 18).

The choice of taxa was guided by expert opinion and early indications from the performance of species in the year 2000 plantings. Species were selected on the basis of rapid growth rates, a high level of adaptability to different site types and amenability to establishment by direct seeding. Economic modelling indicated that these traits were desirable for the phase farming concept (see Section 7.3).

In addition to the replicated plantings, one *Acacia* direct seeding demonstration site was established in the Morawa district.

Table 18. *Acacia* species included in Search project demonstration plantings in 2001.

***Acacia* species**	**Provenances**
Acacia acuminata (broad phyllode form)	3
Acacia acuminata (narrow phyllode form)	3
Acacia aff. *redolens*	2
Acacia anthochaera	3
Acacia beauverdiana	3
Acacia conniana	1
Acacia coolgardiensis subsp. *effusa*	3
Acacia cyclops	3
Acacia lasiocalyx	3
Acacia microbotrya	2
Acacia redolens	3
Acacia resinimarginea	3
Acacia saligna (coastal form)	3
Acacia saligna (wheatbelt form)	3

The selection of *Melaleuca* species to include in the plantings was based on previous work by CALM, that had identified several species with resprouting ability and significant quantities of leaf oil high in 1,8 cineole. These attributes offered scope for *Melaleuca* species to complement the emerging oil mallee industry, in which CALM has played a pivotal research and development role.

The most promising *Melaleuca* species for the production of leaf oils and biomass were included in eight replicated plantings across the wheatbelt, to provide information on species performance, biomass yield and coppicing vigour. Twelve taxa were included, including seven from the *Melaleuca uncinata* complex (Table 19).

Table 19. *Melaleuca* species included in Search project demonstration plantings in 2001.

***Melaleuca* species**
M. acuminata subsp *acuminata*
M. acuminata subsp *websteri*
M. atroviridus (lowland form) *
M. atroviridus (upland form) *
M. fulgens
M. hamata *
M. lateriflora subsp *acutifolia*
M. lateriflora subsp *lateriflora*
M. stereophloia *
M. uncinata *
M. vinnula *
M. zeteticorum *

Taxa marked with an asterisk (*) are part of the *Melaleuca uncinata* complex, recently revised (Craven *et al.* 2004).

8.2.3.2 Sites chosen in 2001

As in 2000, landowners were approached to host the demonstration plantings. District landcare coordinators helped locate participating landowners and suitable sites. A wide coverage across the wheatbelt zone of south western Australia was achieved (Figure 9).

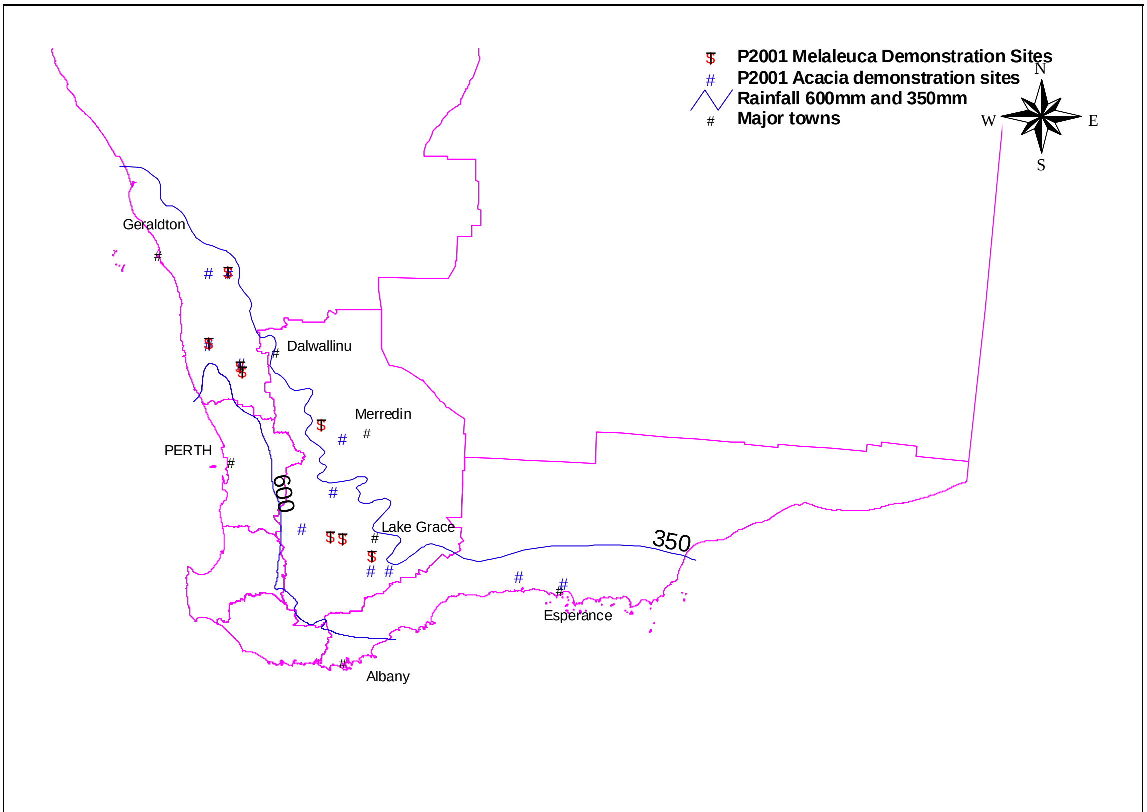


Figure 9. Location of Search project demonstration sites established in 2001.

8.2.3.3 Plant establishment in 2001

Planted seedlings

Seed for use in the *Acacia* demonstration plantings was collected in the summer of 2000. For the *Melaleuca* demonstration planting, a two-stage process was used to obtain the required seed. First, suitable populations were identified and sampled for 1,8 cineole using an ethanol extraction technique developed for the oil mallee program. This allowed parent trees with a high leaf oil percentage to be identified. Seed was then collected from parent trees with a 1,8 cineole percentage greater than 3% on a fresh-weight basis. The seed obtained from both genera was provided to commercial nurseries for the production of containerised seedlings.

Planting configurations amenable to quantitative assessment were developed. The acacias were planted in a randomised block design, with four replicates. Seedlings were planted in blocks of 28 at a spacing of 3 metres between rows and 1.5 metres within rows. For the *Melaleuca* demonstration plantings, a similar randomised block design was used, except that seedlings were planted in blocks of 30 at a spacing of 2.5 metres between rows and 2.5 metres within rows.

Ground preparation for planting was undertaken by participating landowners or contractors. At all sites rip lines were constructed to a depth of 400-600mm. In some cases, the lines were also mounded. Weed control was done by members of the project team to ensure consistency across sites. The seedlings were planted by hand between July and August 2001. All plots were labelled with engraved aluminium tags attached to steel posts.

Abnormally low winter rainfall during 2001 made the establishment of seedlings challenging at many sites.

Direct seeding

Seeding of the *Acacia* demonstration at Morawa used both a conventional air seeder and a commercially available direct seeding machine, to enable comparison of results. The potential advantages of being able to use conventional air-seeding equipment is low cost of establishment and their ready availability on wheatbelt farms.

A randomised block design with three replications was used. Treatments included two species, three seeding rates and three herbicide treatments for each seeding method. The species used were *Acacia acuminata* and *Acacia microbotrya,* which were known to occur on similar soil types in the locality of the site. Initial observations suggested that the level of seed germination at the site was satisfactory. However, by Autumn 2002, very few seedlings had established. The poor result was attributed chiefly to abnormally low winter and spring rainfall, which caused emerged seedlings to perish from drought stress. No additional time was committed to monitoring the site.

8.2.3.4 Monitoring results from 2001 plantings

Results – Acacia species

Six of the *Acacia* demonstration plantings were assessed for plant survival and growth in winter 2002. Individual tree heights were measured in plots with an average height greater than 1.3m, while an average height was estimated for the remainder.

Selected plots were remeasured in winter 2003. For plots with an average height greater than 1.5m, individual tree heights were measured, as well as crown width. Two width measurements were made parallel and perpendicular to the direction of the rip lines respectively. For plots with an average height less than 1.5m, estimates were made of the average or “typical” plant height and crown width.

The monitoring results (Table 20) were analysed quantitatively in the same way that the demonstration plantings established in 2000 were assessed. Crown Volume Index (CVI) and Site Productivity Index (SPI) values were calculated for each measured plot. A two way analysis of variance (ANOVA) of site and taxon mean SPIs was also performed for measured plots.

Each ranking method generated similar results (

Table 21), with a cluster of highly productive species evident. Two provenances of *Acacia lasiocalyx* were clearly the most productive taxa on the one site where they were planted. Other species that performed well across a range of sites included *Acacia* aff. *redolens* (provenances 1 and 2), *Acacia saligna* (all coastal provenances) and *Acacia cyclops* (provenance 3). Species that performed consistently poorly included *Acacia coolgardiensis*, *A. resinimarginea*, *A. anthochaera* and *A. acuminata*.

Figure 10 2¾-year-old Acacia aff redolens at Blake’s, Katanning.

Table 20. *Acacia* species performance in 2001 demonstration plantings (measured in Winter 2003)
Values for Site Productivity Index (SPI) and Crown Volume Index (CVI).

Acacia species and provenance	Mean CVI (m3)	Mean SPI (m3/m2)	Mean SPI ANOVA (m3/m2)	Std Error
A. lasiocalyx P3	7.894	1.633	1.360	0.214
A. lasiocalyx P1	6.098	1.274	1.001	0.214
A. aff redolens P1	4.145	0.784	0.789	0.094
A. saligna (coastal) P1	4.209	0.712	0.767	0.093
A. aff redolens P2	3.775	0.705	0.710	0.094
A. conniana	3.507	0.699	0.626	0.122
A. saligna (coastal) P3	3.920	0.673	0.728	0.093
A. cyclops P3	3.326	0.590	0.522	0.093
A. saligna (coastal) P2	3.058	0.552	0.607	0.093
A. microbotrya P2	3.173	0.545	0.580	0.122
A. cyclops P1	3.016	0.523	0.455	0.093
A. cyclops P2	2.956	0.489	0.421	0.093
A. saligna P2	3.216	0.461	0.535	0.105
A. redolens P3	1.982	0.395	0.505	0.106
A. saligna P1	2.036	0.359	0.433	0.105
A. redolens P1	1.810	0.354	0.464	0.106
A. saligna P3	1.971	0.264	0.338	0.105
A. lasiocalyx P2	1.589	0.263	0.384	0.122
A. redolens P2	1.224	0.248	0.359	0.106
A. beauverdiana P2	1.027	0.203	0.178	0.217
A. beauverdiana P1	1.594	0.169	0.144	0.217
A. beauverdiana P3	1.140	0.168	0.143	0.217
A. anthochaera P2	0.901	0.157	0.395	0.122
A. microbotrya P1	0.963	0.155	0.266	0.106
A. acuminata (broad phyllode) P3	0.786	0.149	0.259	0.106
A. acuminata (narrow phyllode) P2	0.757	0.134	0.338	0.122
A. acuminata (broad phyllode) P1	0.730	0.133	0.254	0.122
A. acuminata (narrow phyllode) P1	0.698	0.128	0.266	0.150
A. acuminata (narrow phyllode) P3	0.720	0.121	0.259	0.150
A. anthochaera P3	0.594	0.108	0.346	0.122
A. resinimarginea P1	0.526	0.096	0.414	0.150
A. anthochaera P1	0.527	0.095	0.333	0.122
A. acuminata (broad phyllode) P2	0.496	0.089	0.210	0.122
A. resinimarginea P3	0.503	0.089	0.277	0.149
A. coolgardiensis P1	0.293	0.044	0.362	0.150
A. coolgardiensis P2	0.257	0.033	0.352	0.150
A. coolgardiensis P3	0.192	0.027	0.345	0.150
A. resinimarginea P2	0.206	0.024	0.342	0.150

Table 21. *Acacia* species performance in 2001 demonstration plantings (measured Winter 2003)
Ranking based on Site Productivity Index (SPI) and Crown Volume Index (CVI).

Acacia species and provenance	Rank (CVI)	Rank (SPI)	Rank (SPI ANOVA)
A. lasiocalyx P3	1	1	1
A. lasiocalyx P1	2	2	2
A. aff redolens P1	4	3	3
A. saligna (coastal) P1	3	4	4
A. aff redolens P2	6	5	6
A. conniana	7	6	7
A. saligna (coastal) P3	5	7	5
A. cyclops P3	8	8	11
A. saligna (coastal) P2	11	9	8
A. microbotrya P2	10	10	9
A. cyclops P1	12	11	14
A. cyclops P2	13	12	16
A. saligna P2	9	13	10
A. redolens P3	15	14	12
A. saligna P1	14	15	15
A. redolens P1	17	16	13
A. saligna P3	16	17	26
A. lasiocalyx P2	19	18	19
A. redolens P2	20	19	21
A. beauverdiana P2	22	20	36
A. beauverdiana P1	18	21	37
A. beauverdiana P3	21	22	38
A. anthochaera P2	24	23	18
A. microbotrya P1	23	24	30
A. acuminata (broad phyllode) P3	25	25	32
A. acuminata (narrow phyllode) P2	26	26	27
A. acuminata (broad phyllode) P1	27	27	34
A. acuminata (narrow phyllode) P1	29	28	31
A. acuminata (narrow phyllode) P3	28	29	33
A. anthochaera P3	30	30	23
A. resinimarginea P1	32	31	17
A. anthochaera P1	31	32	28
A. acuminata (broad phyllode) P2	34	33	35
A. resinimarginea P3	33	34	29
A. coolgardiensis P1	35	35	20
A. coolgardiensis P2	36	36	22
A. coolgardiensis P3	38	37	24
A. resinimarginea P2	37	38	25

There were highly significant differences in SPIs between sites (Table 22). This compounded the difficulty of comparing taxa across sites. However, most species had similar rankings at each site, despite the large variation between sites (Table 23). The large variation in performance between sites suggests that site selection will be an important determinant of productivity in new woody phase crops.

**Table 22. Relative performance of measured *Acacia* demonstration sites established in 2001 (measured Winter 2003).
Mean data for all measured species at each site.**

Site	Mean CVI (m^3)	Mean SPI (m^3/m^2)	Mean SPI ANOVA (m^3/m^2)	Std Error	Rank CVI	Rank SPI	Rank SPI ANOVA
AS SS Ac	5.193	0.990	0.866	0.070	1	1	1
AS DH Ac	4.081	0.812	0.722	0.057	2	2	2
AN UL Ac	2.494	0.445	0.474	0.070	4	3	3
AN SS Ac	2.556	0.409	0.371	0.049	3	4	4
AN UH Ac	0.846	0.126	0.150	0.040	5	5	5
AN DH Ac	0.685	0.096	0.111	0.046	6	6	6

When this data was collected in Winter 2003, the acacias had been established for only 24 months. Different species may invest different amounts of growth into above-ground and below-ground biomass. Therefore, these rankings may change as the plants grow older, with the possibility that some species that appear to be less productive (above ground) in their early years will substantially increase their growth in the years ahead. Conversely, species that appear to he highly productive in the first few years may experience a growth plateau in later years. The life span of many of these species in cultivation is also poorly known.

Therefore, whilst some interesting interim findings have been made at this early stage, the likely productive potential of these species is still uncertain.

**Figure 11. *Acacia* trial at Blake's, Katanning.
Top: 9 months after planting. Bottom: Aged 2¾ years.**

Table 23. Variation in *Acacia* species rankings across measured sites (measured Winter 2003).

	Site Rank	1	2	3	4	5	6
***Acacia* species**	**Mean SPI Rank**	**AS SS**	**AS DH**	**AN UL**	**AN SS**	**AN UH**	**AN DH**
A. lasiocalyx P3	1		1				
A. lasiocalyx P1	2		3				
A. aff. redolens P1	3	3	4		1	2	3
A. saligna (coastal) P1	4	2		1	10	1	19
A. aff. redolens P2	5	4	7		4	4	1
A. conniana	6		6	3	17		
A. saligna (coastal) P3	7	1		2	8	6	2
A. cyclops P3	8	7	10	6	2	8	
A. saligna (coastal) P2	9	5		4	6	3	15
A. microbotrya P2	10		2		22	28	
A. cyclops P1	11	10	5	5	12	29	
A. cyclops P2	12	11	11	7	3	23	
A. saligna P2	13	6			9	7	5
A. redolens P3	14		8		5	14	7
A. saligna P1	15	8			14	5	10
A. redolens P1	16		9		11	17	16
A. saligna P3	17	9			16	9	23
A. lasiocalyx P2	18		12			11	4
A. redolens P2	19		14		7	21	11
A. beauverdiana P2	20			9			
A. beauverdiana P1	21			12			
A. beauverdiana P3	22			13			
A. anthochaera P2	23				13	16	9
A. microbotrya P1	24		13		20	32	17
A. acuminata (broad phyllode) P3	25		16		19	18	6
A. acuminata (narrow phyllode) P2	26			8		10	18
A. acuminata (broad phyllode) P1	27		15			20	14
A. acuminata (narrow phyllode) P1	28			10		24	
A. acuminata (narrow phyllode) P3	29			11		26	
A. anthochaera P3	30				15	31	13
A. resinimarginea P1	31					12	8
A. anthochaera P1	32				18	25	20
A. acuminata (broad phyllode) P2	33		17			13	12
A. resinimarginea P3	34				21	15	
A. coolgardiensis P1	35					19	22
A. coolgardiensis P2	36					22	25
A. coolgardiensis P3	37					30	21
A. resinimarginea P2	38					27	24
Highest ranking – 1 to 5	(pink)		Next highest ranking – 6 to 10				(blue)

Results – Melaleuca species

The *Melaleuca* sites were assessed for plant survival and height in July 2002 (Table 24). All surviving trees were measured. Two of the more productive plots were remeasured in winter 2003. By 2003, biomass production remained relatively low, with mean plot tree heights typically ranging between 50-100cm for all species.

Table 24. Mean plot survival and tree height for *Melaleuca* demonstration plantings established in 2001 (measured Winter 2002).

***Melaleuca* species**	**Survival (%) (All)**	**Height (cm) (All)**	**Height (cm) (Best)**
M. acuminata subsp *acuminata*	58%	53	68
M. acuminata subsp *websteri*	73%	48	68
M. fulgens	84%	49	84
M. lateriflora subsp *acutifolia*	83%	47	58
M. lateriflora subsp *lateriflora*	83%	57	73
M. vinnula *	64%	42	59
M. hamata *	72%	32	52
M. atroviridus (lowland form) *	77%	54	69
M. atroviridus (upland form) *	66%	48	77
M. stereophloia *	54%	46	60
M. zeteticorum *	78%	35	45
M. uncinata *	74%	53	69

'Best' height is the mean height for the best plot.
(*) Taxa in *M. uncinata* complex marked by asterisk, have recently undergone taxonomic review (Craven *et al.* 2004).

The 2001 *Melaleuca* demonstration plantings reaffirmed the findings from the sites established in 2000. All species were relatively slow growing in the years immediately following establishment. The potential for the selected melaleucas contributing to large scale biomass industries appears to be limited, given the availability of other more productive species such as mallee. A commercial application for the selected melaleucas would therefore need to be underpinned by high value products, such as leaf oil extracts of higher value than that from mallee species. Coppicing vigour is another important growth parameter which remains unclear. If further investigations are warranted, the demonstration sites provide a useful resource for this purpose.

8.2.4 2002 demonstration planting

Demonstration plantings established in 2002 complemented those established in 2001 (Figure 12). Only a small number of sites were established, as the emphasis of the project moved to the resource base planting program.

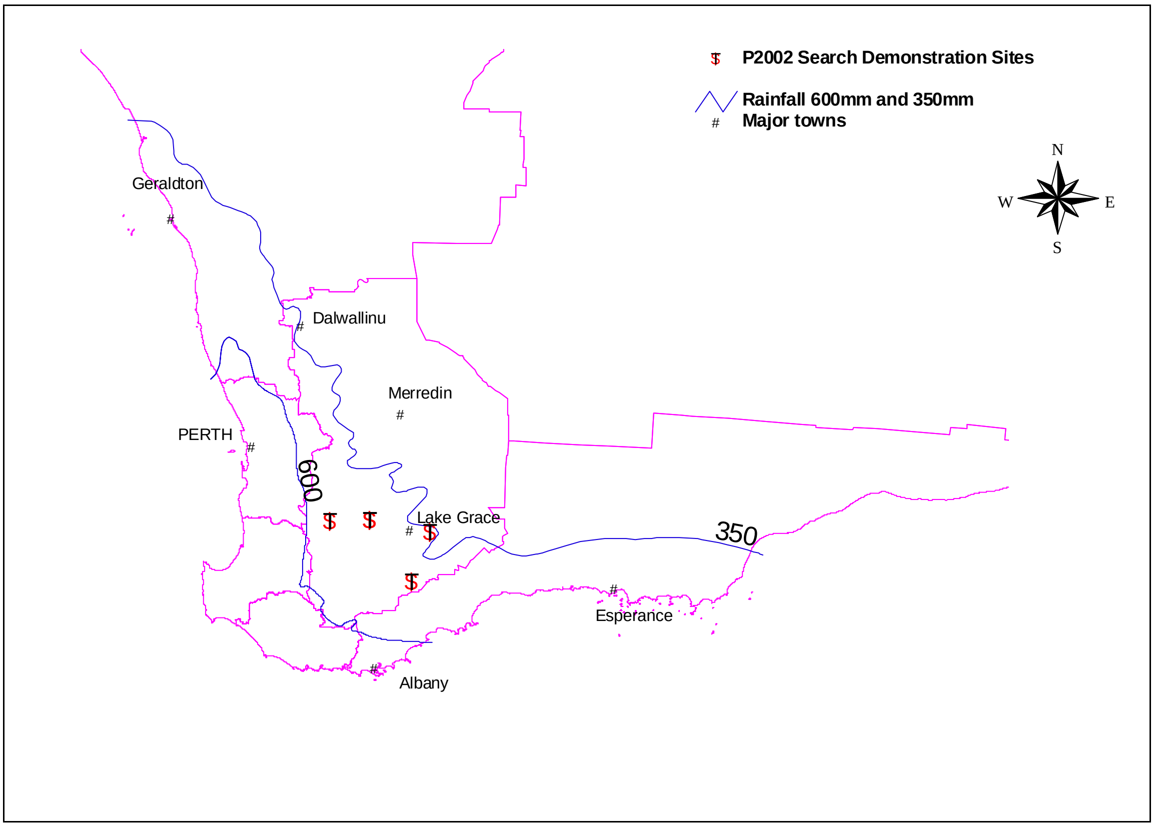


Figure 12. Location of Search project demonstration sites established in 2002.

8.2.4.1 *Acacia* plantings in 2002

Two *Acacia* plantings were established in 2002:

1. An *Acacia saligna* planting density trial, to assess the effect on biomass production, was set up with three replicates of three spacings in blocks. The trial failed due to poor seedling survival, attributed to abnormally low winter rainfall in the year of planting, and therefore, moisture stress in the light-textured soil at the site. Containerised seedlings were used for this planting, and seedling survival was assessed in winter 2003.

2. A direct seeding trial included three *Acacia* species to test the effect of establishment method on productivity - *A. saligna*, *A. lasiocalyx* and *A. bartleana* Maslin (ms). Fast-growing species were chosen, with the final choice being decided by availability of seed. Each species was planted in a five-row block approximately 200m long, with a spacing of 2.5m between the mound lines. A commercial saltbush seeding machine was used to place seed at 2 metre intervals along mounded rip lines. Germination and

growth of all three species is encouraging (Figure 13 and Figure 14). Growth rates of seeded and planted plots will be monitored and compared over the next few years.

Figure 13. ***Acacia*** **direct seedling demonstration site in May 2003, 10 months after seeding (Photo: Dan Huxtable).**

Figure 14. ***Acacia*** **direct seeding demonstration site in August 2003, after second-year weed control.**

8.2.4.2 *Melaleuca* plantings in 2002

Two *Melaleuca lateriflora* plantings using several different provenances were established on two sites in 2002, to assess variation in growth and coppicing ability. A randomised block design was used, with 6 provenances and 5 replicates. Progress of seedlings at each site is satisfactory, based on informal assessments carried out in winter 2003. Growth is relatively slow, as expected from earlier experience with this species.

8.2.5 2003 demonstration planting

8.2.5.1 Site selection

Because duplex soils are likely to be preferred for phase farming with woody perennial crops, sites with duplex soils were chosen for the 2003 plantings. Backhoe pits were excavated on all of the chosen sites to confirm their suitability and allow basic soil properties to be assessed. Sites were chosen in different geographic areas (Figure 15).

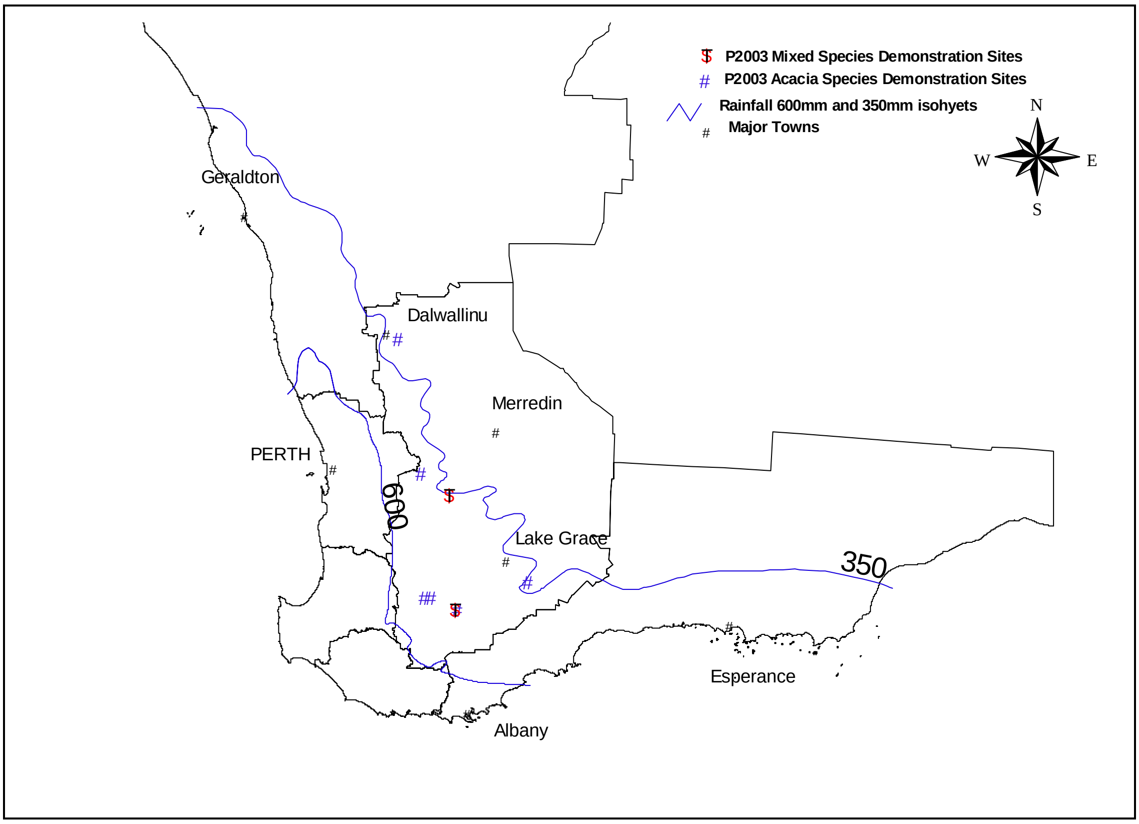


Figure 15. Location of Search project demonstration sites established in 2003.

8.2.5.2 *Acacia saligna* plantings in 2003

Acacia saligna was selected as a major species for the 2003 plantings. In addition to showing promise as a feedstock for reconstituted wood products, this species is well-suited to nursery propagation and field establishment. Growth rates have also been consistently impressive across a large number of previously established planting sites.

Three categories of *Acacia saligna* demonstration plantings were developed including two mixed provenance plantings, three spacing density comparisons and one block planting for investigating temporal interactions between woody crop and annual crops. Replicated planting designs, amenable to quantitative assessment, were used at all sites.

The mixed provenance plantings included twelve different seed lots to encompass the broad genetic diversity of this species. The spacing density comparisons included 10 spacing treatments ranging between 667 and 8,000 stems per hectare.

Acacia saligna seed for the 2003 demonstration plantings was largely collected specifically for this purpose, with some augmentation from private seed merchants.

For the spacing demonstrations, CALM will undertake NMM probe measurements over the next 12 months.

8.2.5.3 Mixed species plantings in 2003

New demonstration plantings for 2003 were planned using preliminary information from product assessment work to guide species selection. A range of promising species were grown in three nurseries, from which a final species selection could be made before planting. However, by planting time, product testing was still not complete, so species selection for planting was based on an assessment of the product testing results to date, and other considerations, such as the health and vigour of nursery seedlings, and taxonomic diversity.

Two mixed species plantings were established, using 19 of the more prospective species (Table 25), many of which had not been included in earlier demonstration plantings. Replicated planting designs amenable to quantitative assessment were used. Seed for the mixed species plantings included both collected and purchased seed, depending on the species.

8.2.5.4 Establishment – all plantings

Ground preparation for planting was undertaken by participating landowners or contractors. At all sites rip lines were constructed to a depth of 400-600mm. In some cases, the lines were also mounded. The seedlings were planted by hand in July 2003. All plots were labelled with engraved aluminium tags attached to steel posts.

8.2.5.5 Outlook

It is anticipated that seedling survival in all the year 2003 plantings will be high due to the favourable season. The sites established in 2003 will provide valuable information on biomass yield and plant water use for the selected species, as well as providing a valuable resource for further research and development of woody plant crops.

Table 25. Species included in the mixed planting demonstrations established in 2003.

Species	Provenances
Acacia lasiocalyx	1
Acacia saligna	1
Agonis flexuosa	1
Agonis juniperina	1
Alyogyne huegelii	1
Anthocercis littorea	1
Casuarina obesa	1
Codonocarpus cotinifolius	1
Eucalyptus leptopoda	1
Eucalyptus rudis	1
Grevillea candelabroides	1
Gyrostemon ramulosus	1
Hakea oleifolia	1
Jacksonia sternbergiana	1
Melaleuca preissiana	1
Paraserianthes lophantha	1
Senna pleurocarpa	2
Trymalium floribundum	1
Viminaria juncea	2

8.3 Resource plantings

8.3.1 Overview

Resource plantings were on a significantly larger scale than the demonstration planting described in the previous section.

The resource plantings commenced on a small scale in 2001, followed by larger planting programs in 2002 and 2003, resulting in the establishment of over 6.5 million seedlings on farms across the Western Australian wheatbelt. Useful information was obtained with respect to seedling production issues, integration of commercial revegetation into farming systems, factors affecting revegetation uptake by farmers and logistical considerations for large-scale planting. The plantings will also provide a resource for assessing the practicality of on-going management and for measuring growth rates of a variety of species over a wide range of sites under farm conditions.

The logic of the sequence of steps in species selection and development, that is, basing selection of species for resource planting on results of growth and product testing, could not be rigorously applied in this project. It was necessary to accommodate both in a project of relatively short duration. Implementation of the resource plantings was delayed for as long as possible to take advantage of the species and product testing work but, especially in the earlier planting, selection was based mainly on the considered judgement of the project team and selected advisers.

8.3.2 2001 resource planting

8.3.2.1 Planning - 2001

At the time of preparation for the 2001 planting season, only a modest amount of information was available for selecting prospective species. The options available included known timber species, fast growing but poorly assessed *Acacia* species, or coppicing species for the production of leaf oils and biomass. In the absence of other information, coppicing species were believed to have the most promise due to synergies with the emerging oil mallee industry. Previous work by CALM had identified several *Melaleuca* species as being prospective for this type of production system. Establishment of a *Melaleuca* resource could complement the oil mallee resource already established and utilise oil mallee harvesting, transportation and processing equipment. Additionally, based on their distribution in the wild, the target *Melaleuca* species showed promise for site types not well suited to oil mallee species.

A small-scale *Melaleuca* planting program was undertaken in 2001, commensurate with the uncertainties surrounding species selection. Four species of *Melaleuca* were included in the program (Table 26). Note that a recent taxonomic revision has subsequently divided *Melaleuca uncinata* into a number of new species.

Table 26. Melaleuca species planted in the 2001 resource planting.

***Melaleuca* Species**	**Number**
M. acuminata subsp *acuminata*	11,000
M. fulgens	5,000
M. lateriflora subsp *lateriflora*	20,000
M. hamata *	17,200
M. atroviridus (upland form) *	18,600
M. stereophloia *	4,600
M. zeteticorum *	4,600
M. uncinata *	19,000
Total	**100,000**

* Part of the *M. uncinata* complex.

8.3.2.2 Operational details - 2001

The Oil Mallee Company was contracted to implement this program. Using seed supplied by CALM, a commercial nursery produced 100,000 seedlings for the project. Seventeen farmers prepared and established planting sites in winter 2001.

The resource plantings in 2001 were in a variety of planting configurations, located on a range of site types. Feedback from participating farmers indicated that the majority of the sites are progressing satisfactorily.

8.3.3 2002 resource planting

8.3.3.1 Planning - 2002

In the last half of 2001, at the planning stage for the 2002 resource planting, there was little more species and product information available than in the previous year. Therefore, it was decided to continue with an expanded *Melaleuca* program, following the successful 2001 program. Synergy with the growing oil mallee industry remained the driving reason for expanding the Melaleuca program, as described for the 2001 planting. Approximately 1.9 million seedlings were planted across 161 farms (Figure 16).

8.3.3.2 Operational details - 2002

Extensive surveys were conducted to locate viable populations of the target species that could underpin seedling production for the 2002 planting program. Parent trees from the wild were selected for seed collection on the basis of leaf oil percentage, using methods previously developed for oil mallee sampling. In total, 120 geographically distinct populations were located and tested from an area encompassing the entire wheatbelt and adjacent pastoral land. Some 1600 individual trees were sampled, with approximately 15% of those sampled exceeding the target leaf oil percentage threshold.

To meet nursery deadlines, seed needed to be collected, extracted, cleaned and supplied by November 2001. Seed was collected from a total of 252 trees, from 27 different provenances. The breakdown of species by provenance was: *M. lateriflora* (15 provenances), *M. uncinata* complex (5 species, 10 taxa) and *M. acuminata* (2 sub-species). The major species used in the program was *M. lateriflora*, due to its high salt tolerance and consistently high leaf oil percentages across its natural range. The taxonomic entities used in the 2002 program are listed in Table 27. Enough seed was collected to produce 2 million seedlings.

Four nurseries, selected by public tender, were allocated equal shares of the total requirement of 2 million seedlings. Despite some difficulties associated with seed germination and growth, the nurseries were able to meet greater than 95% of their production targets. The abnormally dry winter significantly affected delivery logistics. Many deliveries were rescheduled several times and in some cases orders were cancelled and the seedlings reallocated to another site. Approximately 300,000 seedlings were reallocated in this way.

A consultant was engaged, also by tender, to manage site selection, seedling orders and seedling delivery to farmers. Criteria for site selection, planting design and appropriate establishment methods were developed by CALM to assist with this task. The consultant also undertook promotional activities in conjunction with CALM staff, including the delivery of six regional information seminars to landcare coordinators.

Table 27. Melaleuca species included in the 2002 resource planting program.

***Melaleuca* species**	**Provenances**	**Seedlings**
M. acuminata subsp *acuminata*	1	200,000
M. acuminata subsp *websteri*	1	50,000
M. lateriflora subsp *lateriflora*	15	1,147,000
M. hamata *	2	68,000
M. atroviridus (upland form) *	1	94,000
M. stereophloia *	2	53,000
M. zeteticorum *	2	85,000
M. uncinata *	3	204,000
TOTAL	**27**	**1,901,000**

* Part of *M. uncinata* complex.

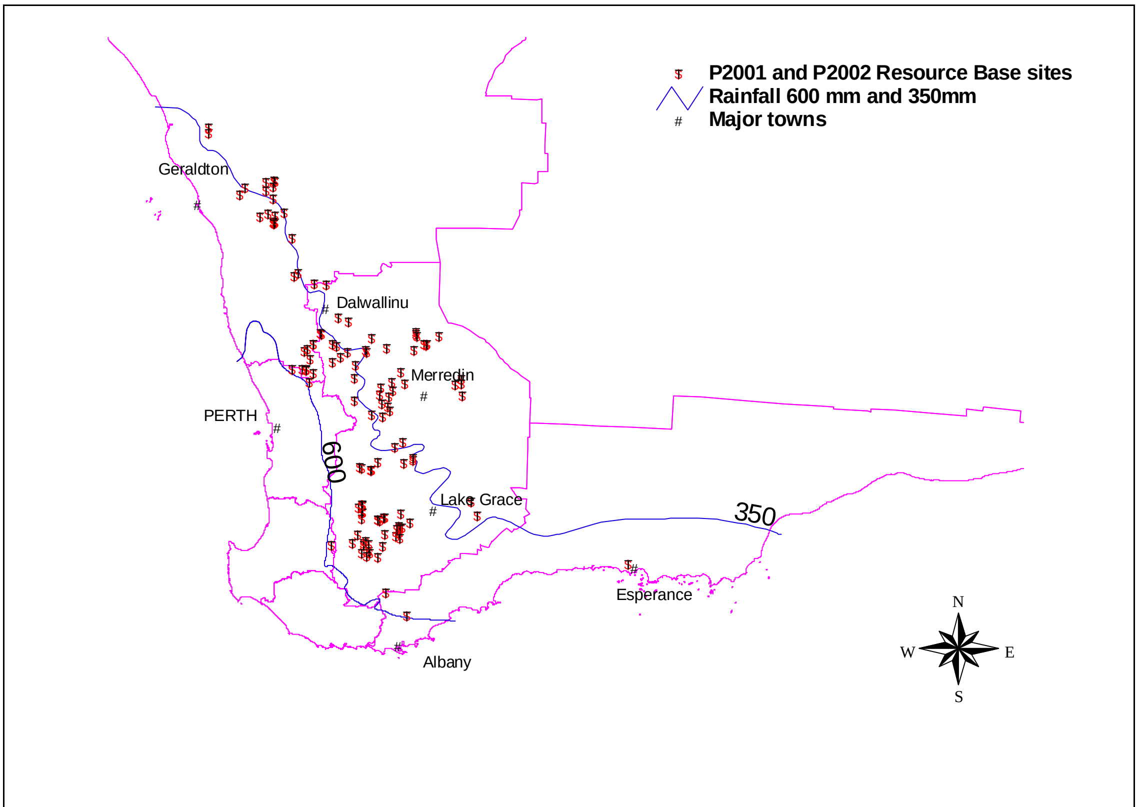


Figure 16. Search project resource plantings established in 2001 and 2002.

To encourage uptake by farmers, a support package was developed which included subsidised seedlings and a contribution toward fencing costs. The fencing subsidy was weighted towards larger planting areas and designs that protected remnant vegetation. Many regional landcare advisors were actively involved in locating suitable sites in their areas.

A minimum of 10,000 seedlings per farmer was stipulated in order to achieve sufficient scale of planting to facilitate harvesting at a future time. As much as possible, provenances of each species were assigned to farmers in the areas of their natural occurrence. Most participating farmers ordered the minimum allocation. In addition, they invariably planted the seedlings in low-productivity areas. This reflects an understandable unwillingness by farmers to risk allocating large areas to tree crops until they are commercially proven, despite potential landcare benefits.

A GIS database was developed for the 2002 planting program, to store information pertaining to growers, seedling orders and site details. The database design includes the facility to add growth data collected in the future, and will be suitable for estimating the size of biomass resource that satisfies various criteria, such as transport distance. The database was structured to accommodate data from future planting programs.

8.3.4 2003 resource planting

8.3.4.1 Planning - 2003

In the later half of 2002, final product testing information for the large number of species being examined for commercial potential was not yet available. However, preliminary results enabled the development of a more varied list of species for inclusion in the winter 2003 planting program. Approximately 4.3 million seedlings were produced in commercial nurseries and allocated to 475 farmers across the Western Australian wheatbelt. The majority of the seedlings were planted in July and August 2003.

A total of 27 species were included in the year 2003 planting program (Table 28). Species were selected for each of three potential woody crop production systems; coppice, phase and timber. The coppicing species included melaleucas and several promising but as yet poorly researched mallee eucalypts, with potential to complement the oil mallee industry. Experimental phase farming species included several fast growing acacias with low wood densities, a prerequisite for paper and panel board production (see Section 6). The species selected for timber included several species for which timber qualities were known from previous studies, and several lesser known species with promising form and growth attributes.

Although economic studies carried out within the Search project indicate relatively poor returns for timber trees compared to the potential returns from short-cycle phase or coppice crops, a high proportion of the resource planting was made up of long-cycle species. Long-lived coppicing species were also well represented, but only a small proportion of the total seedlings were of species suited to phase cropping. Reasons for choosing this mixture of plant types include:

- length of time a new industry would take to become established, by which time most phase species would be senescent,
- lack of information on which phase species had the best product potential,
- continuing benefits from timber and coppicing species, even if never harvested,
- potential integration of coppicing species into new industries fostered by the oil mallee industry (similar harvesting and logistical requirements).
- farmer preference for tall trees.

In addition, some species were chosen because of their higher salt tolerance, to improve their long-term survival.

The role of *Melaleuca* in resource plantings was reviewed prior to species selection for the 2003 program. As an adjunct to the 2001 and 2002 planting programs, a number of older *Melaleuca* plantings (in the 4-6 year old range) were assessed for biomass yield and coppicing vigour. With respect to biomass production, the target *Melaleuca* species were outperformed by the appropriate mallee species on many sites. This applied even on waterlogged and saline sites where it was expected that *Melaleuca* would have a competitive advantage. Also the coppicing vigour of most *Melaleuca* taxa was ambiguous. For these reasons, and because melaleucas were well represented in the 2001 and 2002 programs, they were given a reduced role in the 2003 program.

8.3.4.2 Operational details - 2003

Seed for the 2003 planting programme was either purchased from seed suppliers or collected from wild populations between September 2002 and January 2003. For the timber species, parent trees were selected based on bole length and straightness, tree health and vigour and large population size. The seed for coppicing species was all collected from trees with high leaf oil, as in previous years. Vouchers were collected from all plant specimens that were sampled, and were lodged with the WA Herbarium.

Eleven regional nurseries were selected by public tender to grow containerised seedlings for the program. Under the terms of the contracts, the nurseries were also responsible for marketing the seedlings to farmers using an information package developed by CALM. In order to meet production quotas, nurseries were able to select species production targets subject to several constraints. Firstly, there was a requirement for a minimum of ten species to be grown, selected from a list provided by CALM. Secondly, any single species could only comprise a maximum of 30% of the overall production target. Finally, the species mix was required to include a maximum of 30% coppicing species and a minimum of 20% experimental phase species. These constraints ensured that a suitable mix of species was included, whilst allowing nurseries the flexibility to tailor their quotas to market demand.

Nursery contracts were available for the four National Salinity Action Plan regions that encompass the south west agricultural zone (Figure 17). The seed was provided to the nurseries in December 2002 and January 2003.

The nurseries successfully met over 95% of their production targets A wide range of planting designs and configurations were implemented, suited to the individual needs of participating farmers. Information on growers, seedling orders and site details was provided to CALM by the nurseries and will be added to the database created for the 2002 program.

Table 28. Species included in year 2003 resource plantings.

	Provenances	Seedlings	Farms
Coppicing Species			
Eucalyptus angustissima subsp *quaerenda*	2	256,500	65
Eucalyptus aspratilis	2	6,592	1
Eucalyptus hypochlamydea	3	109,812	28
Eucalyptus leptopoda	3	35,102	16
Eucalyptus myriadena subsp *myriadena*	1	109,174	21
Melaleuca lateriflora subsp *lateriflora*	16	468,149	114
Melaleuca uncinata	4	232,998	78
Melaleuca atroviridus “upland form”	2	139,495	27
Sub-total	**33**	1,357,822	350
Phase Species			
Acacia cyclops	2	32,996	14
Acacia microbotrya subsp *microbotrya*	9	146,968	40
Acacia murrayana	1	2,128	3
Acacia saligna	5	549,110	172
Sub-total	**17**	731,202	229
Timber Species			
Acacia lasiocalyx	2	17,676	9
Acacia bartleana Maslin (ms)	1	2,176	1
Allocasuarina huegeliana	8	216,925	88
Casuarina obesa	8	634,557	163
Eucalyptus argyphea	3	104,926	28
Eucalyptus astringens	5	118,651	39
Eucalyptus capillosa subsp *capillosa*	3	33,420	9
Eucalyptus longicornis	3	161,500	51
Eucalyptus melanoxylon	2	36,291	17
Eucalyptus occidentalis	7	340,349	92
Eucalyptus salicola	2	80,815	40
Eucalyptus salmonophloia	9	217,792	97
Eucalyptus salubris	8	134,198	67
Eucalyptus transcontinentalis	2	7,795	8
Eucalyptus urna	4	5,725	3
Eucalyptus wandoo subsp *wandoo*	5	114,095	44
Sub-total	**72**	2,226,891	756
Total	**122**	**4,315,915**	**1,335**

8.3.4.3 Monitoring

A subset of the sites were visited by representatives of the SEARCH Project in July and August 2003 to validate on-ground outcomes and collect additional site information including GPS locations and photographs. A total of 42 sites were assessed through this process. These visits provided confidence that the majority of the data received for inclusion in the SEARCH database is reliable. Valuable feedback on farmer motives for participating in the project was also recorded. Key findings were:

- The Master TreeGrower ™ program and similar education programs had provided confidence and direction to farmers who had participated in these schemes.

- Most farmers who planted SEARCH seedlings had considerable prior experience in tree planting. In most instances, the quality of seedling establishment methods was high.
- Most farmers planted for non commercial reasons, and fitted their tree planting into existing farm plans. For this reason, the recommended planting configurations for farm forestry outcomes were not always adhered to.
- Water use to combat salinity was a major reason for planting.
- The quality of land selected for tree planting was variable. Much of the targeted land was low productivity, reflecting farmer caution about allocating productive land to trees that may not bring any cash return.

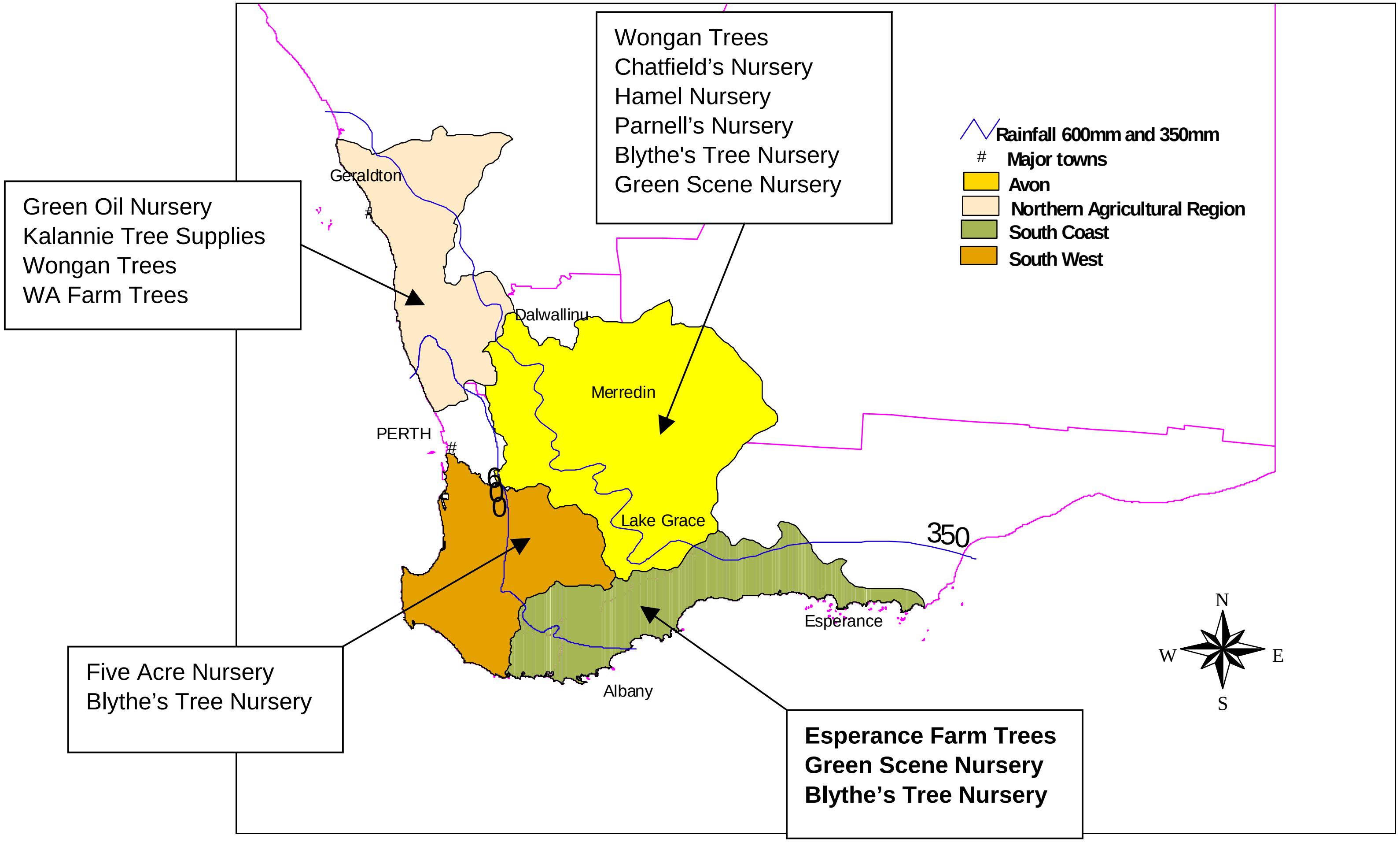


Figure 17. Participating nurseries by NSAP region for the year 2003 planting program.

8.3.5 Outcomes of Resource-Base Program

In terms of creating a pre-commercial resource of woody biomass, the resource planting programs in 2001-2003 were partially compromised by the uncertainty surrounding species selection. Until the biomass testing program was completed, the most prospective species to plant had to be selected based on pre-existing knowledge, and estimation of likely commercial potential. This outcome was inevitable, given the need to implement large-scale planting concurrently with the project's species evaluation and product development work. As a result, some of the species planted may not become contributors to future woody biomass industries. The speculative nature of these plantings was clearly explained to all participants.

Despite this limitation, many positive outcomes were achieved from the resource planting programs. Some of these are listed and briefly described below.

8.3.5.1 Valuable resource

These plantings will provide a valuable pre-commercial resource to be monitored in future for their performance, and perhaps to provide feedstock for large-scale testing. They may become involved in the establishment of prospective new industries, or augment the resources for existing industries such as power generation, solid timber or the oil mallee industry.

8.3.5.2 Good documentation

This resource is well documented, which will facilitate growth monitoring and future assessment of feedstock amounts and quality if required. Information on planting sites, including a site description and details of the species and seed lot planted, are being stored in a standard database format using Microsoft Access. For many sites, GIS linkage is facilitated.

8.3.5.3 Biodiversity benefits

Even though the resource-base plantings are speculative and pre-commercial, the biodiversity benefits they provide are immediate and substantial. A wide variety of robust native species has been introduced into the farm landscape as a result of this project, implemented in a coherent manner, including careful selection of species, provision of high quality seed from healthy parent plants from selected provenances, provision of advice on site selection, appropriate species selection and establishment methods for each site, and accurate documentation of the species and sites planted.

The project has encouraged farmers to implement their plantings in ways that are integrated with their farming practices, will enable commercial exploitation at a later date if suitable new industries develop, and also provide non-commercial benefits to their farms and regions.

8.3.5.4 Increased knowledge of woody plant crops

The planting programs fostered a greater awareness of the role for commercial woody plants in agricultural systems amongst participating farmers. It is estimated that over 600 farmers established planting sites through the project and gained exposure to Search project information. In addition, numerous presentations were made by Search project staff to farmer audiences at field days and educational workshops. Encouraging a farming culture which is aware of, and embraces potential new industries based on woody plants is critical if such industries are to receive support and involvement by the rural community , and the resources necessary to develop them.

8.3.5.5 Confidence boosting and capacity building

Participating farmers gained valuable experience in the requirements for planting and establishing woody crops at semi-commercial scale, and will have greater confidence in adopting new woody crops if they are successfully developed in future.

The nursery industry was exposed to the challenges of successfully propagating and growing some novel species, while both nurserymen and landcare advisors gained experience in providing advice on the implementation of large-scale farm forestry in lower rainfall areas.

8.3.5.6 Contribution to the rural economy

To achieve the benefits listed above, the project invested a significant amount of its resources into the rural community, and encouraged farmers to invest a large amount of their own time and money into revegetation activities. The benefit to the rural community will of course be much greater and more enduring if the research leads to the development of new industries based on woody crops.

8.4 References

Craven, LA, BJ Lepschi, L Broadhurst and M Byrne (2004). "Taxonomic revision of the broombush complex in Western Australia (Myrtaceae, Melaleuca uncinata s.l.)." Australian Systemic Botany **17**: 255-271.

Thackway, R and I Cresswell (1995). An interim biogeographic regionalisation for Australia: a framework for establishing the national system of reserves, version 4.0. Australian National Conservation Agency.

Western Australian Herbarium (1998). Florabase - Information on The Western Australian flora. Accessed: http://www.calm.wa.gov.au/science/florabase.html

Natural Heritage Trust
Helping Communities Helping Australia
An Australian Government Initiative

Search Project Report

Section 9 – Propagation Project

Hakea prostrata seedlings, CALM research nursery, Kensington.

Final report for NHT Project 973849

July 2004

Government of Western Australia
Department of Conservation and Land Management
Conserving the nature of WA

Authors

Graeme Olsen[1]
Don Cooper[2]
Dan Huxtable[2]
Jerome Carslake[2]
John Bartle[2]

This report has been prepared to assist with assessment of potential new commercial opportunities based on woody perennial plants in the wheat-sheep agricultural zone of southern Western Australia. However, the work reported here is of a preliminary nature. While care has been taken in the report's preparation, no responsibility is taken by the authors or publisher for omissions or inaccuracies, or for the use of this information by any other party.

Photographs: Unless stated otherwise, all photographs were taken by Graeme Olsen.

ISBN No: 0 7307 55509

[1] Olsen & Vickery, PO Box 357 Waroona, Western Australia 6215.

[2] Department of Conservation and Land Management, Locked Bag 104, Bentley Delivery Centre, Western Australia 6983.

Sections in this report

Section 1	Summary
Section 2	Background
Section 3	Search Methodology
Section 4	Product Assessment
Section 5	Species Selection
Section 6	Feedstock Testing
Section 7	Economic Analysis
Section 8	Demonstration and Resource Plantings
Section 9	Propagation Project
Section 10	Project Administration
Appendices	

Contents of this Section

Section 9 Propagation Project **5**

9.1 Introduction 5

9.2 Obtaining Seed for Propagation 5

9.3 Seed treatment and germination 5

9.4 Seedling establishment 8

9.5 Results 9

9.6 Conclusions 12

9.7 References 21

Section 9 Propagation Project

9.1 Introduction

This section is based on a report by Matt Rumenos, who also carried out the seed treatment and germination work at the CALM Kensington headquarters.

As part of the demonstration planting program for 2003, the ease of propagation of a number of species was tested in small-scale nursery trials. The aim was to test all the species that were undergoing laboratory feedstock testing and to try to resolve any difficulties with their propagation. This would increase the knowledge base for this group of prospective species, in preparation for larger scale planting of the species that performed best in the laboratory tests. Some of the species were familiar to nursery staff and their propagation requirements were well known, but others are seldom propagated, and little was known about their requirements.

Plants were propagated at three nurseries – CALM's commercial nursery at Narrogin, Kalannie Tree Supplies and CALM's research nursery at Kensington. The two commercial nurseries were provided with recommended germination treatments (Table 1) and asked to use their best estimate of appropriate conditions to provide for these species, while at Kensington, a range of seed treatments were tested. By spreading the project over three locations with different climates and different management practices, it was hoped to learn more about the factors controlling successful germination and establishment.

This report includes a description of the work done at the Kensington research nursery, and a summary of the results from Narrogin and Kalannie nurseries.

9.2 Obtaining Seed for Propagation

The species selected for this test program included all 47 that were selected for feedstock testing at CSIRO Forestry and Forest Products Clayton Laboratories, for their suitability for panel boards or pulp and paper. Seed was obtained for 43 of these species, by collection or purchase. The species grown at each nursery are listed in Table 4.

9.3 Seed treatment and germination

From a combination of literature search and discussion with other horticulturalists, a list of recommended treatments was developed (Table 1). For some species, a combination of treatments was advised in order to obtain optimal results. These treatments are discussed below.

9.3.1 Acid Scarification

Mr Andrew Crawford of the Threatened Flora Seed Centre supplied seed germination data for six *Acacia* species. This work demonstrates that the acid scarification method has a success rate that is closest of all to the germination potential. This method was used for both *Acacia spp.* and *Paraserianthes lophantha*. Other seeds bearing a similarly hard seed coat, or one that posed a significant barrier to germination, such as a dried fruit pulp (*Persoonia elliptica, Exocarpos sparteus*), were treated with acid to nullify such features and remove inhibitors to germination.

9.3.2 Smoked Water

Smoked water in the form of 'Seed Starter' has been tested on a large range of species at a rate recommended by the Kings Park Seed Research Centre (1:10 in water). Seed of over 100 genera of Australian plants, predominantly of southern Australian origin, demonstrate a positive response to chemicals in smoke. Smoked water usage promotes faster germination, uniformity, dormancy breaking for difficult species, and more robust and vigorous seedlings.

9.3.3 Hot Water

Hot water was produced in a standard domestic kettle, then allowed to cool to the desired temperature. While boiling water treatment of *Acacia* seed may give variable results according to species (Cavanagh 1987; Crawford *et al.* not dated), hot water treatment is a reliable method for many *Grevillea* species (Olde and Marriott 1994). At Kensington, hot water was used experimentally on half the seed sown of *Trymalium floribundum*, because this species belongs to the Rhamnaceae, it is a vigorous colonizer after disturbance, and because of its close relationship to *Spyridium globulosum,* which supposedly responds to hot water treatment.

9.3.4 Cool Temperatures and Stratification

Seed of both *Callitris glaucophylla* and *Pittosporum phylliraeoides* were stratified in a refrigerator for two weeks at 4°C, as recommended by Nindethana Seed Service (Peter Luscombe, pers. comm.). *Banksia, Hakea, Lambertia* and *Dryandra* species were all sown into Petri dishes following treatment and raised in an incubation cabinet at a constant temperature of 15°C.

9.3.5 Other Treatments

Other treatments such as soaking in fungicide solution (Phosphoric acid) and gibberellic acid (GA_3) were used experimentally where deemed appropriate, or as recommended.

Table 1. Recommended germination treatments.

Species	Recommended Treatment	Germination Time
Acacia aff. redolens	pour boiled water from kettle over seed and allow to soak for 2-24 hours, depth of sowing should be roughly equal to width of seed	2-7 days
Acacia bartleana Maslin (ms)	pour boiled water from kettle over seed and allow to soak for 2-24 hours, depth of sowing should be roughly equal to width of seed	2-7 days
Acacia cyclops	pour boiled water from kettle over seed and allow to soak for 2-24 hours, depth of sowing should be roughly equal to width of seed, optimum 15ºC, promoted by smoked water/ ash covering	2-7 days
Acacia lasiocalyx	pour boiled water from kettle over seed and allow to soak for 2-24 hours, depth of sowing should be roughly equal to width of seed	2-7 days
Acacia microbotrya		2-7 days
Acacia murrayana	pour boiled water from kettle over seed and allow to soak for 2-24 hours, depth of sowing should be roughly equal to width of seed, keep warm, optimum 20-28ºC	2-7 days
Acacia saligna	pour boiled water from kettle over seed and allow to soak for 2-24 hours, depth of sowing should be roughly equal to width of seed, keep warm, optimum 15ºC	2-7 days
Actinostrobus arenarius	should germinate without treatment if fresh, promoted by smoked water/ ash covering	?
Adenanthos stictus	sow shallowly, may be difficult, advise smoked water or ash covering	?
Agonis flexuosa	sow shallowly, but light is inhibitory, smoked water promotes	14-21 days
Allocasuarina huegeliana	plant as for Banksia, high viability if fresh, optimum probably 15-23ºC	14-21 days
Alyogyne hakeifolia	sow shallowly	?
Alyogyne huegelii		?
Anthocercis littorea	?, smoked water is probably required - as this species is a coloniser of dunes after fire events	?
Banksia prionotes	germinates easily but slow, should be planted horizontally or vertically with wing uppermost and lightly covered with soil, optimum probably 15ºC	3-6 weeks
Bursaria occidentalis	do not allow to come into contact with smoke chemicals, sow in cool to cold conditions - stratification at 2-4ºC for 3-4 weeks will overcome the need for winter sowing in summer, water with fungicide solution	8-10 weeks?
Callitris glaucophylla	should germinate without treatment if fresh, stratification at 2-4ºC for 2-4 weeks would increase germination	?
Casuarina obesa	seed is short lived (use or store in refrigerator), keep hot, optimum 30ºC	14-21 days
Codonocarpus cotinifolius	difficult, however, smoked water promotes germination	?
Corymbia calophylla	easily raised, optimum 13-28ºC	7-14 days
Dryandra arborea	plant as for Banksia, high viability if fresh but many are damaged by insect attack, optimum 15ºC	3-6 weeks
Dryandra sessilis		3-6 weeks
Duboisia hopwoodii	?, advise smoked water and/or gibberellic acid	?
Eucalyptus camaldulensis	sow shallowly or cover with a single layer of coarse sand, easily raised, optimum 15-30ºC	7-14 days
Eucalyptus erythrocorys	sow shallowly or cover with a single layer of coarse sand, optimum 15-23ºC	7-14 days
Eucalyptus loxophleba ssp. lissophloia	sow shallowly or cover with a single layer of coarse sand	7-14 days
Eucalyptus rudis	sow shallowly or cover with a single layer of coarse sand, optimum 20-30ºC	7-14 days
Eucalyptus todtiana	sow shallowly or cover with a single layer of coarse sand	7-14 days
Exocarpus sparteus	difficult, if passed through the gut of a bird or mammal germination increases dramatically, otherwise to mimic this effect try soaking in dilute acid for 24 hours, smoked water	?

Species	Recommended Treatment	Germination Time
	and gibberellic acid promotes, optimum probably 15ºC	
Grevillea candelabroides	soak in lukewarm or hot (not boiling) dilute fungicide solution for 28 hours	30 days
Grevillea leucopteris	soak in lukewarm or hot (not boiling) dilute fungicide solution for 28 hours, often germinates erratically	30-40 days
Gyrostemon ramulosus	difficult, if passed through the gut of a bird germination increases dramatically (emus eat and disperse this species), otherwise to mimic this effect try soaking in dilute acid for 24 hours	?
Hakea oleifolia	plant as for Banksia, high viability if fresh, 15-18ºC increases germination	2-5 weeks
Hakea prostrata		2-5 weeks
Jacksonia sternbergiana	pour boiled water from kettle over seed and allow to soak for 3-24 hours, depth of sowing should be roughly equal to width of seed, optimum probably 15ºC	7-14 days
Kunzea glabrescens	sow shallowly or cover with a single layer of coarse sand	14-21 days
Lambertia inermis	should germinate without treatment if fresh, optimum probably 15ºC	?
Melaleuca preissiana	sow shallowly or cover with a single layer of coarse sand, optimum 15ºC	14-21 days
Melaleuca rhaphiophylla	sow shallowly or cover with a single layer of coarse sand	14-21 days
Paraserianthes lophantha	pour boiled water from kettle over seed and allow to soak for 2-24 hours, depth of sowing should be roughly equal to width of seed, optimum 15-23ºC	2-7 days
Persoonia elliptica	soaking in gibberellic acid increases germination, otherwise very difficult	?
Pittosporum angustifolium	keep warm, optimum probably 28ºC	to 12 weeks
Pittosporum phylliraeoides	keep warm, optimum 28ºC	8-10 weeks
Senna pleurocarpa	Senna spp. are generally treated with hot water as for Acacias etc., although some may be killed by temperatures close to boiling point	?
Taxandria juniperina	sow shallowly, but light is inhibitory, smoked water promotes	14-21 days
Trymalium floribundum	pour boiled water from kettle over seed and allow to soak for 2-24 hours, optimum 15ºC	?
Viminaria juncea	easily raised, pour boiled water from kettle over seed and allow to soak for 3-24 hours, depth of sowing should be roughly equal to width of seed, optimum probably 15ºC	7-14 days

9.4 Seedling establishment

Specialised treatments were performed under laboratory conditions at Kensington. See Table 3 for a summary of all treatments used at Kensington. For proteaceous species, seed handling was relatively easy. After treatment, seeds of these species were placed in sterilised Petri dishes, with a basal layer of vermiculite to maintain even moisture, covered by a Whatman filter paper as the germinating medium. The filter paper was moistened using 5% smoked water and 0.2% phosphoric acid in standard tap water. Each Petri dish was labelled with species and date and placed into a germination cabinet at a constant temperature of 15°C. The number of germinants and date of emergence of the radicle was recorded regularly for each species.

All nurseries used 64 cell seedling trays featuring root training, air venting, air pruning and propping holes. These trays were washed for 15 minutes in a sterilising bath of

Phytoclean, rinsed, filled with potting mix and levelled. All nurseries had the option of following the recommendations on treatment and planting in Table 1. Following their respective treatments, imbibed seeds or pre-sprouted seeds (at Kensington) were placed in trays at the appropriate depth and watered in. Fine seeds were covered with a thin layer of coarse river sand at the Kensington Nursery. All trays were placed on raised steel benches and received overhead irrigation from fine sprinklers.

The number of trays sown at Narrogin and Kalannie was higher than Kensington for many of the species (Table 4). At Kensington, all species were sown into three trays except *Codonocarpus cotinifolius* and *Gyrostemon ramulosus* which were sown into six trays per provenance.

All Nurseries submitted data pertaining to the number of stock plants emerged or actively growing twice during the growing period. At Kensington, each tray was observed regularly for signs of emergence of germinating seedlings. Dates of emergence were recorded according to the appearance of cotyledons above soil level. The date at which 80% or higher germination was achieved was also recorded.

9.5 Results

9.5.1 Germination and growth

Germination data for Kensington is presented in Table 2, while summary production data for all three nurseries are contained in Table 4. For photographs of the Kensington nursery and some of the seedlings, including some for which germination and establishment was highly successful, and some which proved more difficult, see Figure 3 to Figure 9.

Most species germinated without problem and grew satisfactorily. However, as expected, some species were more difficult or patchy. Some observations made during this project include:

- Notable differences were seen in germination of provenances of *Acacia spp.,* except for *A. saligna*, which had uniform germination between provenances.
- The success rate of *Actinostrobus* was high following soaking in smoked water.
- Both *Alyogyne* species had a poor germination rate, although germination of one provenance of Alyogyne huegelii (NS21854) was relatively high.
- *Anthocercis littorea* performed far better at Narrogin than Kalannie. This species flowered in both nurseries and had set seed in the Narrogin nursery by July.
- *Callitris glaucophylla* had a very low germination rate, and none of the nurseries produced more than half a tray of seedlings, although the highest number of these were produced at Kalannie.
- *Codonocarpus cotinifolius* did not germinate at Kalannie, and was poor at Narrogin and Kensington. No nursery achieved 50% of the specified quantity. Both Kensington and Narrogin experienced problems with seedlings smothering each other due to the initial flat growth habit, so the number of germinants exceeded the

number of seedlings produced. The trays used in this work are not suitable for large scale production of these seedlings, unless 75% of cells are not used.

- *Dryandra arborea* had excellent germination, but slow growth, while *D. sessilis* had poorer germination and faster growth.

Table 2. Germination at Kensington.

Species	First appearance	≥80% Emergence
Acacia aff. *redolens*	1 week	ND
Acacia bartleana Maslin (ms)		ND
Acacia cyclops		2 weeks
Acacia microbotrya		
Actinostrobus arenarius	2.5 weeks	1 month
Agonis flexuosa	1 week	2 weeks
Alyogyne hakeifolia	2 weeks	ND
Banksia prionotes	2 weeks	1 month
Callitris glaucophylla	3 weeks	
Codonocarpus cotinifolius	3 weeks	
Dryandra arborea	2 months	3 months
Dryandra sessilis		
Eucalyptus erythrocorys	1 week	2 weeks
Eucalyptus loxophleba ssp. *lissophloia*		
Eucalyptus todtiana		
Exocarpus sparteus	6 months	ND
Grevillea candelabroides	1 week	3 weeks
Grevillea leucopteris	ND	ND
Gyrostemon ramulosus (smoked water)	2 weeks	3 weeks
Gyrostemon ramulosus (smoked water + acid)	2.5 weeks	
Hakea oleifolia	2 weeks	
Hakea prostrata		
Lambertia inermis	1 month	1.5 months
Melaleuca preissiana	1 week	2 weeks
Melaleuca rhaphiophylla		
Paraserianthes lophantha	1 week	1.5 weeks
Persoonia elliptica	ND	ND
Pittosporum phylliraeoides	1 month	2 months
Taxandria juniperina	1 week	2 weeks
Trymalium floribundum	3.5 months	

NB: those results not determined ('ND'), are due to the low germination of this species resulting in less than 80% germination.

- None of the *Grevillea leucopteris* seed germinated, but *G. candelabroides* was partially successful at Kalannie. The success rate at Kensington was lower, while it did not germinate at Narrogin at all.
- All eucalypts (and *Corymbia*) performed well, with the exception of *Eucalyptus todtiana* at Kalannie and Kensington, but it was successful at Narrogin. The *E. todtiana* seedlings at Kensington were infected with a fungal disease, but neighbouring *Eucalyptus* seedlings of other species were unaffected.

- *Exocarpus sparteus* germinated poorly and took six months to germinate at all nurseries. Narrogin was the most successful with this species, followed by Kensington.
- *Gyrostemon ramulosus* failed to germinate at Narrogin and Kalannie, where vinegar was used, but was germinated and grew well at Kensington, where the seeds were treated with 5% sulphuric acid.

9.5.2 Comments on Proteaceous species

Differences in the overall germination characteristics of Proteaceous species were clearly defined. While germination of *Lambertia inermis* and *Dryandra* species tended to increase with time, both *Hakea* species had a short period of high germination (Figure 1).

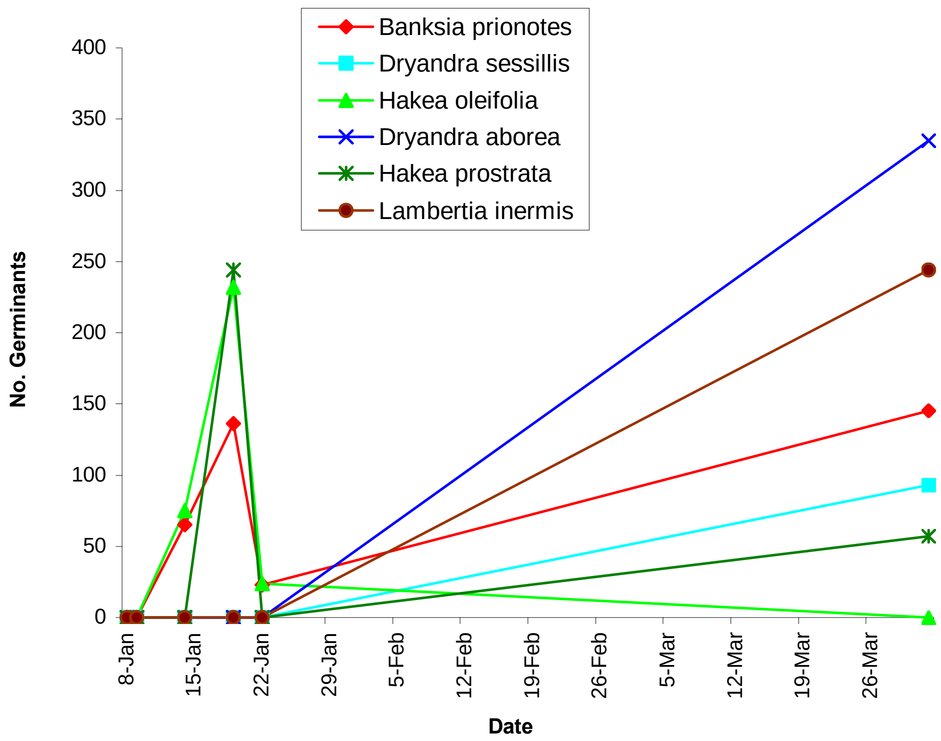


Figure 1. Progressive germination of Proteaceous species in vitro over 80 days.

For *Hakea oleifolia*, germination tended to decrease markedly after two weeks. *Banksia prionotes* possessed a more moderated germination habit, whereby germinant population remained relatively constant over the duration of the experiment.

Seed viability observations are summarised in Figure 2. Seed of *Lambertia inermis* and *Hakea prostrata* had the highest potential viability (>90%), while *Dryandra sessilis* and *Banksia prionotes* had a comparatively poor viability in vitro (≤70%). *Dryandra arborea* and *Hakea oleifolia* had good germination – higher than 80% of seed planted.

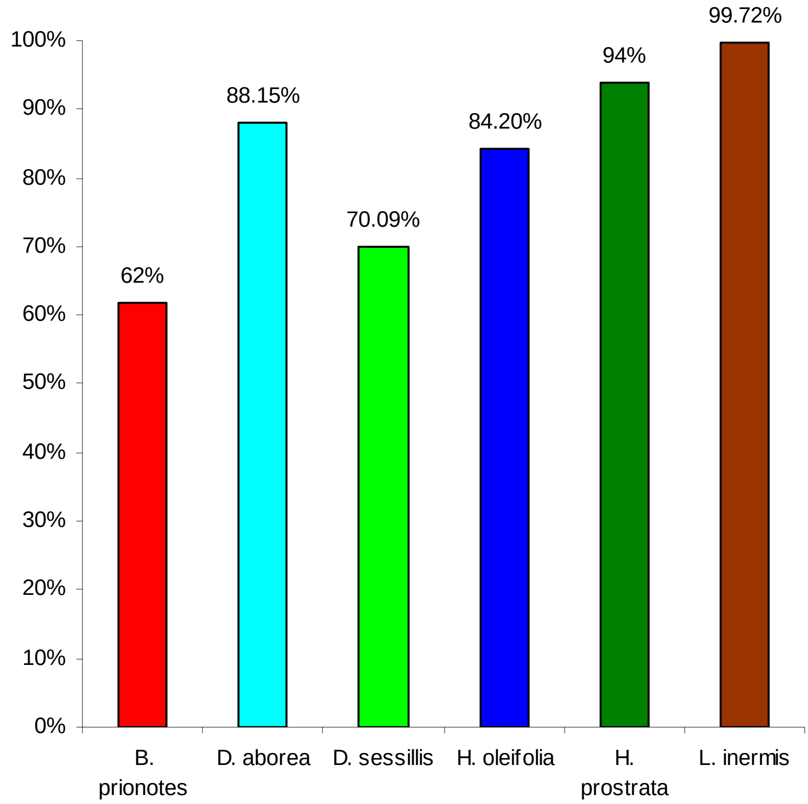


Figure 2. Percent viability of Proteaceous species in vitro.

9.6 Conclusions

Production of Myrtaceous, Casuarinaceous, Mimosaceous and Proteaceous species was predominantly uniform and reliable, although the germination of *Lambertia inermis* and especially *Dryandra* species required a relatively long time. The germination potential of *Banksia prionotes* and *Dryandra sessilis* were lower than the other Proteaceous species. Location did not have a large impact on germination for these families, except for some *Acacia* species, which performed better at Kalannie than Narrogin. *Grevillea spp.*, *Dryandra sessilis* and *Eucalyptus todtiana* showed the poorest overall performance in this grouping. Lack of germination in *Grevillea leucopteris* indicated that the seed was not viable or of poor quality, since this species is not usually difficult to propagate, and appropriate conditions were present for germination to occur.

Other plant families were more variable and generally more problematic. The most variable performers between nurseries were *Anthocercis littorea*, *Exocarpus sparteus*, *Codonocarpus cotinifolius* and *Gyrostemon ramulosus*.

The better performance of Gyrostemonaceae at Kensington, especially *Gyrostemon ramulosus*, is likely to be due to specific seed treatments that were used there. The best results in *Codonocarpus cotinifolius* were obtained from seed treated with acid and smoked water. A higher percentage of germination occurred in *C. cotinifolius* seed treated with acid although these took a longer time to germinate. Vinegar was not a successful substitute for acid treatment of *Gyrostemon ramulosus* seed.

An external experiment led to observations that germination of these species is far better when the surface of the potting mix is allowed to dry out between waterings. This indicates that the moist conditions that are required to raise most other species, especially tree eucalypts and melaleucas, may be detrimental to these species.

Alyogyne hakeifolia, *A. huegelii* and *Callitris glaucophylla* all showed consistently poor germination rates. For these species, low germination may present a significant barrier to larger scale use. It is possible that *Alyogyne spp.* require treatment with smoked water or another form of treatment to raise germination to an acceptable level.

One of the major barriers to successful germination of seedlings at Kensington was the presence of rodents, which predated on seed of *Acacia*, *Persoonia* and *Exocarpus*. Rodents were not controlled until substantial damage had already occurred to some species. Where additional seed was available some resowing was required.

Seed planted in Narrogin and Kalannie was invariably subjected to greater diurnal extremes of temperature, and this may have enhanced germination of *Callitris glaucophylla*, which seemed to perform slightly better with increasing diurnal range. However, it may simply be that such a species has a naturally staggered germination habit, perhaps as a result of adaptation to an unreliable arid climate.

Figure 3. CALM research nursery at Kensington, February 2003.

Figure 4. ***Dryandra arborea*, CALM Kensington, March 2003.**

Figure 5. ***Actinostrobus arenarius*, CALM Kensington, May 2003.**

Figure 6. ***Alyogyne hakeifolia*, CALM Kensington, May 2003.**
Note patchy establishment.

Figure 7. ***Codonocarpus cotinifolius*, CALM Kensington, June 2003.**
Note large rosettes.

Figure 8. ***Grevillea candelabroides*, CALM Kensington, May 2003. Note patchy establishment.**

Figure 9. ***Gyrostemon ramulosus*, CALM Kensington, June 2003.**

Table 3. Germination treatments used at Kensington.

Species	Pre-Sowing Treatment	Sowing Position
Acacia aff. *redolens*	Soaked in concentrated (98.08%) sulphuric acid for 60 minutes, washed in water, soaked in smoked water solution 1:10, washed	Imbibed seeds mainly sown 3-4mm covered with coarse sand.
Acacia bartleana Maslin (ms)		
Acacia cyclops		
Acacia microbotrya		
Actinostrobus arenarius	Soaked in smoked water for 24 hours	Sown at various depths varying from 2-15mm
Agonis flexuosa	None	Sown on flattened surface and covered with sand (effective 2-3mm)
Alyogyne hakeifolia		
Banksia prionotes	Soaked in smoked water for 24 hours	raised till radicle emergence in Petri dishes and transferred into trays, sown 3-4mm
Callitris glaucophylla	Stratified for 2 weeks at 4ºC	Sown at depth of 3-7mm
Codonocarpus cotinifolius	1) 3 trays of each Morawa and Youanmi collections were soaked in smoked water for 24 hours, washed of debris	Sown on flattened surface and covered with sand (effective 2-3mm)
	2) 3 trays of each provenance treated as above, but pre-treated by soaking in diluted sulphuric acid (5%) for 60 min	
Dryandra arborea	Soaked in Yates Anti-Rot (200g/L phosphorus acid present as mono-di potassium phosphite) 5mL:300mL water	raised till radicle emergence in Petri dishes and transferred into trays, sown 3-4mm
Dryandra sessilis		
Eucalyptus erythrocorys	None	Sown on flattened surface and covered with sand (effective 2-3mm)
Eucalyptus loxophleba ssp. *lissophloia*		
Eucalyptus todtiana		
Exocarpus sparteus	Soaked in 10% sulphuric acid solution for 24 hours, washed, soaked in smoked water 1:10 for 24 hours, exocarp removed	Sown ~5mm and covered with sand
Grevillea candelabroides	Soaked in hot water (~70ºC) with smoked water concentrate 1:10	Planted with 'pointed' end up and tip just emerging from surface, some of the cells had their soil level corrected by adding coarse sand
Grevillea leucopteris		

Species	Pre-Sowing Treatment	Sowing Position
Gyrostemon ramulosus	1) Soaked in 5% sulphuric acid for 24 hours, washed, soaked in smoked water for 24 hours	Sown at various depths and covered with sand (effective 2-3mm)
	2) Soaked in smoked water for 24 hours	
Hakea oleifolia	Soaked in smoked water for 24 hours	raised till radicle emergence in Petri dishes and transferred into trays, sown 3-4mm
Hakea prostrata		
Lambertia inermis	None	
Melaleuca preissiana	None	Sown on flattened surface and covered with sand (effective 2-3mm)
Melaleuca rhaphiophylla		
Paraserianthes lophantha	Soaked in concentrated (98.08%) sulphuric acid for 100 minutes, washed in water, soaked in smoked water solution 1:10, washed	Imbibed seeds mainly sown 3-4mm, covered with coarse sand
Persoonia elliptica	Soaked in pure gibberellic acid (ProGibb (110g/L GA3)) for 2 hours, soaked in concentrated (98.08%) sulphuric acid for 24 hours, soaked in water for 1 week (changed daily), pulp removed on a screen, seeds cracked carefully in a vice	Sown ~5mm and covered with sand
Pittosporum phylliraeoides	Stratified for 2 weeks at 4ºC	Sown on flattened surface and covered with sand (effective 2-3mm)
Taxandria juniperina	None	
Trymalium floribundum	1) Near boiling (~95ºC) water poured over seed, smoked water added to ratio 1:10, soaked in this for 24 hours	
	2) Soaked in smoked water 1:10 for 24 hours	

Table 4. Sowing date, trays sown, and number of stocked trays (May 2003) at each nursery.

Species	Provenance	CALM Narrogin			Kalannie Tree Supplies			CALM Kensington		
		Sown	Trays	Stock	Sown	Trays	Stock	Sown	Trays	Stock
Acacia aff. redolens	Scaddan	24/12/02		<1	20/12/02	5	(>9)	6/2/2003	3	2
Acacia bartleana Maslin (ms)	-	24/12/02		5	20/12/02	5	3	6/2/2003	3	2
Acacia cyclops	NS 21897	23/12/02		4	20/12/02	5	(>9)	4/2/2003	3	2
Acacia lasiocalyx	NS 19055	2/1/03		(>9)	28/12/02	12	(>9)			
	BRM 7953	2/1/03		4	28/12/02	12	(>9)			
Acacia microbotrya	Boddington	6/1/03		3	3/1/03	5	(>3)	23/1/2003	3	3
Acacia murrayana	P2 7942	2/1/03		<1	28/12/02	12	(>9)			
	P1 7942	2/1/03		6	28/12/02	12	(>9)			
Acacia saligna	Mandurah	6/1/03		9	3/1/03	11	(>9)			
	Boddington	6/1/03		9	3/1/03	10	(>9)			
Actinostrobus arenarius	SP 12	24/12/02		3	20/12/02	5	3	9/1/2003	3	3
Agonis flexuosa	N 202665	17/12/02		3	17/12/02	5	3	17/1/03	3	3
Allocasuarina huegeliana	SW 1	2/1/03		9	31/12/02	12	(>9)			
	SW 3	2/1/03		9	31/12/02	12	(>9)			
Alyogyne hakeifolia	NS 19177	3/1/03		1	20/12/02	5	<1.5	17/1/03	3	1
Alyogyne huegelii	Jerome	3/1/03		<1	16/12/02	12	1			
	NS 21854	3/1/03		4	20/12/02	12	6			
Anthocercis littorea	9584	6/1/03		9	28/12/02	13	<1			
Banksia prionotes	96104	23/12/02		3	28/12/02	5	2.5	9/1/03	3	3
Callitris glaucophylla	NS 24007	24/12/03		<1	21/12/02	6	<1	16/1/03	3	<1
Casuarina obesa	NA 4	2/1/03		9	18/12/02	10	(>9)			
	AV 15	2/1/03		9	31/12/02	12	9			
Codonocarpus cotinifolius	Youanmi	3/1/03		<2	20/12/02	12	0	9/1/03	6	2.5
	RD 9123	3/1/03		<2	20/12/02	12	0	9/1/03	6	4.5
Corymbia calophylla	N201493a	11/2/03		8	17/12/02	12	(>9)			
	N201497a	11/2/03		9	17/12/02	12	(>9)			
Dryandra arborea	WOS SP9a	6/1/03		(>3)	3/1/02	5	(<3)	10/1/03	3	3
Dryandra sessilis	11396	23/12/02		2.5	28/12/02	3	1.5	10/1/03	3	2.5

Species	Provenance	CALM Narrogin			Kalannie Tree Supplies			CALM Kensington		
		Sown	Trays	Stock	Sown	Trays	Stock	Sown	Trays	Stock
Eucalyptus camaldulensis	N 11997	31/1/03		9	28/12/02	12	9			
	N 13097	31/1/03		9	28/12/02	12	9			
Eucalyptus erythrocorys	N13997	17/12/02		3	17/12/02	5	(>3)	17/1/03	3	3
Eucalyptus loxophleba ssp. *lissophloia*	N 21497	17/12/02		3	17/12/02	5	(>3)	17/1/03	3	2.5
Eucalyptus rudis	N 200237	31/1/03		9	28/12/02	12	9			
	N 98169	31/1/03		9	28/12/02	12	9			
Eucalyptus todtiana	N 13897	24/12/02		3	28/12/02	5	1.5	17/1/03	3	2
Exocarpus sparteus	NS 22016	2/1/03		<2	20/12/02	5	0	21/1/03	3	0
Grevillea candelabroides	NS 21542	7/1/03		0	21/12/02	6	3	16/1/03	3	1
Grevillea leucopteris	NS 21863	7/1/03		0	21/12/02	5	0	16/1/03	3	0
Gyrostemon ramulosus	provenance 2	6/1/03		0	20/12/02	12		-	-	
	RD 9025	6/1/03		<1	20/12/02	12	<1	10/1/03 21/1/03	3 3	5
Hakea oleifolia	N 200195a	17/12/02		(>3)	17/12/02	6	3	9/1/03	3	3
Hakea prostrata	NS 24260	23/12/02		(>3)	28/12/02	6	(>3)	9/1/03	3	3
Jacksonia sternbergiana	NS 21837	27/12/02		7	20/12/02	11	5	-	-	
	15466	27/12/02		7	28/12/02	12	6	-	-	
Lambertia inermis	NS 21341	3/1/03		3	20/12/02	5	3	10/1/03	3	2.5
Melaleuca preissiana	N 16397	17/1/03		3	17/12/02	5	(>3)	17/1/03	3	<3
Melaleuca rhaphiophylla	NS 23323	23/12/02		3	20/12/02	5	(>3)	17/1/03	3	3
Paraserianthes lophantha	NS 19267	3/1/03		(>3)	20/12/02	5	3	23/1/03	3	>2.5
Persoonia elliptica								22/1/03	3	0
Pittosporum phylliraeoides	NS 21180	3/1/03		3	20/12/02	5	3	21/1/03	3	3
Senna pleurocarpa	NS 24177	24/12/02		9	20/12/02	11	9			
	NS 24176	24/12/02		9	20/12/02	11	9			
Taxandria juniperina	NS 20667	23/12/02		3	20/12/02	5	(>9)	17/1/03	3	2
Trymalium floribundum	Waroona	6/1/03		4	20/12/02	6	(>3)	23/1/03	3	3
Viminaria juncea	NS 21656	24/12/02		9	20/12/02	12	9			
	NS 19368	24/12/02		9	20/12/02	12	9			

9.7 References

Cavanagh, T (1987). Germination of hard-seeded species (order Fabales) *In* Germination of Australian Native Plant Seed. P Langkamp, Ed. Melbourne, Inkata Press.

Crawford, T, A Cochrane and R Probert (not dated). Acid scarification: an effective method of increasing the speed and synchrony of germination in five Western Australian Acacia (Mimosaceae) species. Department of Conservation and Land Management.

Olde, P and N Marriott (1994). The Grevillea Book. Kenhurst, NSW, Kangaroo Press.

Natural Heritage Trust
Helping Communities Helping Australia
An Australian Government Initiative

Search Project Report

Section 10 – Project Administration

Don Cooper and Jerome Carslake in CALM's research nursery at Kensington
(Photo: Graeme Olsen)

Final report for NHT Project 973849

July 2004

Government of Western Australia
Department of Conservation and Land Management
Conserving the nature of WA

Authors

Graeme Olsen[1]
Don Cooper[2]
Dan Huxtable[2]
Jerome Carslake[2]
John Bartle[2]

This report has been prepared to assist with assessment of potential new commercial opportunities based on woody perennial plants in the wheat-sheep agricultural zone of southern Western Australia. However, the work reported here is of a preliminary nature. While care has been taken in the report's preparation, no responsibility is taken by the authors or publisher for omissions or inaccuracies, or for the use of this information by any other party.

ISBN No: 0 7307 55509

[1] Olsen & Vickery, PO Box 357 Waroona, Western Australia 6215.

[2] Department of Conservation and Land Management, Locked Bag 104, Bentley Delivery Centre, Western Australia 6983.

Sections in this report

Section 1	Summary
Section 2	Background
Section 3	Search Methodology
Section 4	Product Assessment
Section 5	Species Selection
Section 6	Feedstock Testing
Section 7	Economic Analysis
Section 8	Demonstration and Resource Plantings
Section 9	Propagation Project
Section 10	Project Administration
Appendices	

Contents of this Section

Section 10 Project Administration 1

10.1 Funds management 1

10.2 Personnel 1

10.3 Contracts 2

10.4 Logistics 2

10.5 Project reporting 2

10.6 Project objectives – NHT application 3

Section 10 Project Administration

10.1 Funds management

The project was proposed and accepted in the 1997 Natural Heritage Trust round. However, there were protracted negotiations before the first NHT funds were transferred in 1998/99 and operations began in July 1999.

Project administration was the responsibility of CALM. John Bartle manager of the Farm Forestry Unit in the CALM Science Division supervised the project. The total funds allocation by NHT was $4.5 million, of which $1 million was provided under the Farm Forestry Program, and $3.5 million was provided under the Bushcare Program (Table 1). All funds were managed by CALM Corporate Services and subject to State Government accounting procedures and standards.

Funds provided by the two separate Programs (Farm Forestry and Bushcare) were managed as different sub-projects and accounted for separately.

Table 1. Expenditure sources and totals

	In-kind Investment by CALM	In-kind investment by farmers	NHT Funds		Total Project Funds
			Farm Forestry Program (AFFA)	Bushcare (Environment Aust)	
Approved	$500 000	$4 000 000	$1 000 000	$3 500 000	$9 000 000
Expended	$500 000	$4 000 000	$1 000 000	$3 500 000	$9 000 000
Unspent			Nil	Nil	Nil
TOTAL	$500 000	$4 000 000	$1 000 000	$3 500 000	$9 000 000

10.2 Personnel

The project employed three staff full time. Don Cooper was employed as project scientist under the Farm Forestry section of the project. Dan Huxtable and Jerome Carslake managed the Bushcare section.

Graeme Olsen of Olsen and Vickery was contracted to provide project management services to the project and in particular to oversee the technical and commercial aspects of the Farm Forestry section.

Wayne O’Sullivan of Arboressence Consultancy was contracted intermittently to collect plant specimens, seed and wood samples from the native flora of the south west of WA.

David Kabay was contracted to supervise the Bushcare field operations in 2002 and provide support in 2003.

10.3 Contracts

Contracts were entered into with some 15 nurseries throughout the south-west of Western Australia to supply the 6.7 million seedlings planted during the term of the project.

Contracts to supply wood testing services were let in the final year. CSIRO Forestry and Forest Products provided an array of wood and product testing services for pulp, paper and panel boards at Clayton in Victoria, CSIRO Energy Technology at Newcastle in New South Wales tested biomass combustion properties, and the Forest Products Commission in Western Australia conducted tests on timber suitable for solid wood products. Wood and bark samples were tested for ash properties by Simcoa Operations Pty Ltd at Kemerton, Western Australia.

10.4 Logistics

CALM provided the administrative home base for the project. The Farm Forestry Unit within the Science Division supervised the project, accommodated staff and provided services and overheads.

The project was managed as a whole, but the separate identity of the two parts was retained so that the expenditure of funds accurately reflects the undertakings made by the project. For convenience the project team selected a short title, the 'Search Project', and the project became widely known by this name.

All NHT projects required approval of a 'continuing project' proposal each new 'NHT year' (October to September). The approval process was protracted and in every year of the project approval was delayed well into the ensuing year, often up to December, which caused considerable difficulty in the logistics of collecting seed and ordering nursery stock for the following winter's planting programs.

10.5 Project reporting

NHT has prescribed 'Project Final Report' and 'Financial Acquittal Certificate' documents. These documents have been completed and submitted separately.

They are essentially administrative reports and are not sufficient to fully report the process, analysis and outcomes of the project. This Terminating Report has therefore been prepared for this purpose.

The project has completed a considerable body of data collection and analysis and this is fully reported here. Much of the laboratory testing of biomass components, especially wood, was completed very late in the project term and the project team is aware that there has not been sufficient time to prepare a full synthesis of these results. However, the ‘Search Project’ has built a considerable following. The Joint Venture Agroforestry Program, a consortium of national R&D corporations, and the Co-operative Research Centre for Plant-based Management of Dryland Salinity have both adopted the search theme and are committed to further development, based on the foundation work provided by the Search Project. Since the members of the project team are also major participants in this further work, there will be an opportunity to complete a full synthesis and analysis of the Search Project’s results as part of direction setting for the new work.

10.6 Project objectives – NHT application

This section is presented here to provide a complete background to the “Search” project.

It presents the statement of objectives and method within the industry development framework as originally proposed in the NHT application which led to the establishment of the “Search” project – formally known as NHT Project 973849, “Selection and development of multiple purpose species for large scale revegetation”.

10.6.1 Background – Industry development framework

This framework for development of new woody plant crop prospects has been prepared to indicate the position of the search and pre-feasibility steps in the development process. It is shown schematically in Figure 1. Each step in the process is briefly described below.

10.6.1.1 Search routine

Develop a procedure by which the most prospective perennial species and products can be systematically identified. Will consist of sets of biological, environmental, management and economic attributes for assessment of likely prospects.

10.6.1.2 Pre-feasibility analysis

More rigorous assessment of search attributes to identify a shortlist of most prospective species/products with particular reference to:

- cost of production
- yield and quality
- markets and prices
- potential for economies of scale
- biodiversity, landcare and community benefits
- initial economic analysis

10.6.1.3 Industry exploration

Plan and commence building the foundation for an industry.

Technical development

- select and improve genetic resources
- produce improved seed and develop propagation techniques
- design all aspects of agronomy/silviculture for multiple purpose management
- develop harvest and processing techniques
- invest in product development science
- residue utilization

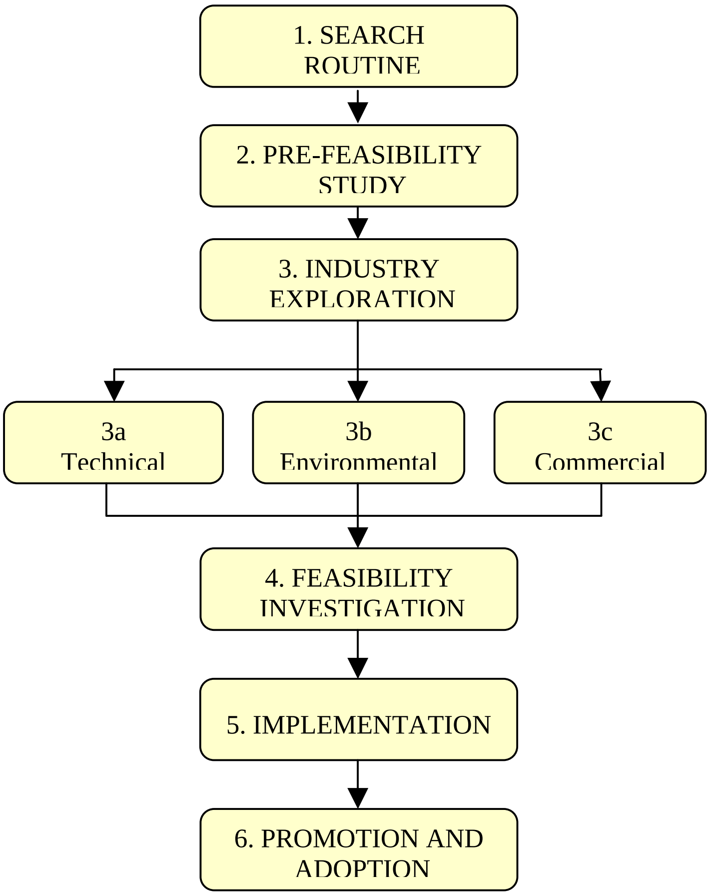


Figure 1 Industry development framework.

Environmental design and management

- design agricultural systems to incorporate land, water and biodiversity conservation
- evaluate prospects for commercial species mixtures

- o role of revegetation and biomass residue in carbon sequestration, renewable energy
- o assess the economic value of environmental benefits
- o prepare extension materials to promote land, water and biodiversity conservation

Commercial and business development

- o build a grower constituency
- o establish an initial resource
- o establish demonstration plantings/farms
- o investigate major product options
- o find buyers and markets
- o conduct economic analyses

10.6.1.4 Full feasibility investigation

Prepare industry business plans

- assemble all interests
- prepare full feasibility and industry development plans
- corporate structure
- raise capital
- formalise legal arrangements
- tax incentives

10.6.1.5 Implementation

- Formation of industry group
- Arrangements to overcome initial investment barriers to new crops

10.6.1.6 Promotion and adoption

- Awareness raising material and activities

10.6.2 Search project description and method

The Search project will undertake the first three stages of commercial development of new revegetation species:

- selection of prospective species and products,
- preliminary investigation of the feasibility of their development, and
- commencement of industry exploration

Each development stage is described below.

10.6.2.1 The search routine

The potential number of native species to be considered is very large, requiring a systematic selection process to identify a manageable number of prospective species for feasibility investigations.

The search stage will include the creation of a database system to store and manipulate data relating to these attributes. It is expected that a conceptual level identification of the most prospective species and product combinations will be readily achieved. This will then be used to focus the investigations of stage 2. The search routine will be applicable nationally.

The assumption underlying the search routine is that value for commercialization can be estimated by systematic assessment of species and product attributes, and that this process will identify those species and products with a high priority for pre-feasibility investigation. Attributes will be selected from the following classes of information:

Species autecology

What inherent biological characteristics of the species might favour commercial development? For example, if a species can coppice it would be suited to short cycle harvests, if it is amenable to modern breeding and propagation methods genetic gain will be rapid. A conceptual selection of attributes relating to species systematics, morphology, breeding system, longevity, site requirements (landscape, edaphic, climatic preferences and tolerances) will be assembled.

Nature conservation values

These will be developed around the criteria used in REX e.g. weed risk, local and regional species, capacity to provide fauna habitat and other wildlife resources.

Management systems

What is the likely adaptability of the species to management within sustainable agriculture? Can it be readily integrated? This will require assessment of characteristics such as palatability to grazing animals, root systems and their degree of competition or complementarity with agricultural plants, harvest frequency, contribution to land and water conservation.

Species product potential

What are the attributes of the wood, leaf, bark, fruits of the species? For example, is the wood amenable to pulping, chipping, flaking and gluing for panel board products? Attributes relating to wood properties, non-wood product potential, piece sizes, by-products and residues will be assembled.

Products

Major product groups include sawn timber, reconstituted wood, extractives, fibre, carbon, chemicals and energy. Attributes relating to national and international market volumes, prices, trends in volume and price, areas of product innovation and major producers and competitors will be required.

Economics and marketing

What is the likely unit cost of production, scale of production, economies of scale, industry and product development costs, infrastructure and market development cost.

10.6.2.2 Pre-feasibility investigation

This stage will assemble information on the full range of attributes in the search database. This will be done by scouring existing sources of information, but will also require new investigations - especially for key attributes for which there are no existing data. Pre-feasibility investigation might initially be conducted at a general level to assess the suitability of particular plant types for certain products, for example, short-cycle species for panel board feedstocks, long-cycle species for sawn timber, or the suitability of particular families or genera to supply chemical extractives. This will help refine search attributes, provide data in a priority sequence and give early indication of most promising prospects. More detailed pre-feasibility investigation will then focus on particular prospects. The aim is to rapidly build a short list of 12 best prospects.

Pre-feasibility will evaluate the basic parameters of success i.e. cost, yield, quality, price and non-commercial benefit for each prospect, by passing through the following sequence:

- collate existing information: from published literature, unpublished reports, consultation with authorities and experts, workshop sessions.
- collect new information: from existing trial plots, native populations or market research.
- generate new information: establish new plots to test field performance, laboratory assessment of product potential, product and market testing, investigate non-commercial benefits on and off farm.
- analysis: conduct appropriate economic analyses to rank prospects.

10.6.2.3 Industry exploration

The most promising prospects identified by these processes will then be carried forward to the next stage of commercial development, called industry exploration. Note that the project includes some initial industry exploration work prior to completion of the search stage, in the form of demonstration plantings. For these initial plantings, species will be chosen that are considered by local experts to have high potential for commercial development, with emphasis on the genera *Eucalyptus*, *Melaleuca*, *Acacia* and *Allocasuarina*.

Industry exploration work will initially involve demonstration planting of obvious or intuitive prospective options. In the second and third years it will be directed into the development of good prospects identified by the search and pre-feasibility stages.

Hence industry exploration will have 2 parts as follows:

Initial testing of subjective selections

It is proposed that some 10 to 20 potentially commercial native wheatbelt species will be planted in typical integrated arrays totalling at least 50 ha at each of 20 sites selected to represent the full range of wheatbelt environments. These sites will be designed to be permanent demonstrations of multiple purpose tree crop management incorporating commercial, biodiversity and landcare objectives. A high public profile will be developed for the project by involving the major regional groups in the project especially to help with site selection, species selection and on-going management. The size of the planting site and the need to have wide discretion to apply suitable planting arrays for each species diminishes the potential for cost sharing with the farmer. However, cost-sharing arrangements will be sought and where successful this will be used to increase the size of the planted area. The project's large demonstration component, dispersal of sites and need for considerable detailed planning will require a project manager for 15 months. On a comparable basis to the oil mallee work the effective treated landscape area will be 2 to 3,000 ha.

Species selection will be decided by the Project Management group but will include some species from each of the key genera (*Eucalyptus, Melaleuca, Allocasuarina* and *Acacia*). It will include likely prospects from the most of the main categories of potential products (sawn timber, reconstituted wood, extractives, fibre, carbon, chemicals and energy).

Development planting of new prospects identified by the search process

As short-listed species are identified a sample of the 3 highest priority prospects will be inducted into field-scale development which will consist mainly of planting to establish a resource base. It is hoped that stages 1 and 2 will have advanced far enough by year 2 for a clear identification of the highest priorities to be made, and for actual field planting to commence in winter 2001.

Each prospect will require a sub-project manager and finance for seedlings to encourage rapid adoption. The objective will be to build a viable resource base for an industry within the context of sustainable agriculture and biodiversity conservation.

This process will follow the demonstrably successful oil mallee model.

Search Report

Appendix 1

Pulp and paper review

CSIRO Forestry and Forest Products

Commercial in Confidence
Client Report No. 1344

An overview of the pulp & paper industry

J. R. B. Hague and N. B. Clark

September, 2003

Client: Dept of Conservation & Land Management, Dept of Industry & Technology, WA Govt.

Contract No: FFP 02/235

EXECUTIVE SUMMARY

This report provides an overview of the pulp and paper industry, covering markets, manufacturing processes, feed-stocks, paper types and future trends in the industry. Against this background, potential opportunities and prospects in the pulp and paper industry for woody biomass grown in low rainfall regions in WA are identified.

Key Features of the Pulp and Paper Industry

- The world consumption of paper products is currently around 330 million tonnes per annum.
- Strong growth in world demand for all the main types of paper product is expected over the next decade. Growth in the Asia-Pacific region will be particularly strong (between 6 and 12% depending on paper type).
- The technologies used to produce pulp and to manufacture paper will remain essentially unchanged for the foreseeable future. The most significant changes will occur in the value-adding sector of the industry e.g. printing, coating etc.
- Worldwide, Kraft chemical pulp and recycled fibre currently dominate the paper industry, with each providing approximately 40% of the total fibre used in the manufacture of products. The remaining fibre needs are met largely by mechanical, semi-chemical and non-wood pulps. In the Asia-Pacific region, recycled fibre comprises around 50% of paper products, and Kraft pulp around a quarter.
- Kraft pulp and recycled fibre will continue to dominate the industry in the future, and non-wood pulp will decline in importance. New Kraft mills will be constructed around the world in the next decade, with older, less competitive mills being closed.
- The current market for hardwood chips for pulping in the Asia-Pacific region is around 13.5 million bone dry tonnes per annum. Japan is the dominant consumer (87%), and Australia is a major supplier (30%). The hardwood chip market in the region will remain strong in the future, with Japan continuing as the principal consumer.

Opportunities and Prospects for Low Rainfall Woody Biomass

- Woody biomass grown in the low rainfall agricultural regions of WA would most likely be derived from hardwood species. The material could thus potentially be a feed-stock for the Kraft hardwood pulp industry.
- To penetrate the wood chip market, low rainfall woody biomass would need to be competitive with respect to price and quality, with pulp yield, wood density and fibre length being the key material properties that would need to be addressed.
- A major barrier to market entry could be the generation of feed-stocks from species which were new and unfamiliar to the pulp industry. Significant initial investments would probably be required (from growers and suppliers) to ensure that the resource became accepted in the market place.
- An ideal scenario for low rainfall woody biomass would be the construction of an ‘in-land’ pulp mill in WA, which could be supplied by wood resources derived from both high and low rainfall zones. This would reduce the impact of transport costs. However, it is likely that significant incentives would be required to persuade potential investors to fund such a venture.

AN OVERVIEW OF THE PULP & PAPER INDUSTRY

Jamie Hague & Noel Clark

30 September 2003

TABLE OF CONTENTS

EXECUTIVE SUMMARY **1**

KEY FEATURES OF THE PULP AND PAPER INDUSTRY 1
OPPORTUNITIES AND PROSPECTS FOR LOW RAINFALL WOODY BIOMASS 1

TABLE OF CONTENTS **2**

INTRODUCTION **3**

MARKETS **3**

WORLD PRODUCTION 3
ASIA-PACIFIC REGION 4
AUSTRALIA 4

MANUFACTURING PROCESSES **5**

RAW MATERIALS 5
PULPING PROCESSES 7
Chemical Pulping Processes *7*
Mechanical Pulping Processes *11*
Semi-chemical Pulping Processes *14*
RECYCLED FIBRE 15
BLEACHING 17
PAPER-MAKING 18
Stock Preparation *18*
Additives *18*
The Paper Machine *18*
TYPES OF PAPER PRODUCT 20

PROSPECTS **21**

PROSPECTS FOR LOW RAINFALL WOODY BIOMASS GROWN IN WA 23

CONCLUSIONS **24**

BIBLIOGRAPHY **25**

Information for CSIRO abstracting:

Contract number	FFP 02/235
Products investigated	Literature pertaining to the pulp and paper industry
Wood species worked on	N/A
Other materials used	N/A
Location	Clayton, VIC.

INTRODUCTION

The creation of new industries, based on novel, short rotation woody biomass crop systems, in low to medium rainfall regions of WA is proposed as one of the solutions for mitigating the effects of salinity and the associated degradation of agricultural land. However, for large scale planting of woody crops to succeed, it will clearly be important that there are markets for the woody biomass that will be produced. An established, large scale consumer of woody biomass is the pulp and paper industry, which produces over 300 million tonnes of paper-based products annually worldwide. This industry thus represents a major potential market for low rainfall woody biomass.

The document reviews the main elements of the pulp and paper industry, focusing on markets and the key types of feed-stock, pulping processes and paper products. Against this background, the potential prospects for woody biomass feed-stocks grown in low to medium rainfall zones of WA are discussed.

MARKETS

Despite all the predictions in the latter half of the 20th century regarding the 'paperless' office with the advent of the computer age, world demand and consumption for pulp and paper-based products has continued to increase steadily. Consumption is broadly linked to GDP, and whilst there is certainly evidence that in developed counties the rate of increase in consumption is slowing, consumption is increasing strongly in other parts of the world, in particular Asia.

World Production

Annual world *pulp* production is currently around 185 million tonnes. Production is dominated by chemical pulp (principally alkaline Kraft pulp), which stands at around 125 million tonnes per annum, constituting some 70% of total world pulp production. Of the remainder, some 20% of world pulp production is mechanical pulp, with 10% being comprised of 'other' pulp types, primarily semi-chemical and non-wood pulps.

Annual world *paper* production is currently around 330 million tonnes. There are numerous grades of paper product, but they can be broadly grouped into 3 categories. Packaging and other paperboard dominates world production, and production currently stands at around 200 million tonnes per annum i.e. 60% of total world paper production. Printing and writing papers comprise some 30% of world production i.e. 100 million tonnes per annum, with newsprint accounting for around 10% (30 million tonnes) of world annual paper production.

The disparity between world pulp and paper production figures reflects the increasing reliance by paper-makers on recycled, or secondary, fibre as a feed-stock for products. Much of the growth in paper production in recent years has been met almost exclusively by recycled fibre, and use of the latter now exceeds at least 100 million tones per annum worldwide. Considerable quantities of fillers, principally clays, are also used in the manufacture of paper products.

Whilst all pulp types and products are traded internationally or regionally to some extent, international trade is dominated by chemical pulp. Prices for chemical pulp can fluctuate dramatically over time, and this can cause some instability in the industry and market place. Over the last 15 years the price for bleached Kraft pulp has varied between A$500/tonne (in 1993) and A$1300 / tonne (in 1996). More recently (2001) prices have been relatively low at around A$550/tonne, but have shown some signs of increasing.

Asia-Pacific Region

In 2000 the consumption of paper fibre in the Asia-Pacific region was estimated to be around 95 million tonnes. Around half of this consumption was comprised of recycled fibre, approximately one quarter was chemical pulp, and the remainder was a mixture of mechanical, semi-chemical and non-wood pulps. The major consumers in the region are China and Japan, each accounting for around a third of the regions total consumption.

Consumption of printing and writing papers in 2000 was 27 million tonnes, with 28 million tonnes being manufactured in the region. Newsprint consumption, at 9.5 million tonnes exceeded production by around 1 million tonnes. Consumption of corrugated medium and carton-board was around 39 million tonnes, which exceeded production by around 2.5 million tonnes.

In 2000 some 21 million tonnes of bleached Kraft pulp were consumed in the region. Of this total, 10 million tonnes were traded or purchased as market pulp, with 6 million tonnes being derived from hardwoods and 4 million tonnes from softwoods. The region imported approximately 3 million tonnes of hardwood pulp and 3.5 million tonnes of softwood pulp to meet its needs. Brazil, Canada and the USA were the main suppliers of hardwood pulp, whilst Canada, USA and Russia were the main suppliers of softwood pulp.

It is worth noting that in the Asia-Pacific region there is significant trade in wood chips for pulping. The major consumer of wood chips is Japan, accounting for 87% of the 13.4 million bone dry tonnes of hardwood chips that were traded in the region in 2000, and the bulk of the softwood chips, with Japanese imports amounting to 6.5 million m^3 in 2000. Australia supplied approximately 30% of the hardwood chips and nearly 40% of the softwood chips to Japan in 2000. The USA was the other major supplier of chips.

Australia

Figures for the production, export, import and apparent consumption of the major types of paper products in Australia in 2000-2001 are summarised in Table 1 (ABARE, 2002). It should be noted that whilst there are some obvious apparent discrepancies in the data, they do nonetheless serve to highlight the key features of the industry in Australia. For example, differences in the trade balances in household, sanitary, packaging and industrial products are relatively small when compared with newsprint and printing and writing papers in particular. Imports of printing and writing papers totalled over 750,000 tonnes, with North America, Finland and Indonesia being the main suppliers. Imports of newsprint approached 300,000 tonnes, with over half being supplied by New Zealand, almost a quarter from South Korea and the bulk of the remainder coming from Indonesia.

Table 1: Apparent consumption, production, imports and exports of major paper products in Australia in 2000-2001.

Product Type	Production (kT)	Exports (kT)	Imports (kT)	Apparent Consumption (kT)
Newsprint	465	3	284	700
Printing & Writing	554	100	760	1253
Household & Sanitary	204	23	55	252
Packaging & Industrial	1449	404	311	1510
TOTAL	**2672**	**530**	**1410**	**3715**

In 2000-2001 Australia imported around 300,000 tonnes of pulp, predominantly bleached softwood and hardwood Kraft pulps. The softwood pulps were supplied primarily from New Zealand, Canada and the USA whilst the hardwood pulps were supplied predominantly by Indonesia, New Zealand and Thailand. The softwood pulps were used in tissue manufacture as well as reinforcements in a range of paper grades. The hardwood pulps were used for printing and writing and tissue grades.

MANUFACTURING PROCESSES

The pulp and paper industry is vast and complex, with a large range of paper products produced worldwide. However, the basic principles of pulping, bleaching and paper-making are relatively straightforward and differ only in minor detail between products and processes. This section provides an overview of the key elements and processes comprising the industry, including:

- Raw materials
- Pulping processes
- Recycled fibre
- Bleaching
- Paper-making
- Types of paper product

Raw Materials

Worldwide wood is by far the most common raw material used for manufacturing pulp and paper, with less than 10% of the worlds' feed-stocks derived from non-wood materials. The wood of both softwoods e.g. pines, firs etc. and hardwoods e.g. Eucalypts, Acacias etc. is used extensively. The choice of wood raw material is dictated by a number of factors, including local availability, pulping process and paper product. Both hardwoods and softwoods are pulped using full chemical pulping processes, with the softwood pulps being predominantly used in products where high tensile and tear strength is required e.g. sacking and liner paper in corrugated cardboard. Bleached hardwood chemical pulps are used extensively in printing and writing papers. In contrast, only softwoods tend to be utilised in mechanical pulping operations, as the process leads to significant shortening in mean fibre length. Mechanical pulps are used in newsprint, magazine and packaging applications. Both hardwoods and softwoods are pulped using semi-chemical (i.e. pulping processes which combine both a chemical and mechanical component) processes, with the resulting pulps being used predominantly for packaging applications.

Non-wood materials have been classified into three main categories based on their source, availability and properties (Misra, 1980):

- By-products from agriculture e.g. cereal and rice straws, bagasse (the fibrous residue from sugar cane processing).
- Naturally growing plants, primarily 'grasses' e.g. bamboo, esparto and sabai grasses, reeds, miscanthus (Elephant grass).
- Long fibred cultivated crops, with fibres derived from particular parts of the plant e.g. leaf fibres from abaca, sisal and henequen; bast (stem) fibres from jute, hemp, kenaf, flax; 'fruit' fibres from cotton, kapok, coconut.

The agricultural by-products and grasses effectively represent alternatives for wood, and hardwoods in particular. They are typically processed via chemical or semi-chemical routes, and often require less severe pulping regimes compared with wood owing to their lower lignin content and more accessible cellular structure. The Soda process (pulping with sodium hydroxide) is commonly employed. The unbleached pulps may be used for a variety of packaging products, whilst the bleached pulps can be used for printing and writing papers. The pulps will often be blended with wood-based pulps.

The long-fibred non-wood materials are typically chemically pulped, and the resulting pulps used for high value, speciality papers. Classic examples include bank note, cigarette and tea-bag papers.

Non-wood materials have tended to be used in those parts of the world where pulping technology is less advanced, operations are relatively small scale, the discharge of effluents into the environment is tolerated (though it has a high environmental impact) and where wood is relatively scarce. China and India have been the traditional dominant players in this respect, but more recently these countries have started to switch towards wood as the favoured raw material for pulp, as older, smaller operations are shut down and new larger mills come on line. These latter investments have been made possible by increasing quantities of plantation wood coming to maturity, and have also been driven by sharp increases in domestic demand for pulp and paper with increasing GDPs. Non-wood materials are less suited to large scale, modern chemical pulping operations for a number of reasons, including:

- The transport costs for the relatively bulky materials become increasingly significant and eventually prohibitive.
- The silica present in many of the materials causes scaling problems in the evaporators and boilers of the recovery process.
- Pulp yields are often lower than those obtained with plantation woods.
- The pulps are relatively ‘delicate’ compared with their wood counterparts, and can be significantly degraded just through being transported and pumped around the mill.
- The bulky nature of the feed-stocks can reduce throughputs, leading to increased unit production costs.

Wood costs vary significantly between different regions of the world, and can also fluctuate over time as a result of cyclic changes in supply and demand. In general, apart from a marked peak in the price of wood chips in particular (as opposed to roundwood) around the world in the mid 1990s, the real cost of wood delivered to mills has generally fallen over the last 15 years. In Australia the price of softwood chips has varied from around A$100 to A$80 / oven dry metric tonne (odmt) of delivered chips, whilst the delivered price for hardwood chips has varied between $110 and A$130/odmt. In both cases the lower prices reflect prices for chips in the latter half of 2002.

The global average delivered price for softwood pulp logs and chips was approximately US$69/odmt in the latter half of 2002. The price for hardwood logs and chips was slightly lower at approximately US$66/odmt. However, there was significant variation around these global average prices. For example, hardwood roundwood prices in the US Northwest averaged US$69/odmt, with a range of US$49 - US$84/odmt, whilst those in Brazil averaged US$23/odmt, with a range of US$21 - US$32/odmt. In Australia prices averaged US$51/odmt, with a range of US$28 - US$71/odmt. The highest prices for wood are typically found in Japan, with imported hardwood chips commanding an average delivered price of US$128/odmt, with a range of US$93 - US$148/odmt. The marked range in prices of wood chips to some extents reflects differences in chip quality, particularly in relation to pulp yield. Pulp yield has a significant effect on pulp mill profitability, and high yielding chip resources will command a premium price in the market place.

Pulping Processes

Pulping processes can be broadly divided into three main categories:

- **Full chemical**. Fibre separation is achieved by dissolution of the lignin component by chemical action at elevated temperatures.
- **Mechanical**. Fibre separation is achieved by physically rubbing fibres apart with mechanical energy.
- **Semi-chemical**. Fibre separation is achieved by a combination of chemical and mechanical action.

The principal components of the main pulping processes are described in the following.

Chemical Pulping Processes

Amongst the oldest chemical pulping processes are the so-called Soda process, in which wood is pulped under alkaline conditions in a solution of sodium hydroxide, and the Sulphite process, in which wood is pulped under acid conditions in sulphurous acid with calcium as the base. For many years the Sulphite process was the dominant chemical pulping process, utilising mainly softwoods, as it produced the brightest unbleached chemical pulps which could be easily bleached to high brightness levels. However, today it is now very much a minor player in the chemical pulping industry. The decline in popularity of the process has been due to a number of factors:

- The Sulphite process is only capable of effectively utilising a limited number of softwood species; softwoods and hardwoods which contain polyphenolic (tannins) extractives cause problems.
- The Sulphite process lacks an effective process for recovery of the pulping chemicals and utilisation of the waste generated by pulping.
- The introduction of the Kraft process as the successor to the Soda process, in which sodium sulphide was added to the sodium hydroxide, resulting in accelerated delignification of wood with less damage to the cellulose and hemicellulose, giving rise to higher pulp yields. The Kraft process also has an effective process for recovering the cooking chemicals and utilising the waste as a fuel in the plant.

The Kraft pulping process is now not only the dominant chemical pulping process worldwide, but is also *the* dominant pulping process, with around 70% of the worlds' paper pulp being produced using the process. A feature of the Kraft process is that there are significant economies of scale associated with the recovery process, and this has resulted in modern mills being typically very large in scale, with high associated capital costs. Such mills have input capacities of between 2 and 3 million green tonnes of wood per annum, and output capacities of the order of 500,000 to 750,000 air dry tonnes of pulp per annum, and require between A$1.4 and A$2 billion of capital investment. Such investments are not made lightly!

The pulping process itself is relatively straightforward, and is performed in a continuous digester (see Figures 1 and 2). The pulping chemicals consist of sodium hydroxide and sodium sulphide. The reactions that occur in the pulping process are complex and not fully understood, but it is generally believed that the sulphide component causes sulphonation of the propane chains connecting the phenolic groups in the lignin molecule. Further reaction causes break up of the lignin molecules into smaller fragments (see Figure 3), the sodium salts of which are soluble in the cooking liquor. The sodium sulphide also hydrolyses the sodium hydrosulphide and hydroxide, such that as sodium hydroxide is consumed in the process more is made available. In this way, excessively high concentrations of sodium hydroxide in the cooking liquor are avoided, which would otherwise lead to significant degradation of the cellulose and hemicelluloses in the wood (Britt, 1970).

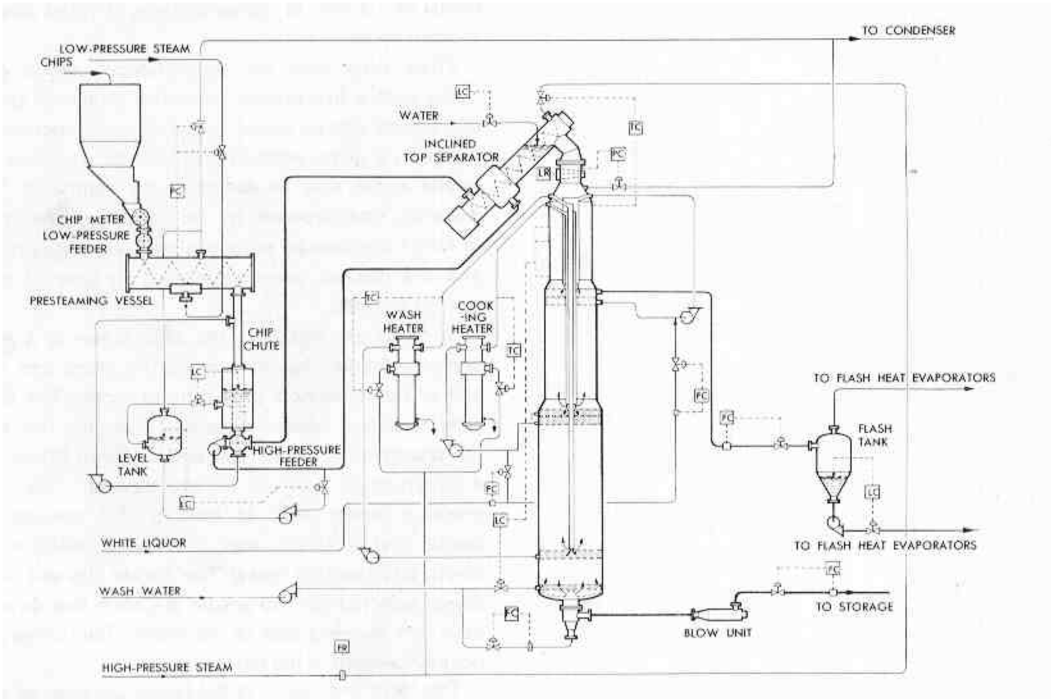
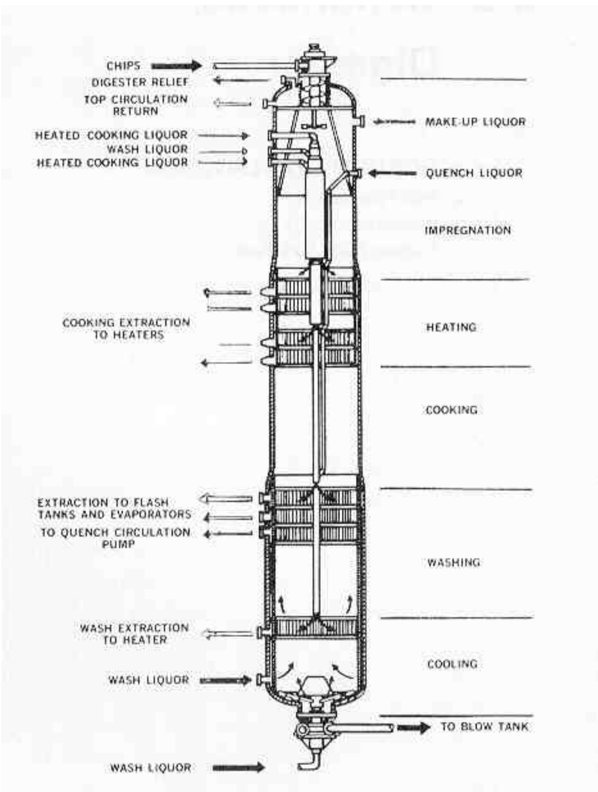


Figure 1: Schematic overview of a continuous chemical pulping plant (from Britt, 1970).



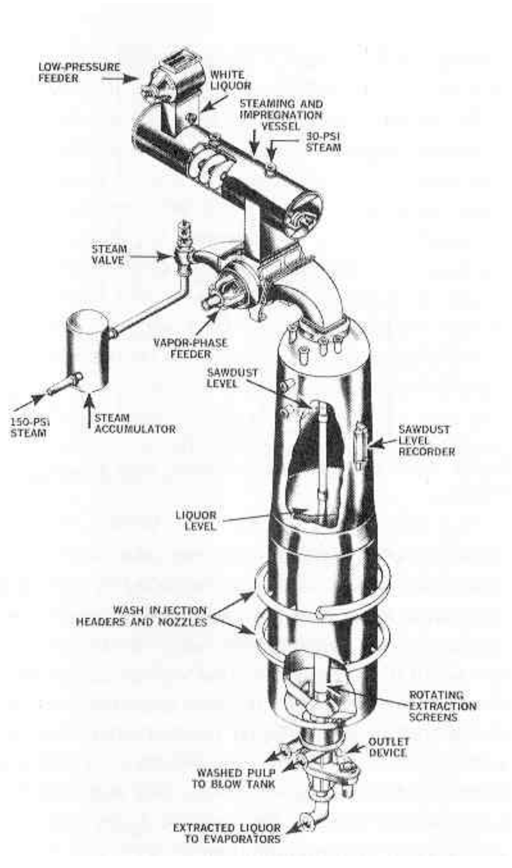


Figure 2: Schematic views of continuous chemical pulping digesters (from Britt, 1970).

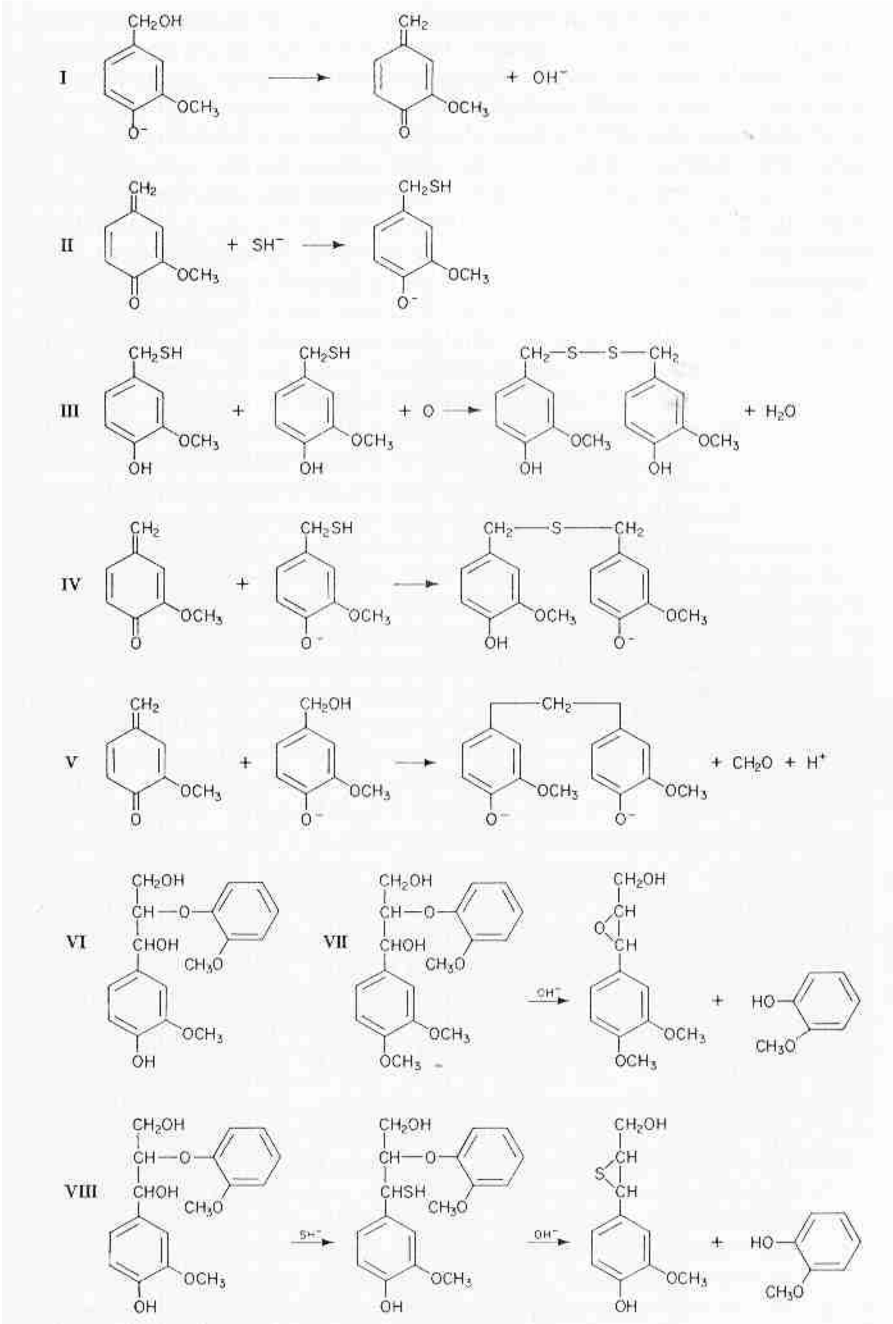


Figure 3: Model lignin reactions in the Kraft pulping process (from Rydholm, 1965).

Cellulose and hemicelluloses are unavoidably degraded and dissolved during the pulping process. The aim is to minimise such degradation and thus maximise the yield of pulp. The yield is influenced by the degree of delignification required, low lignin contents resulting in lower pulp yields. The lignin content will depend on the intended end-use for the pulp, with low lignin contents required for bleached pulps destined for printing and writing grades of paper, and higher lignin contents tolerated in unbleached packaging applications.

Uniformity of wood chip form and size are important to the efficiency of the pulping operation and for maximising pulp yield and properties. The chemical charges used in the process vary considerably between different operations, and are also species dependent. Typically the active alkali content will be around 16%, though can range from 12 to 20%. Sulphidities range from

15 to 35%. Cooking temperatures range from 165 to 175 C, with cooking times of between 1 and 3 hours. At the completion of the cook the chips are 'blown' from the digester which assists in separating the fibres, and the resulting pulp is then washed. The spent cooking liquor, which is known as 'black liquor' is then put through the recovery process, which involves concentration of the solids through evaporation, burning of the organic solids and recovery of the pulping chemicals. The principal features of a typical Kraft recovery process are outlined in Figure 4.

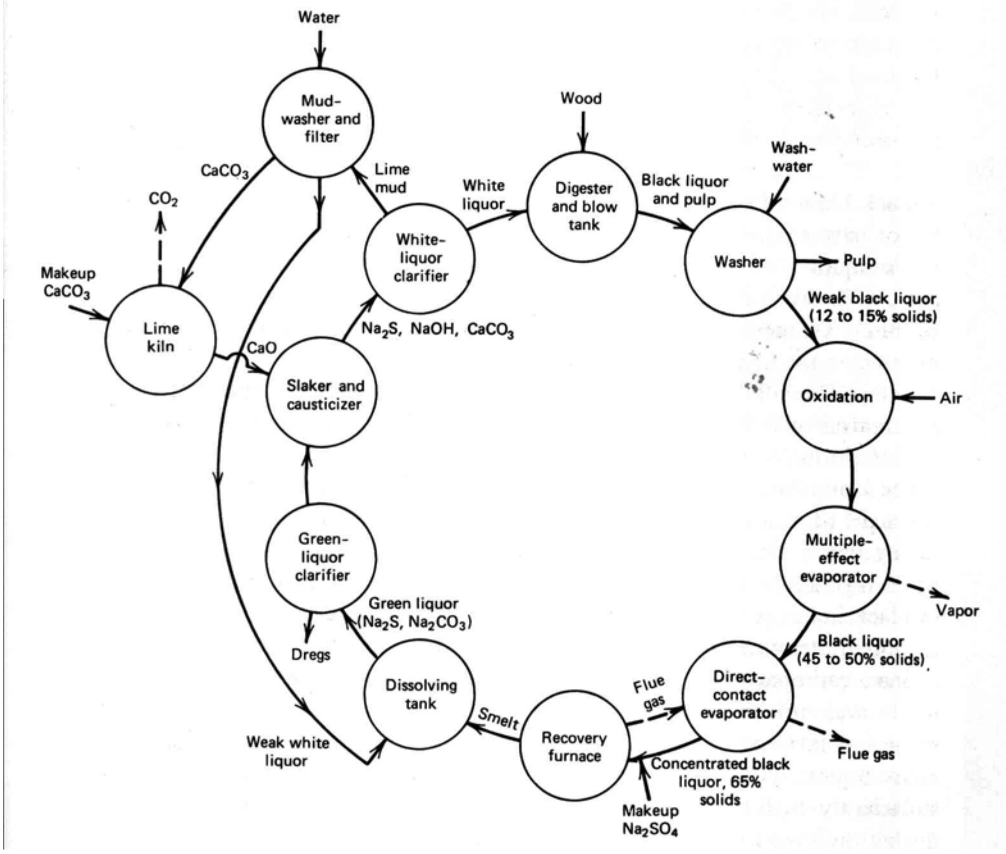


Figure 4: Overview of key components of the Kraft chemical recovery process (from Casey, 1980).

The most important property of wood feed-stocks in determining their suitability for Kraft pulping is pulp yield. This is because wood costs are the single largest variable cost of pulp production. Hardwoods, with their lower lignin content, typically give higher pulp yields than softwoods. Chemical composition, and cellulose content in particular, is thus an important property of wood feed-stocks. Typical pulp yields for plantation Eucalypts are between 50 and 55% before bleaching.

The total costs of producing Kraft pulp vary considerably between regions and with the capacity and age of mill. The wood cost can typically comprise between 30 and 50% of the total production cost, with chemicals, labour, other materials, water, interest and depreciation and delivery costs making up the remainder of the costs. Pulping requires significant amounts of water, ranging from 10 to 30 m^3 for every tonne of pulp produced. Energy is not a significant cost in the Kraft process, since the bulk of the energy for the process is actually generated during the recovery process (indeed some of the more modern mills actually sell excess energy to other users). The total production costs for large scale modern Kraft mills with access to low cost wood supplies may be as low as A$250 / air dry tonne, whilst at the other extreme older, smaller mills which are dependent upon higher cost feed-stocks may have production costs of the order of A$650 / air dry tonne.

Wood density is also a relatively important property for a number of reasons. Interestingly, there is no firm evidence that, within certain limits, basic wood density has any influence on pulp yield. However, above basic densities of 600 to 650 kg/m^3, there is some evidence that pulp yield (mass basis) actually declines (Higgins *et al*, 1973). This has been attributed to problems with the permeability of the high density chips and their incomplete impregnation with cooking liquors. At basic wood densities above 650 kg/m^3 the fibres of pulps tend to be very stiff and rigid, which whilst providing high bulk, also result in poor conformability and low paper strengths. One advantage of higher wood densities is that transport and shipping costs to the pulp mill are reduced.

In very general terms, suitable characteristics for hardwoods for chemical pulps are as follows:

- Basic wood density in the range 400 to 650 kg/m^3
- Moderate cell wall thickness, and mean fibre lengths of around 1mm.
- Small and relatively infrequent vessels.

Woods towards the lower end of the density range will tend to produce pulps with high tensile and tear strengths suitable for packaging grades of paper, whilst those towards the higher end will tend to produce pulps with high bulk, opacity and smoothness, making them better suited for printing and writing papers.

Mechanical Pulping Processes

In contrast to the chemical pulping process, mechanical pulping processes do not employ any chemicals in the fibre separation process. Instead they rely on mechanical energy to separate fibres from one another. The original, classic, mechanical pulping process was the stone groundwood process. This, as its name implies, relied upon the use of large grinding stones which were rotated in water and against which bolts of wood were forced. The grinding action of the stones against the bolts rubbed the wood fibres apart and generated the pulp.

The stone groundwood pulping process has now largely disappeared and has been superseded by the refiner- or thermo-mechanical pulping (RMP, TMP) processes, in which disc refiners are used to grind up wood chips to generate the pulps. The key advantage of these processes is that they are able to utilise lower cost residues from other wood processing industries, and this cost saving is reflected in the overall production cost of the pulp, since wood costs comprise a significant proportion of the total cost.

The refining of wood chips is normally accomplished in two stages, with a digestion phase in pressurised steam (approximately 2 MPa) preceding the primary refining stage. Disc refiners may be of the single or twin disc variety, with the former having only one rotating disc acting against a static counterpart, whilst in the latter both opposing discs are driven in opposite directions. Typical examples of pressurised first stage refiners are shown in Figures 5 and 6. Refining is accomplished at consistencies of around 20% i.e. 1 part wood to 4 parts water m/m, though secondary refining may be carried out at lower consistencies. The primary aim in the refining process is to initiate failure within fibre walls, away from the lignin rich middle lamella, so that hollocellulose rich cell wall surfaces are exposed for subsequent inter-fibre bonding in the paper-making stage. Considerable quantities of electrical energy are used in the refining process, with specific energy consumption being typically between 1.5 and 2 MWh / oven dry tonne of pulp. Many different designs of refiner plate exist, with much effort having been put into designing plates which will maximise pulp properties whilst minimising energy usage. The design of plates for primary and secondary refining varies (see Figure 7).

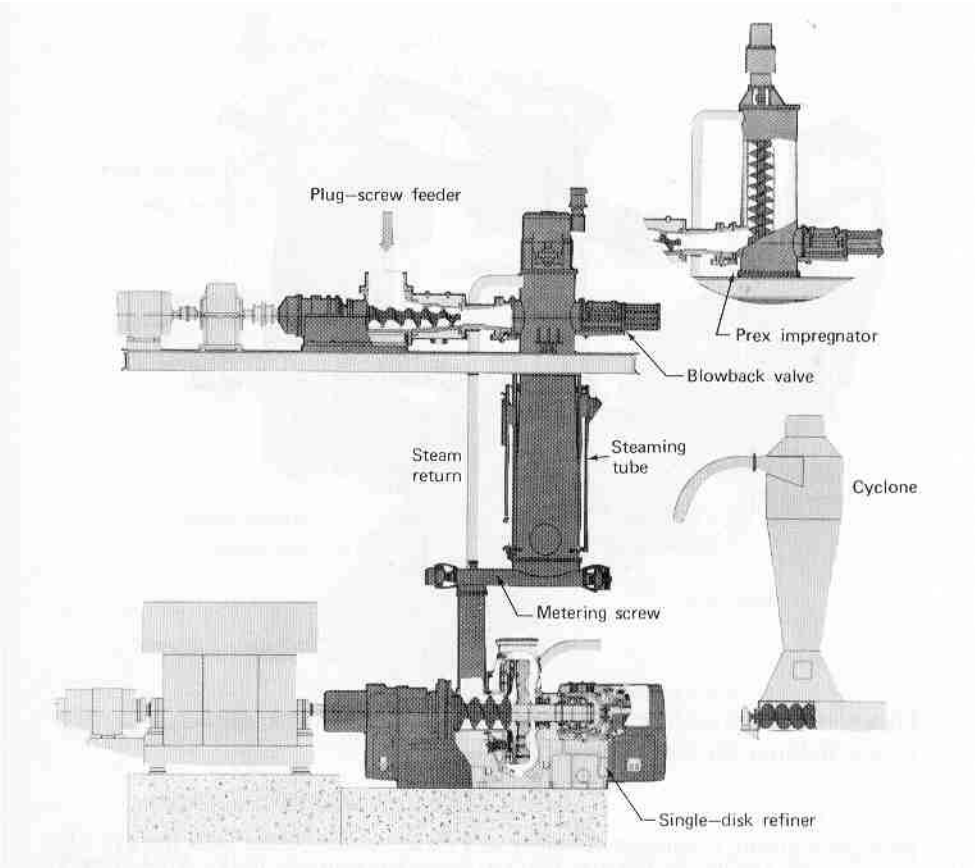


Figure 5: Schematic view of a single disc pressurised refiner (from Casey, 1980).

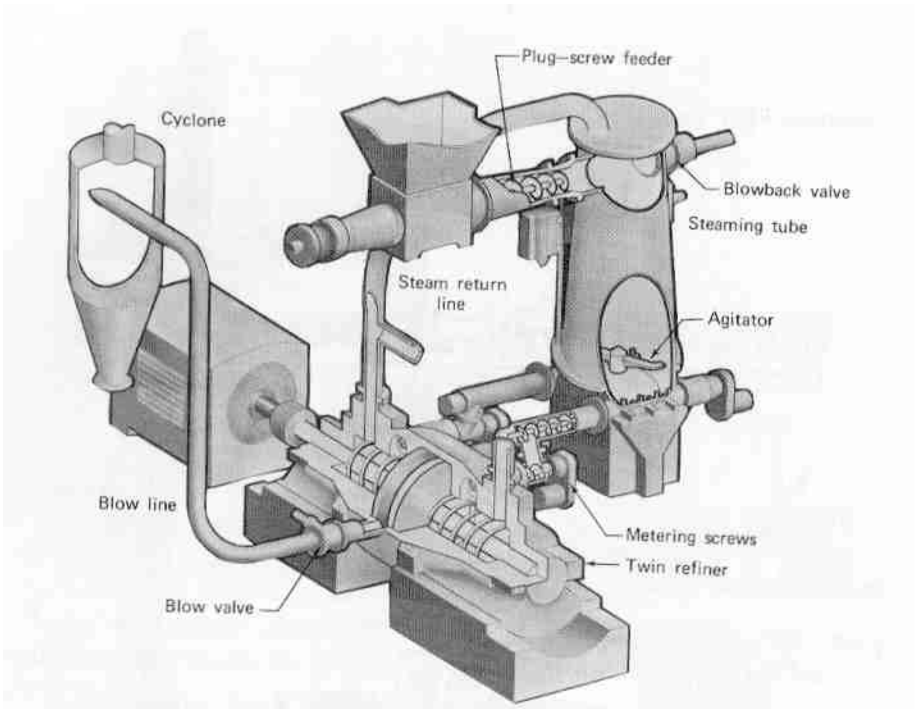


Figure 6: Schematic view of a twin disc pressurised refiner (from Casey, 1980).

Pulp yields from mechanical pulping are dictated largely by the water soluble extractives content of the wood feed-stocks, and generally fall in the range 92-98%. An important feature of the process is that only softwoods are generally considered to be suitable for pulping, since the refining action causes significant fibre shortening. Mechanical softwood pulps often have mean fibre lengths similar to, or even less than, those of hardwood chemical pulps. The classic application for mechanical pulps is in newsprint and similar short-life products. The pulps are also used in packaging and some lower grade printing and writing papers. However, in recent years recycled fibre has been increasingly used as a substitute for mechanical pulps, such that many newspapers are now manufactured from recycled fibre alone.

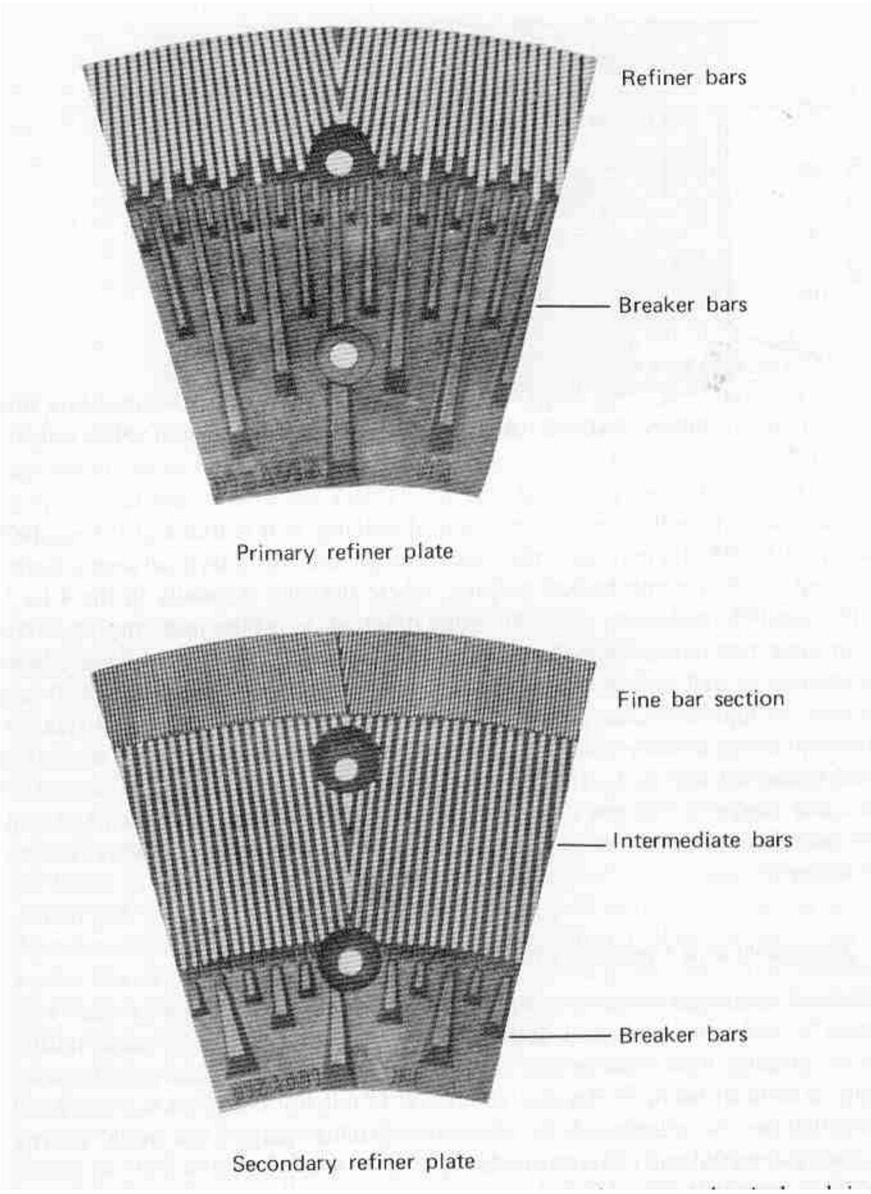


Figure 7: Typical plate patterns for primary and secondary mechanical refiner discs (from Casey, 1980).

Modern mechanical pulp mills can vary markedly in size, and are normally integrated with paper machines. Input capacities might typically fall in the range 300,000 to 750,000 tonnes of green wood per annum, with output capacities of between 140,000 and 350,000 tonnes of air dry pulp per annum.

Semi-chemical Pulping Processes

Semi-chemical pulping processes are comprised of both a chemical and a mechanical component. The classic, definitive semi-chemical pulping process is the neutral sulphite semi-chemical (NSSC) process, in which wood chips are partially cooked in a digester (see Figure 8) in a pulping liquor comprised of sodium sulphite buffered with sodium carbonate or similar, and then mechanically refined using disc refiners to fully separate the fibres. Typical yields for the pulps can be between 65 and 85%. Both softwoods and hardwoods can be pulped by the NSSC process, and the pulps are generally used unbleached for packaging applications, in particular the fluting in corrugated box board.

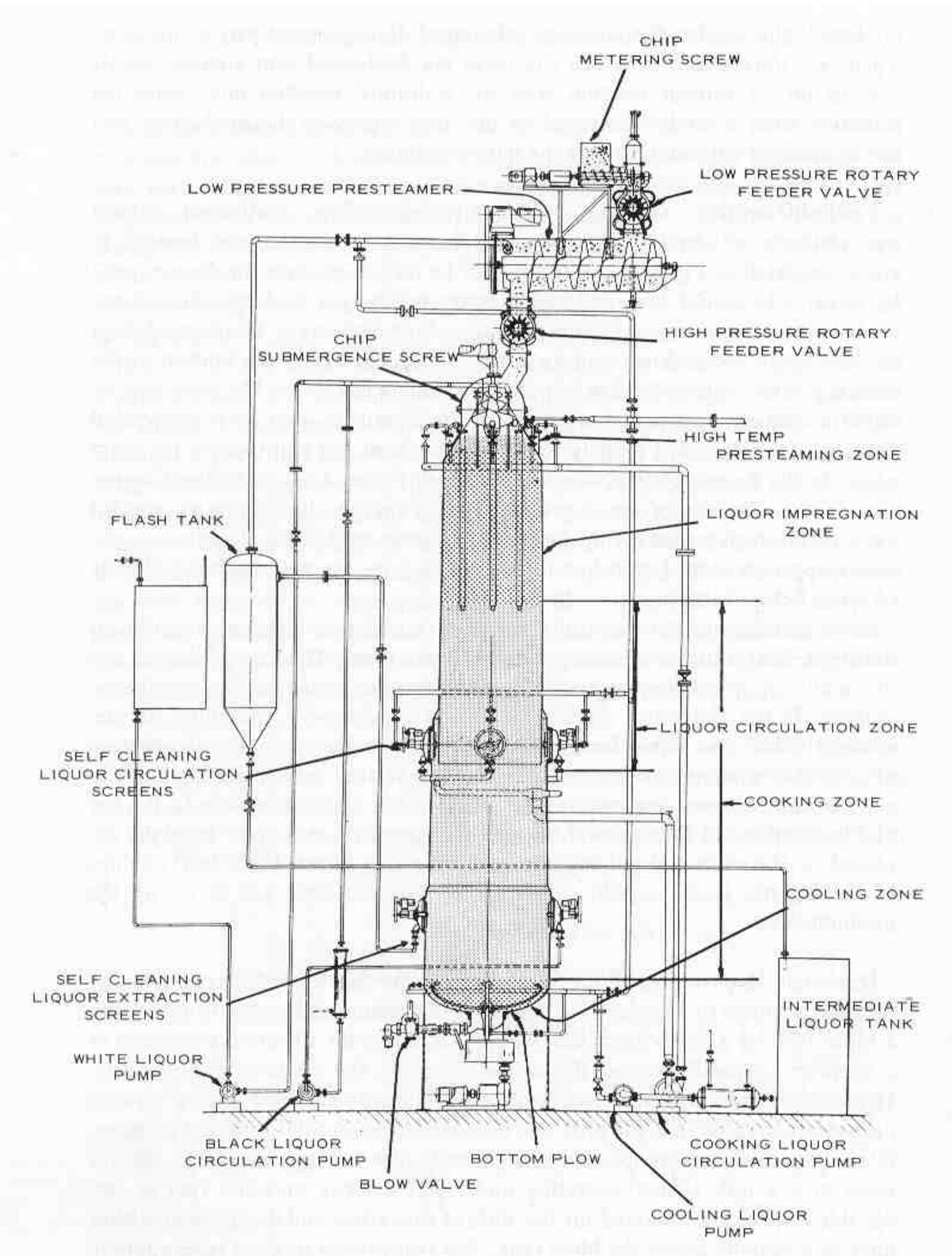


Figure 8: Schematic overview of a continuous digester used for semi-chemical (NSSC) pulping (from Casey, 1980).

A major drawback of semi-chemical processes such as the NSSC process is that the digestion phase produces a black liquor effluent. The scale of the process makes a stand alone recovery process along the lines of that used in the Kraft process uneconomic, and this has led to a gradual decline in the popularity of the NSSC process over the years as increasingly stringent environmental legislation has been introduced throughout the world. A few mills do still operate, either because they are still able to discharge effluent into waterways or because they are sited alongside Kraft mills where their effluent is processed within the latter's recovery plant. However, no new mills have been constructed in recent times and it is highly unlikely that any will be in the foreseeable future. The capacities of semi-chemical mills vary, with inputs generally ranging from 400,000 to 700,000 tonnes of green wood per annum and corresponding output capacities of between 150,000 and 250,000 tonnes of air dry pulp per annum. Semi-chemical mills are frequently integrated with packaging grade paper machines.

An alternative to the NSSC process and its variants (where the difference is primarily in the chemicals used in the digestion phase) is the chemi-thermo-mechanical pulping (CTMP) process. Such processes are essentially TMP processes with a variety of chemicals added at the digestion phase to enhance fibre softening and separation. The processes have the advantage of reducing refining energy and improving fibre length and bonding characteristics i.e. pulp strength. However, pulp yield is reduced compared with mechanical pulping operations, there is an additional cost in terms of chemicals and the process produces an effluent which must be treated. Modern chemi-thermo-mechanical pulp mill input capacities might typically vary between 700,000 and 1,000,000 tonnes of green wood per annum, with corresponding output capacities of between 300,000 and 420,000 tonnes of air dry pulp per annum. Whilst CTMP mills do operate around the world, the increasing dominance of Kraft pulp and recycled fibre in the world pulp and paper industry, coupled with the drive towards improved environmental practices, makes their long term future uncertain at best.

Recycled Fibre

The use of recycled fibre, also known as secondary fibre, in paper products has increased rapidly in recent years. On a worldwide basis this has been driven in part by increased environmental concerns on the part of consumers, which has led to significant improvements in the segregation and collection of waste materials. This in turn has provided the paper industry with a relatively cheap source of fibre for its paper-making operations. Countries which are heavily reliant on pulp imports have become increasingly dependent upon recycled fibre as a resource. Recycled fibre constitutes at least 50% in total of all paper products manufactured in many western European countries, and it is estimated that recycled fibre currently comprises at least 40% of the pulp used in paper-based products worldwide. The Australian paper industry utilises around 1.4 million tonnes of recycled fibre per annum.

The recycled fibre industry has become increasingly sophisticated over the years, and a range of waste paper grades are generated through selective collection and segregation. The quality of these grades differs according to the relative amounts of short, long, mechanical or chemical pulps they contain, and the quantity of inks and other contaminants (e.g. staples, plastic etc.) present in the materials. One advantage of some grades of recycled fibre is that they have a lower water retention value (WRV) than many virgin (mechanical and semi-chemical) pulps, thus facilitating potentially faster production rates and lower energy usage for products such as newsprint and paperboard. However, in general the freeness (the rate at water will drain through a pulp) of recycled pulps is often reduced compared with that of many virgin pulps, and this can be detrimental to productivity and energy usage.

A major disadvantage of recycled paper is that it invariably contains foreign substances or contaminants. Examples include staples, plastics, grit, string, clays (fillers) and ink. The waste paper thus has to be treated and processed before it can be utilised as a pulp feed-stock for paper-making. The initial treatment phase typically consists of the disintegration of the waste in water in a pulper, flaker or disintegrator of some form. From here solid contaminants such as staples, plastics, fillers and inks are removed using a variety of methods e.g. washers and screens. Figure 9 shows one example of a schematic arrangement of plant for processing recycled paper into pulp.

For low cost grades of packaging material e.g. solid board, significant de-inking is often not required (this is why solid board used in packaging tends to be grey in colour). However, where the recycled fibre is to be used in products requiring reasonable brightness, the recycled fibre must be de-inked. In recent years flotation cells have been increasingly used for this part of the operation. Appropriate chemicals are added to the stock, which encourage ink particles separated from the fibres to adhere to air bubbles generated at the base of the cell. The bubbles rise to the surface of the cell and form an inky froth which is subsequently removed from the surface.

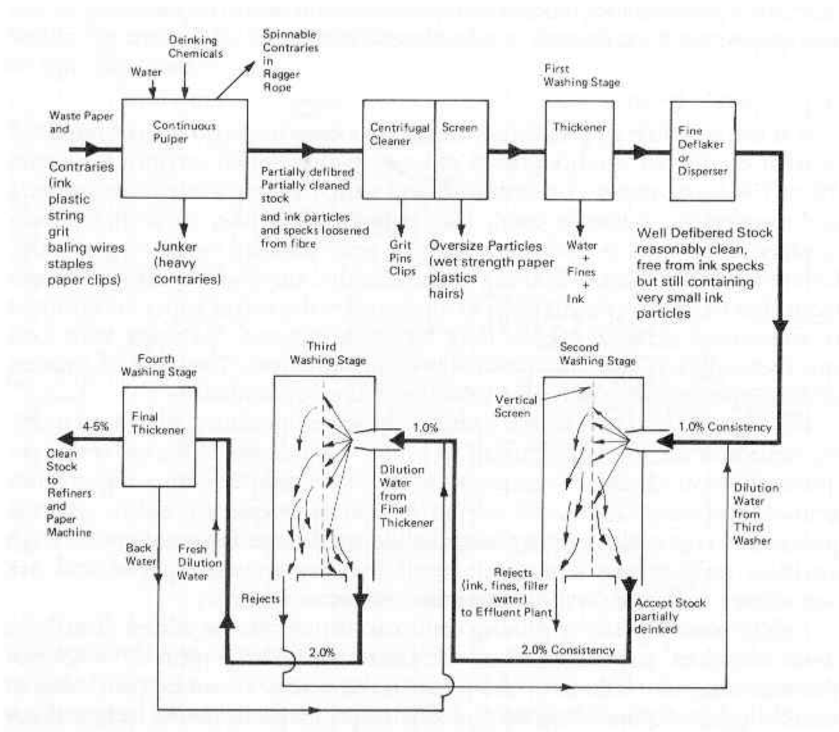


Figure 9: Flow diagram of a plant for processing and de-inking recycled paper (from Grant *et al*, 1978).

Paper fibre cannot be recycled indefinitely. Every time a fibre is recycled it is damaged to some extent, and eventually it is reduced to fragments or fines which are lost in the recycling and paper-making processes. These fines, along with fillers, comprise the bulk of the solid waste or 'sludge' which is produced by paper mills, and which represents a major waste disposal problem for the industry.

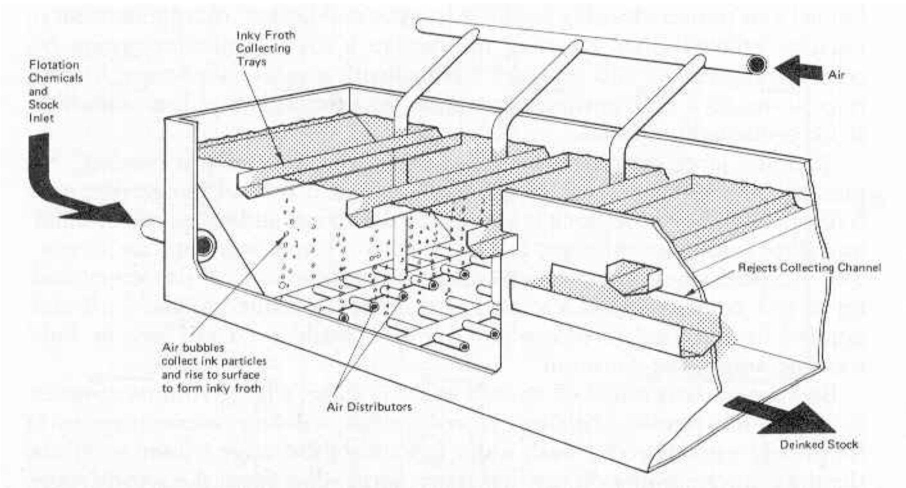


Figure 10: Example of a flotation cell for de-inking recycled paper (from Grant *et al*, 1978).

Bleaching

Pulps destined for use in high grade products such as printing and writing papers, sanitary and personal care products etc. need to be treated to improve their brightness (whiteness). The treatment process used by the industry is known as bleaching, and it is used to treat all types of pulp. Kraft pulps can be quite dark in colour and can therefore require quite extensive bleaching. The brightness of such pulps can be improved by removing more lignin in the pulping operation, but the subsequent lower pulp yield cannot normally be justified. In any case, the colouring of unbleached pulps is not caused by the presence of lignin itself, but largely by colouring compounds formed from the lignin during the pulping process. It is primarily these compounds that need to be removed by bleaching.

Throughout much of the 20th Century the pulp industry predominantly used elemental chlorine and / or calcium or sodium hypochlorite as bleaching agents. However, the industry was hit hard in the 1980s by revelations that the effluents discharged from the bleaching processes contained high levels of dioxins and furans, which are known carcinogens, and that the presence of these was directly linked to the elemental chlorine used in the processes. These findings caused the industry to rapidly re-evaluate its bleaching processes, and there was a move away from the use of elemental chlorine to the use of various combinations of other oxidising agents, including oxygen itself, ozone, hydrogen peroxide and chlorine dioxide.

The revolution in the bleaching part of the industry has been such that nowadays bleached pulps are typically marketed as either being elemental chlorine free (ECF) or totally chlorine free (TCF). ECF bleaching, in which chlorine dioxide is used in place of chlorine, has been championed by the North American industry in particular, whilst the European industry has favoured TCF bleaching. The latter has been driven primarily by pressure from the environmental lobby, and has placed the European industry at a disadvantage to some extent. This is because TCF bleaching tends to be less effective than ECF, requiring pulps of lower lignin content to achieve required brightness levels. As a consequence TCF bleached pulps tend to be more expensive. Bleaching sequences based on oxygen chemicals (ozone, peroxide, peracids) also require the addition of chelating agents at the start of the process to remove trace amounts of metal ions (e.g. copper, iron and manganese) which can cause degradation of the bleaching compounds. Ethylene diamine tetra-ethanoic acid (EDTA) is an example of a typical chelating agent used in the process.

It is likely that the bleaching industry will continue to undergo change and development as it seeks to identify lower cost and more efficacious and environmentally acceptable solutions to improving pulp brightness.

Paper-making

There are a number of stages involved in making paper. The main elements of the process are briefly outlined in the following.

Stock Preparation

Stock preparation is the process by which a suspension of fibres in water is generated prior to the addition of other additives and the manufacture of the paper product. The main steps of the process include disintegration, beating or refining, and blending of different pulp stocks to generate a furnish with the desired properties for paper forming and finished product properties.

Pulp for paper-making may be obtained or be available in a range of forms e.g. air dry sheets, dry crumbs, moist bales or as a 'slush' i.e. at consistencies between 2 and 5%. These need to be dispersed in water, and this is achieved through the use various types of disintegrators (hydrapulpers) or breakers.

Once disintegrated, pulps need to be 'developed' or beaten. This process primarily aims to tailor fibre length, increase fibre flexibility and increase the effective surface area of fibre for bonding through a process known as fibrillation. Pulp beating may be achieved using 'Hollander' type beaters or conical or disc refiners. The latter are usually used for continuous operations, whilst the former are used for batch operations.

Additives

A range of additives may be added to pulp stock prior to the paper forming stage. Common examples include sizing agents, fillers, dyes and starch, as well as additives to improve the wet strength of paper and to overcome various process problems e.g. foaming, bacterial and pitch build up and retention of fillers and pigments. Sizing is performed primarily to improve the printing properties of paper; without this, paper would essentially have the properties of blotting paper. Rosin, a naturally derived product from wood, consisting of a mixture of organic acids, is the classic sizing agent. It is used in conjunction with paper-makers alum (aluminium sulphate), with the latter being added to lower pH and to precipitate the rosin onto the fibres. A range of other synthetic sizing agents are available, which often operate in neutral or alkaline conditions. Starch is a commonly added to many furnishes to improve paper sheet strength and stiffness.

Solid, insoluble fillers added to paper include China clay, chalk and titanium dioxide. These are added principally to improve the smoothness and opacity of papers, and hence their 'printability'. China clay is used extensively because it is suitable for use in acidic conditions, which is a drawback of chalk. Titanium dioxide provide excellent opacity, but at a cost.

The Paper Machine

A schematic view of a generic 'Fourdrinier' paper machine is shown in Figure 11. The basic design of such machines has remained essentially unchanged for the last 200 years. A paper machine essentially consists of a ‘wet’ and a ‘dry’ end. The wet end is comprised of the flow box, the wire and the press. The dry end consists of the dryer, calender and machine reel.

The flow box, also known as the ‘head box’, is used to meter the correct amount of stock onto the moving wire. The flow box may be open or closed, with the former relying on gravity for discharging the stock and the latter using pumps and pressure. Closed flow boxes tend to be used on fast paper machines, where gravity alone is not sufficient to meter stock at the required rate. The wire section of the wet end consists of an endless wire mesh which runs at speeds of between 500 and 2000 m/min depending on the type and grade of product being produced. The fastest speeds are generally found on newsprint and packaging paper machines, where fast throughputs are essential for keeping costs down. The stock is metered onto the moving wire at consistencies of between 0.2 and 1%. The bulk (approximately 97%) of the water is then removed on the wire section via a combination of free drainage and suction. The wet web is often consolidated and its formation improved via application of pressure with a ‘dandy roll’; the latter is also used to apply watermarks where needed. At the end of the wire the wet web is transferred into the press via the couch roll. The press consists of felts which pick up the web and rollers with ‘nip’ points. The function of the press is to remove additional water and consolidate the paper web.

In recent years there have been improvements made to the forming operation, whereby stock is metered between two fast moving wires (on so-called twin wire paper machines), with the water being removed by a combination of pressure and suction. Various designs of twin wire formers exist, and the technology has allowed paper to be manufactured at even greater rates. Tissue and newsprint are examples of products manufactured on twin wire machines.

After pressing the paper web enters the dryer section. This can consist of up to 80 steam heated drying cylinders, each up to 1.5m in diameter. Paper entering the dryer can still consist of up to 70% water, and the dryer removes the bulk of this. The paper passes over and around each of the cylinders at high speed, with each side of the web alternately contacting a drying cylinder to ensure even drying. The web is held against the cylinders by continuous moving felts. After drying the paper enters the calender section, which consists of a set of cast iron rolls with hardened surfaces, which rotate against one another. The aim of calendering is primarily to improve the surface finish of the paper. The degree of calendaring used varies considerably between types and grade of paper. After calendering the paper is wound onto a steel spool, and the final reel of paper may have a diameter of up to 3 metres. After removal of the reel from the paper machine, it may be unwound and cut to generate smaller reels at the required widths. Paper may also be further treated e.g. coated

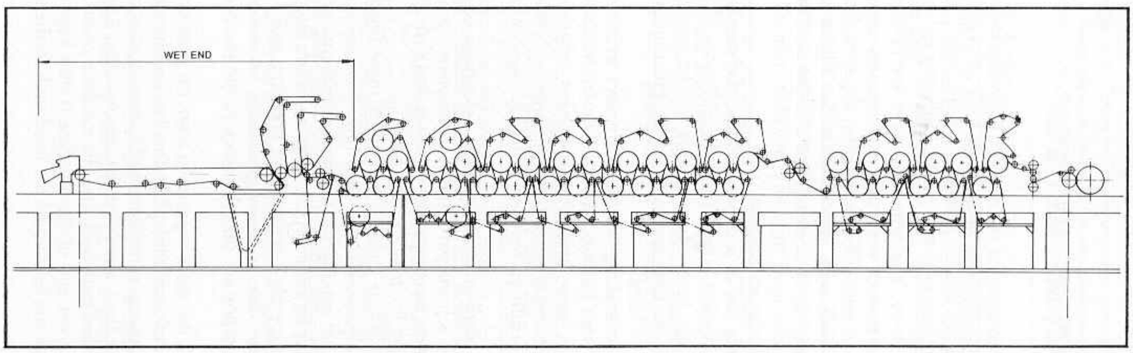


Figure 11: Schematic layout of a paper-making machine (from Grant *et al*, 1978).

Paper board, which is essentially ‘thick’ paper, may consist of one or more plies of paper or board, and can be made in a variety of ways. A cylinder mould is often used in place of the fourdrinier wire former to manufacture thick plies. The device consists of a large horizontal cylinder, covered with a wire cloth, which rotates approximately three quarters submerged within a vat of pulp stock. The wire cloth picks up stock and as it leaves the stock water drains through the cylinder leaving a web on the cloth. This is picked up by means of a couch roll pressing a felt onto the web surface, and the web is transported from the forming cylinder on the felt. By using a number of such moulds in series, it is possible to form multi-ply board products on a continuous basis.

The quantities of water used in paper-making have been dramatically reduced over the last 50 years (e.g. by at least 50% for many products), but are still significant. Usage varies markedly according to product type, age of equipment, and the level of investment in water recycling capability. Typically, water usage can vary between 5 and 100 m^3 / tonne of paper produced.

The output capacities of paper machines vary significantly, with the highest outputs associated with lower grade, commodity products. In the latter case, output capacities might typically range between 200,000 and 500,000 tonnes of paper per annum.

Types of Paper Product

There are numerous types of paper and paper-based product manufactured around the world. However, they can be broadly categorised as follows:

- Packaging
- Printing and writing
- Tissues and sanitary
- Newsprint

There are a number of end-uses or types of product within each grade, and each has key properties and characteristics which make it suited for its intended application. These are summarised in Table 2.

Table 2: Main categories of paper product manufactured worldwide and key properties for the principal end uses.

Product Class / End-use	Key Properties
PACKAGING	
Linerboards	• Convertability (tear, tensile) • Ring crush • Extensional stiffness • Top to bottom compression strength • Printability
Corrugated medium	• Runnability • Concora or ring crush • Internal bond, tensile, stretch
Bag and sacks	• Ability to absorb shock • Tensile energy absorption (TEA) • Tear, tensile, stretch
Cartonboards	• Bending stiffness • Density • Creasability

PRINTING & WRITING	
Copy	• Optical (opacity, whiteness) • Bulk and stiffness • Formation
Offset printing	• Optical (opacity, whiteness) • Surface strength • Bulk • Formation • Print response
Continuous forms	• As above, but bulk and stiffness critical
Envelope and stationary	• As for offset printing • Foldability
Coating base	• Runnability (tear, tensile) • Formation • Uniformity
TISSUE & SANITARY	
Toilet and facial	• Optical (brightness, whiteness) • Softness/smoothness • Absorbency • Cleanliness
Towelling	• Absorbency • Wet tensile strength
Table napkins	• Absorbency • Softness/smoothness • Wet tensile strength
NEWSPRINT	
	• Runnability (tear, tensile) • Printability (linting, IGT) • Appearance (colour, cleanliness) • Formation

PROSPECTS

The majority of analysts predict that there will be increasing demand for all the major types and grades of paper-based product over the next decade. Average growth predictions for the major paper grades over the next 10 years are summarised in Table 3 on a world and regional basis.

Table 3: Projected growth rates for paper products for the period 2003 - 2013.

Grade of paper	Projected World Annual Growth 2003-2013	Projected Australasian Annual Growth 2003-2013	Projected Asia-Pacific Annual Growth 2003-2013
Packaging & industrial papers	4%	5%	10%
Printing & writing papers	8%	8%	12%
Newsprint & magazine papers	1%	0%	6%
Tissue & health care papers	4%	2%	10%

It is evident from Table 3 that much of the predicted growth in demand and output of paper products will occur in the Asia-Pacific region. China and South East Asia will likely be the ‘engine rooms’ driving the growth, as these regions undergo rapid economic development. Much of the growth in the manufacturing capacity in these regions is likely to be focused on commodity papers in the short term. As a consequence, other producers in the Asia-Pacific region are likely to focus on adding value to products to differentiate themselves in the market place.

Worldwide, Kraft chemical pulp and recycled fibre currently dominate the paper industry, with each providing approximately 40% of the fibre used in the manufacture of products. It is likely that this dominance will continue over the next decade, with much of the increased demand for fibre being met by these two sources. In the Asia-Pacific region recycled fibre already provides more than 50% of the fibre needs of the paper industry. The major trend over the next ten years will likely be a marked reduction in the production of non-wood pulps, with recycled fibre and Kraft pulp growing their market share. It is likely that a number of new Kraft pulp mills will be built both worldwide and in the Asia-Pacific region. It is possible that a mill could be built in Australia, but despite many feasibility studies e.g. in Tasmania, Victoria and WA, there does not appear to be a ‘cast iron’ investment case for such an undertaking. The new mills will not necessarily dramatically increase world annual output however, as it is probable that once they come into production they will force the closure of other older, less efficient mills. It is predicted that there will be a major deficit in Kraft softwood pulp in the Asia-Pacific region, at least over the next five years, and that demand will need to be met with imports of pulp. The deficit is likely to occur primarily due to lack of suitable resources in concentrated areas to feed local mills.

The above predications are based on the assumption that there will be little radical technological change in the pulp and paper industry in the foreseeable future. It is believed that this view is reasonable, given the history of the industry to date. It is by nature extremely conservative, and is reluctant to embrace radically new processing technologies in particular, owing to the very high investment costs associated with modern manufacturing and processing facilities. The old adage ‘nobody wants to be first’ very much applies in the industry. Indeed, when considering the basic technologies used in the industry, it is remarkable how little it has changed over the last 100 years or so. Some of the more significant changes that *have* occurred include:

- The emergence of the alkaline Kraft process as the dominant chemical pulping process.
- The introduction of disc refiners (defibrators) for mechanical pulping in the 1950s, and their subsequent displacement of the stone groundwood process as the main mechanical pulping method.
- The increase in the use of recycled fibre and the subsequent decline of the semi-chemical pulping industry.
- The switch from elemental chlorine to more environmentally friendly oxygen-based bleaching chemicals.

Over the years a large number of ‘alternative’ pulping processes have been investigated for their technical and economic viability. Whilst many have passed the technical hurdles, few have presented compelling investment cases when compared with the existing industry. One of the ‘alternative’ pulping processes which has received the most attention in recent years has been the so called organo-solve process and its variants. The process essentially involves dissolving the lignin out of wood using a variety of organic liquids e.g. ethanol, methanol etc. at elevated temperatures. Key draw-backs to the process include the very high vapour pressures involved, necessitating stringent engineering standards and difficulties in recovering all of the solvents at the completion of the pulping cycle (wood fibre has a strong affinity for polar liquids such as water and alcohols). Furthermore, it is often stated that the viability of the process depends on finding markets for the by-products of the process, principally lignin. Whilst a range of applications for lignin have been investigated e.g. as a feed-stock for plastics and adhesives, it has not shown any advantages over existing synthetic feed-stocks, and in most cases has been shown to be inferior. In spite of these difficulties and uncertainties, at least two major investments have occurred in pilot / full scale organo-solve pulp mills in Canada and Germany in the last 20 years. Both ventures failed with significant investment losses, and this has certainly not increased the industry's willingness to invest in radically new unproven technologies and processes.

Other pulping processes which have previously been investigated include steam explosion, microwave, and the use of a range of alternative chemicals such as ammonia, carbonates, potassium and ammonium compounds (which it is proposed could be used as fertilisers etc. after the pulping operation), peracetic acid and hydrogen peroxide, formic acid and microbiological agents. To date none of these have been adopted on a full commercial scale.

Similarly to the pulping sector of the industry, there is no evidence that there will be radical changes in the technology used to make paper in the foreseeable future. The basic method of making the bulk of paper i.e. the metering of very dilute stock onto or between wires and then removing the water, has remained largely unchanged for the 200 years since the invention of the Fourdrinier machine, and this is likely to continue. The 'Holy Grail' of the industry, that of the use of significantly less water to manufacture commodity paper products without compromising web formation and, most importantly, production rates, is still some way off.

There is no doubt that new variants of paper products will be developed in the future, but these will still, however, be based on existing pulp types. The most significant changes in the industry are likely to occur down the value chain, with the development of new coatings and inks, and the use of novel polymers to create so-called 'smart' products.

The wood used by the pulping industry will increasingly be dominated by plantation grown material, at the expense of material from native forests and non-wood materials. Japan will remain the dominant consumer in the wood chip market in the Asia-Pacific region, with Australia and the USA being the major suppliers. It is predicted that there could be an oversupply situation in the market by the year 2010. However, beyond this date, some analysts have predicted that there could be a shortage of wood due to falling investment in the plantation industry as returns fail to meet the original market expectations.

Prospects for low rainfall woody biomass grown in WA

It is reasonable to assume that woody biomass grown in the low rainfall agricultural regions of WA will be done so under short rotation cropping regimes, and that the species grown will be hardwoods. There is no reason why such material could not penetrate the wood chip market supplying the Kraft pulping industry, providing that it met required quality criteria and was competitive on cost with other established resources. In this respect, the most important properties would be:

- Pulp yield
- Density
- Fibre length
- Bark (and other contaminants) content

Other important properties that would need to be considered would include paper properties, bleaching properties, extractives content and black liquor properties.

Possibly the greatest hurdle to penetrating the market, at least initially, could be the genus or species from which the material was derived. If it were not derived from those that are already well known as feed-stocks for short-fibred pulps around the world e.g. e.g. *Eucalyptus*, *Betula* (Birch), *Quercus* (Oak), *Acacia*, *Fagus* (Beech) etc., it is likely that there would be some resistance to purchasing the material until its performance in full scale processes was known and understood. Developing this knowledge could require significant investment on the part of growers and suppliers of the resource.

An additional hurdle that low rainfall woody biomass would have to overcome would be the costs associated with transport to ports. An optimum solution would be the establishment of an ‘inland’ pulping plant in WA, which could be economically supplied by wood resources derived from all rainfall zones. However, it is likely that sizeable incentives would need to be made available to potential investors for such an undertaking to be realised, including guarantees of long term supplies of wood resources from low rainfall regions which met minimum volume and quality criteria.

CONCLUSIONS

The world consumption of paper products is currently around 330 million tonnes per annum, and strong growth is expected over the next decade for all types of product. Growth in the Asia-Pacific region will be particularly strong. There are unlikely to be any significant changes in the technologies used to produce pulp or to manufacture paper for the foreseeable future, with the most significant changes likely to occur in the value-adding sector of the industry. Kraft pulp and recycled fibre currently dominate the industry and if anything, their position will be strengthened in the future. There are likely to be new Kraft mills constructed around the world in the next decade, with a large proportion of their capacity probably replacing that of older mills which will be closed down as they become increasingly uncompetitive. In the Asia-Pacific region the amount of non-wood pulp manufactured will decline.

The hardwood chip market in the Asia-Pacific region will remain strong, with Japan continuing as the principal consumer. Australia and the USA are well positioned to continue their dominance as the major suppliers of wood chips in the region. In principle, woody biomass grown in the WA wheat belt could successfully penetrate the wood chip market providing it was competitive with respect to price and quality, with pulp yield, wood density and fibre length being the key properties that would need to be addressed. However, if derived from species unfamiliar to the industry, significant initial investments would probably be required on the part of growers and suppliers to ensure that the resource became trusted and readily accepted in the market place. Similarly, the construction of an ‘in-land’ pulp mill in WA, supplied by wood resources derived from both high and low rainfall zones, would also likely require sizeable incentives for potential investors.

BIBLIOGRAPHY

ABARE (2002). Australian Forest & Wood Products Statistics, March-June Quarters 2002, Canberra, ABARE.

Beca Simons (1997). Further Development of the Forest Products Industry in Western Australia. Report prepared for Western Australia Department of Resources Development.

BIS Shrapnel Forestry Group & URS Forestry. (2000). Wood Processing Industry Development and Infrastructure Strategy and Action Plan for Western Australia. Report prepared for Western Australia Department of Resources Development.

Britt, K. W. (1970). Ed. Handbook of Pulp and Paper Technology. Van Nostrand Reinhold Company, New York.

Casey, J. P. (1980). Ed. Pulp and Paper – Chemistry and Chemical Technology. Vol. 1. John Wiley & Sons, New York.

Grant, J., Young, J. H. and Watson, B. G. (1978). Eds. Paper and Board Manufacture – A general account of its history, processes and applications. The British Paper and Board Industry Federation, London.

Halpern, M. G. (1975). Pulp Mill Processes – Pulping, Bleaching and Recycling. Noyes Data Corporation, Park Ridge, New Jersey.

Higgins, H. G., Jong, J, De, Balodis, V., Phillips, F. H. and Colley, J. (1973). The Density and Structure of hardwoods in relation to paper surface characteristics and other properties. Tappi 56(8): 127-131.

Jaakko Poyry Consulting (2001). Investment Opportunities in the Australian Forest Products Industry. Report prepared for Department of Agriculture, Fisheries and Forestry – Australia.

Macdonald, R. G. & Franklin, J. N. (1969). Eds. Pulp and Paper Manufacture. Vol. 1. The Pulping of Wood. McGraw-Hill Book Company, New York.

Misra, D. K. (1980). Pulping and Bleaching of Non-wood Fibres. In: Pulp and Paper – Chemistry and Chemical Technology. Vol. 1. Ed. Casey, J. P. John Wiley & Sons, New York.

Patrick, K. L. (1997). Ed. Advances in Bleaching Technology. Miller Freeman Books, San Fransisco.

Rydholm, S. A. (1965). Pulping Processes. John Wiley & Sons, New York.

Wood Resources International Ltd. (2002). Wood Resource Quarterly – Global Wood Fiber Market Update – 3rd Quarter 2002.

Search Report

Appendix 2

Investigation of pulp, paper and panelboard potential of selected Western Australian species

CSIRO Forestry and Forest Products

<u>Commercial in Confidence</u>

Client Report No. 1378

Assessment of native woody plant biomass for use in forest products

G. Freischmidt, S Terrill, P. Warden, M. Reilly, A. Farrington, M. McHenry, F. Catela, R. Wearne, P. Collins, J. R. B. Hague, A. Pereira, J. Wright

November, 2003

Client: Dept of Conservation & Land Management, Dept of Industry & Technology, WA Govt.

Contract No: FFP 02/235

SUMMARY

OBJECTIVE

The aim of this work was to identify woody perennials from Western Australia for planting in medium to low rainfall regions that could be of commercial use to a number of forest products industries. This report presents results from the assaying of 51 Western Australian woody perennials, trials of 51 species for pulp yield and paper properties, the mechanical and physical performance of 19 species used in medium density fibreboard (MDF) pilot scale production and 20 species used for the preparation of particleboard.

KEY RESULTS

The major results of the study were:

- A number of species were found to be useful feedstocks for papermaking based on yield, paper properties and bleachability. The most promising were: *Taxandria juniperina*, *Grevillea leucopteris, Alyogyne huegelii* and *Grevillea candelabroides.* A second group worthy of further study would include; *Senna pleurocarpa, Acacia lasiocalyx, Anthocercis littorea* (at older age), *Trymalium floribundum, Viminaria juncea* and *Agonis flexuosa.*
- Species density and extractives content were the dominant criteria used for considering woody species for composite studies (MDF and particleboard).
- All species selected for MDF fabrication were successfully processed into panels. Although a range of responses was obtained for physical and mechanical properties, the species studied were comparable to the pine used as the control species. After holding all processing variables constant between trials (with different species), no one individual species could be identified as greatly out performing the others. High fines (in the fibre furnish) were encountered in all species including the one softwood species, *Callitris glaucophylla* after high pressure refining.
- Species selected for particleboard fabrication resulted in very similar performance compared with the pine control. Species density would be an important factor in any selection process along with conformability of the wood (the ability to be compressed into a shape and to retain that shape). Two species behaving similarly to the pine control in being compressed into shape were *Codonocarpus cotinifolius* and *Gyrostemon ramulosus.*

FURTHER WORK

Further work is required in all three major product areas investigated in this report. Pulp and paper assessment carried out on successful species needs to be revisited with an emphasis on species age. For any future commercial gain to be made from successful species discovered so far, the age of the wood at time of cropping must be correlated against yield and paper properties. To this end a series of trials should be carried out (on the species named above) for a range of ages.

Revisit the lowest density species for MDF production with a view to quantifying fines content and fibre furnish geometry. The species would include; *T. juniperina, E. rudis, V. juncea, A. littorea, G. ramulosus, C. cotinifolius* and select species based on growth rate criteria. Many fabrication variables were not trialed in the first round of panel making. To optimise panel performance the fabrication variables should be investigated in future.

The same low-density species should be investigated in particleboard form using alternative wood flaking techniques to improve the particle geometry. To this end commercial ring knife flakers should be sourced for further trials. A comprehensive study of panel density versus panel properties should then be undertaken.

Finally, a reassessment of the screening methodologies should be made to help in future woody biomass assessments. In the case of pulp and paper assessment, there appears to be no short-cut alternative to carrying out laboratory pulping trials .

ASSESSMENT OF NATIVE WOODY PLANT BIOMASS FOR USE IN FOREST PRODUCTS

G. Freischmidt, S Terrill, P. Warden, M. Reilly, A. Farrington, M. McHenry, F. Catela, R. Wearne, P. Collins, J. Hague, A. Pereira, J. Wright

November 2003

TABLE OF CONTENTS

SUMMARY 1
Objective 1
Key Results 1
Further Work 1
TABLE OF CONTENTS 2
INTRODUCTION 4
RECOMMENDATIONS AND CONCLUSIONS 4
RESULTS AND DISCUSSION 5
Cellulose content 6
Hot Water Solubles, pH and Buffering Capacities 6
Fibre length and width 8
pulp yields 9
Paper Quality and bleaching results 10
MEDIUM DENSITY FIBREBOARD 12
MDF – Modulus of Rupture 13
MDF – Modulus of Elasticity (MOE) 14
MDF – Internal Bond Strength 15
MDF – Thickness Swell 16
Discussion 17
PARTICLEBOARD 18
Particleboard – Modulus of Rupture (MOR) 19
Particleboard – Modulus of Elasticity (MOE) 20
Particleboard – Internal Bond Strength 21
Particleboard – Thickness Swell 22
Discussion 23
MATERIALS AND METHODS 24
Cellulose Content 24
Wet Chemistry *24*
Near I-R Analysis *24*
Hot Water Soluble Extractives 24

pH and Wood Meal Buffering Capacity 24
Fibre length....................24
Chemical Pulping....................24
Wood Basic Density....................*24*
Pulp Yield....................*25*
Pulp Bleaching....................*25*
Paper Properties....................*25*
Wood Based panels....................25
Medium Density Fibreboard....................*25*
Particleboard....................*26*
Testing Panel Products....................*27*
Analysis of Results....................*27*
Appendix 1: wet chemistry and NIR results for cellulose content....................28
Appendix 2: Pulp properties....................30
Appendix 3: Paper brightness values....................35
Appendix 4: Summary of MDF properties....................36
Appendix 5: Summary of particleboard properties....................37

Information for CSIRO abstracting:

Contract number	FFP 02-235
Products investigated	Paper, MDF, particleboard.
Wood species worked on	Various
Other materials used	UF resin and Wax emulsion
Location	Clayton, Vic.

INTRODUCTION

The aim of this work was to identify woody trees and plants from Western Australia which might be of commercial use as feed stocks in the forest products industry. Identification of candidate species could encourage their planting to compliment agricultural sustainability in medium to low rainfall areas.

This report presents results from the chemical and physical assaying of 51 woody perennials indigenous to Western Australia, along with product characterizations of paper, medium density fibreboard (MDF) and particleboard from a selection of the species. In total, 51 species were investigated for their paper properties, 19 species for their performance in MDF and 20 species for particleboard. *Pinus radiata*, sourced from North Eastern Victoria, was used a benchmark material for the work.

Promising species, as a result of this work, will be planted in a series of trials to better understand the biomass yield based on region and species provenance.

RECOMMENDATIONS AND CONCLUSIONS

The major results of the study were:

- Accurate screening of species for desirable pulp and paper properties was not possible using the basic assaying methods used here. The most effective method to determine species suitability was to carry out laboratory scale pulping and to test hand sheets made from the pulps of those species with the most promising yields. The outcome of these trials suggests that the following species should be considered for further study: *Taxandria juniperina, Grevillea leucopteris, Alyogyne huegelii* and *Grevillea candelabroides.* A second group including: *Senna pleurocarpa, Acacia lasiocalyx, Anthocercis littorea* (at older age)*, Trymalium floribundum, Viminaria juncea* and *Agonis flexuosa* would also be worthy of consideration. The age of wood is an important consideration for paper quality and to this end trials should be conducted across a range of ages for each of the target species to better determine species suitability.
- Wood density and, to a lesser extent, water soluble extractives content, would typically be the key selection criteria for species for medium density fibreboard and particleboard.
- Selected species for MDF and particleboard production were all successfully converted into panels with minor variations in panel quality.
- Particleboard furnish was not optimised in this study. Future trials should include waferising or flaking of woodchips to produce more commercially relevant particle geometries. The conformability of wood particles was generally poor in panels made from most species. Only two species appeared to have promising properties in this respect, *Codonocarpus cotinifolius* and *Gyrostemon ramulosus.*
- The lower density species already trialed (*T. juniperina, E. rudis, V. juncea, A. littorea, G. ramulosus, C. cotinifolius*) should be used for further trials to optimise MDF and particleboard production by investigating and optimising a range of production variables. In the case of MDF, optimising process variables to reduce the ‘fines’ content would have high priority.

RESULTS AND DISCUSSION

Table 1 below lists the species for consideration in chemical assaying, pulp and paper assessment and composite work in MDF and particleboard.

Table 1: Basic wood density of species investigated in this study. Note, data for some species was derived from two separate wood collections.

Species	Basic Density (kg/m^3)	Species	Basic Density (kg/m^3)
Eucalyptus kochii ssp. plenissima	758	*Alyogyne hakeifolia*	600
Acacia microbotrya	742	*Banksia prionotes*	594
Acacia aff. redolens	734	*Exocarpus sparteus*	593
Acacia bartleana Maslin (ms)	709, 735	*Acacia saligna*	585
Dryandra arborea	720	*Trymalium floribundum*	582
Pittosporum angustifolium	719	*Eucalyptus occidentalis*	581
Pittosporum phylliraeoides	719	*Jacksonia sternbergiana*	577
Eucalyptus astringens	718	*Eucalyptus camaldulensis*	576
Eucalyptus loxophleba spp lissophloia	707	*Actinostrobus arenarius*	571
Acacia rostellifera	697	*Hakea oleifolia*	565
Acacia cyclops	657	*Senna pleurocarpa*	557
Dryandra sessilis	656	*Hakea prostrata*	552
Acacia lasiocalyx	648	*Melaleuca rhaphiophylla*	547
Eucalyptus erythrocorys	627, 669	*Grevillea leucopteris*	544
Kunzea glabrescens	633	*Adenanthos stictus*	543
Bursaria occidentalis	629	*Melaleuca preissiana*	514
Agonis flexuosa	620	*Persoonia elliptica*	505
Alyogyne huegelii	617	*Taxandria juniperina*	501
Casuarina obesa	613	*Paraserianthes lophantha*	501
Corymbia calophylla	612	*Eucalyptus rudis*	468, 494
Eucalyptus todtiana	611	*Duboisia hopwoodii*	446
Grevillea candelabroides	608	*Viminaria juncea*	436
Allocasuarina huegeliana	606	*Anthocercis littorea*	418
Lambertia inermis	604	*Gyrostemon ramulosus*	384, 384
Acacia murrayana	580, 627	*Codonocarpus cotinifolius*	378
Callitris glaucophylla	601	*Pinus radiata (control)*	~350

CELLULOSE CONTENT

Two methods for determining cellulose content were used in this work; wet chemistry digestion and near infra-red analysis. As can be seen a good correlation was found between the two methods which could in future lead to rapid cellulose determination by NIR alone.

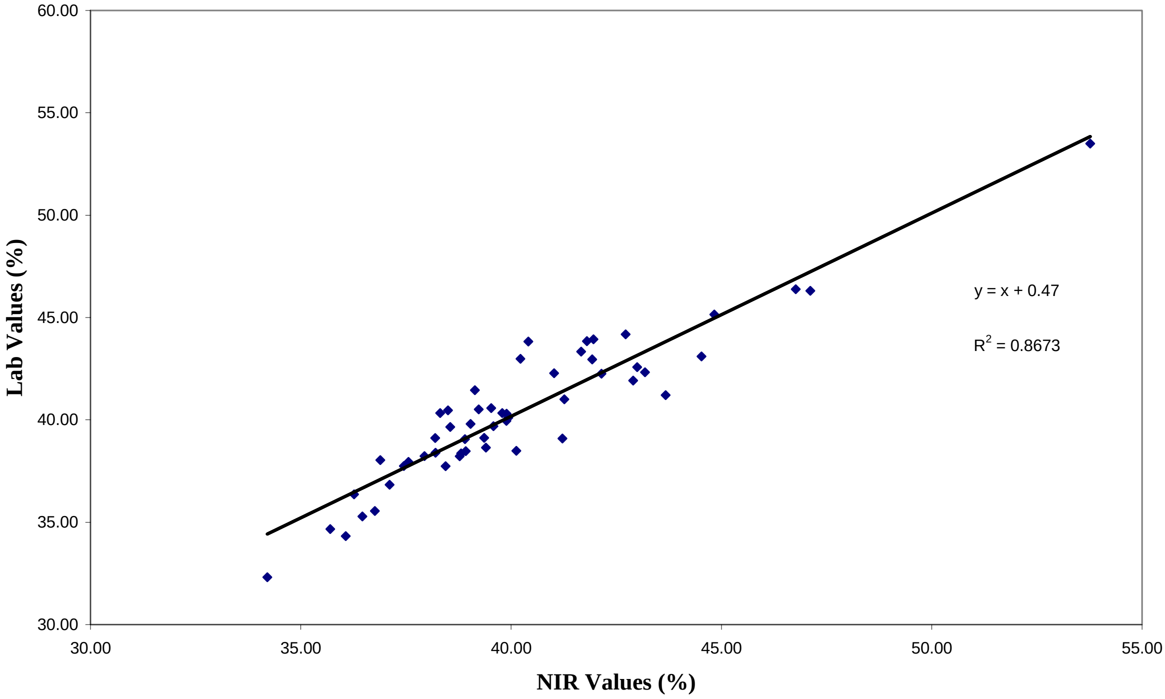


Figure 1: Wet chemistry determination of cellulose content plotted against results of NIR analysis. See **Appendix 1** for complete data.

HOT WATER SOLUBLES, pH AND BUFFERING CAPACITIES

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

Table 2: Alphabetical order of species with respective pH buffering capacities and hot water soluble extractive contents. ABC= Acid Buffering Capacity, BBC= Base Buffering Capacity, WBC= Wood Buffering Capacity.

Species	pH	ABC	BBC	WBC	Water soluble extracts
		mmol/g	mmol/g	mmol/g	%
Acacia aff. redolens	4.7	0.038	0.093	0.131	12.3
Acacia bartleana Maslin (ms)	5.2	0.028	0.127	0.154	15.3
Acacia cyclops	5.3	0.033	0.145	0.178	9.3

Species	pH	ABC	BBC	WBC	Water soluble extracts
Acacia lasiocalyx	5.2	0.024	0.120	0.144	7.6
Acacia microbotrya	5.2	0.019	0.123	0.142	9.5
Acacia murrayana	5.6	0.033	0.170	0.203	14.9
Acacia rostellifera	4.4	0.049	0.085	0.133	11.8
Acacia saligna	5.4	0.022	0.140	0.1626	10.3
Actinostrobus arenarius	5.7	0.011	0.144	0.155	5.1
Adenanthos stictus	5.0	0.036	0.132	0.168	9.0
Agonis flexuosa	5.5	0.019	0.132	0.151	8.6
Allocasuarina huegeliana	5.2	0.020	0.136	0.157	8.7
Alyogyne hakeifolia	5.2	0.022	0.106	0.128	10.9
Alyogyne huegelii	6.1	0.028	0.249	0.277	12.0
Anthocercis littorea	6.2	0.011	0.199	0.210	6.8
Banksia prionotes	5.0	0.029	0.091	0.120	14.3
Bursaria occidentalis	6.0	0.017	0.261	0.278	11.7
Callitris glaucophylla	4.8	0.024	0.096	0.120	6.4
Casuarina obesa	5.7	0.028	0.182	0.209	9.4
Codonocarpus cotinifolius	5.9	0.018	0.178	0.197	9.0
Corymbia calophylla	5.1	0.038	0.181	0.219	15.2
Dryandra arborea	5.5	0.023	0.134	0.156	11.4
Dryandra sessilis	5.1	0.035	0.117	0.151	9.9
Duboisia hopwoodii	5.0	0.027	0.156	0.183	12.2
Eucalyptus astringens	5.0	0.024	0.074	0.098	7.8
Eucalyptus camaldulensis	5.4	0.033	0.189	0.222	16.0
Eucalyptus erythrocorys	4.7	0.038	0.089	0.128	8.8
Eucalyptus kochii ssp. plenissima	5.4	0.020	0.100	0.119	7.6
Eucalyptus loxophleba ssp. lissophloia	5.3	0.026	0.195	0.221	6.4
Eucalyptus nitens (control)	5.1	0.029	0.166	0.195	3.1
Eucalyptus nitens (control)	5.2	0.030	0.112	0.142	5.0
Eucalyptus occidentalis	4.9	0.030	0.105	0.134	7.4
Eucalyptus rudis	5.9	0.026	0.156	0.182	10.2
Eucalyptus todtiana	4.8	0.071	0.120	0.190	11.5
Exocarpus sparteus	4.7	0.032	0.077	0.109	10.3
Grevillea candelabroides	5.0	0.030	0.141	0.170	12.1
Grevillea leucopteris	5.2	0.033	0.152	0.185	9.5
Gyrostemon ramulosus	5.7	0.023	0.213	0.236	8.6
Hakea oleifolia	4.6	0.033	0.085	0.119	12.3
Hakea prostrata	5.0	0.030	0.112	0.142	10.4
Jacksonia sternbergiana	5.7	0.027	0.230	0.257	7.9
Kunzea glabrescens	5.2	0.031	0.131	0.163	9.4
Lambertia inermis	5.0	0.025	0.121	0.146	7.9
Melaleuca preissiana	4.9	0.050	0.093	0.143	12.0
Melaleuca rhaphiophylla	4.7	0.033	0.085	0.118	12.7
Paraserianthes lophantha	4.7	0.030	0.085	0.116	7.6
Persoonia elliptica	5.0	0.031	0.123	0.154	11.6
Pinus radiata (control)	5.7	0.018	0.175	0.193	6.2
Pinus radiata (control)	5.4	0.018	0.128	0.146	4.4
Pittosporum angustifolium	5.2	0.029	0.129	0.158	16.9
Pittosporum phylliraeoides	5.3	0.026	0.121	0.148	14.4
Senna pleurocarpa	6.0	0.017	0.232	0.249	9.3
Taxandria juniperina	5.5	0.024	0.128	0.153	4.8
Trymalium floribundum	4.8	0.027	0.118	0.145	7.6

Species	pH	ABC	BBC	WBC	Water soluble extracts
Viminaria juncea	4.9	0.045	0.153	0.198	9.4

FIBRE LENGTH AND WIDTH

Fibre length and widths are given for all species assayed below. As well as the data being weighted, the first 0 to 200 μm lengths and 0 to 10 μm widths were omitted from the calculations as standard practice to eliminate fines and cellular detritus from the determination of fibre length and width.

Table 3: Fibre length and width of wood species determined on samples taken from pulp yield trials.

Species	Mean Weighted Fibre Length (μm)	Mean Weighted Fibre Width (μm)
Grevillea candelabroides	843 (306)	22.0 (7.0)
Actinostrobus arenarius	826 (435)	23.6 (6.4)
Persoonia elliptica	821 (391)	30.1 (10.2)
Taxandria juniperina	786 (321)	22.7 (6.6)
Agonis flexuosa	745 (318)	21.9 (6.8)
Callitris glaucophylla	727 (379)	22.1 (6.4)
Lambertia inermis	689 (307)	22.9 (6.2)
Grevillea leucopteris	686 (355)	20.7 (5.7)
Hakea oleifolia	667 (342)	22.7 (8.3)
Corymbia calophylla	661 (311)	20.0 (6.1)
Trymalium floribundum	634 (260)	23.0 (8.5)
Dryandra sessilis	633 (334)	23.4 (6.7)
Melaleuca rhaphiophylla	633 (263)	23.1 (7.9)
Pittosporum phylliraeoides	623 (239)	23.3 (8.9)
Dryandra arborea	621 (294)	21.1 (6.0)
Melaleuca preissiana	611 (274)	20.3 (6.1)
Gyrostemon ramulosus	597 (255)	20.5 (5.6)
Banksia prionotes	596 (275)	21.5 (6.2)
Hakea prostrata	591 (284)	20.5 (5.7)
Kunzea glabrescens	588 (272)	21.3 (6.0)
Adenanthos stictus	577 (229)	21.8 (6.1)
Viminaria juncea	575 (244)	19.8 (5.5)
Eucalyptus erythrocorys	566 (239)	20.6 (5.4)
Jacksonia sternbergiana	563 (242)	19.4 (4.7)
Alyogyne huegelii	561 (320)	18.1 (4.4)
Eucalyptus nitens (control)	556 (235)	18.1 (4.5)
Acacia cyclops	553 (232)	20.2 (5.4)
Pittosporum angustifolium	532 (207)	24.4 (9.4)
Allocasuarina huegeliana	531 (235)	19.3 (5.2)
Exocarpus sparteus	529 (233)	19.6 (5.0)
Eucalyptus todtiana	529 (228)	20.1 (5.7)
Anthocercis littorea	526 (262)	20.7 (6.5)
Alyogyne hakeifolia	523 (231)	19.7 (5.4)
Acacia bartleana Maslin (ms)	513 (217)	18.8 (4.6)
Codonocarpus cotinifolius	506 (268)	19.9 (5.8)

Species	Mean Weighted Fibre Length (µm)	Mean Weighted Fibre Width (µm)
Eucalyptus camaldulensis	486 (179)	18.7 (4.8)
Acacia aff. redolens	477 (247)	18.0 (4.5)
Paraserianthes lophantha	474 (204)	19.8 (5.1)
Duboisia hopwoodii	465 (185)	20.1 (6.7)
Senna pleurocarpa	465 (162)	18.9 (4.9)
Eucalyptus rudis	460 (209)	19.1 (6.1)
Casuarina obesa	454 (176)	17.7 (4.3)
Acacia microbotrya	449 (227)	19.4 (5.9)
Acacia murrayana	447 (245)	18.5 (4.4)
Bursaria occidentalis	447 (160)	20.2 (5.4)
Acacia saligna	430 (232)	18.8 (4.4)
Acacia lasiocalyx	411 (215)	18.1 (4.7)
Eucalyptus loxophleba ssp. lissophloia	383 (138)	16.6 (4.5)
Pinus radiata (control)	2000[1]	30

PULP YIELDS

Table 4: Pulp yields, listed in descending order, determined at 18 Kappa number.

Species	Basic Density (kg/m^3)	At 18 Kappa No.	
		AA* Na_2O (%)	Yield (%)
Taxandria juniperina	501	13	54.3
Senna pleurocarpa	557	13	53.2
Paraserianthes lophantha	501	14.5	52.9
Grevillea leucopteris	544	17.8	52.4
Acacia lasiocalyx	648	17	51.6
Anthocercis littorea	418	14	49.7
Trymalium floribundum	582	19	49.7
Eucalyptus occidentalis	581	14	49.4
Adenanthos stictus	543	<15	49.2
Eucalyptus astringens	718	14	48.9
Acacia cyclops	657	17.5	48.8
Acacia murrayana (1)	580	16	48.7
Acacia murrayana (2)	627	19	43.4
Eucalyptus loxophleba spp lissophloia	707	13	48.7
Lambertia inermis	604	14	48.6
Eucalyptus rudis (1)	494	17	48.4
Eucalyptus rudis (2)	468	15	43.5
Alyogyne huegelii	617	15.5	47.8
Jacksonia sternbergiana	577	16	47.6
Acacia aff. redolens	734	17	47.3
Eucalyptus kochii ssp plenissima	758	16	47.3
Acacia microbotrya	742	16	47.1
Codonocarpus cotinifolius	378	14.5	46.5
Eucalyptus erythrocorys (1)	627	16.5	46.2
Eucalyptus erythrocorys (2)	669	15.5	44.0
Allocasuarina huegeliana	606	17	45.6

[1] Properties and uses of New Zealand radiata pine. Volume 1 - Wood Properties. J.A. Kininmonth and L.J. Whitehouse. Forest Research Institute, Rotarua New Zealand. 1991

Species	Basic Density (kg/m^3)	At 18 Kappa No.	
		AA* Na_2O (%)	Yield (%)
Acacia saligna	585	16.5	45.2
Grevillea candelabroides	608	17.5	45.1
Dryandra sessilis	656	16	44.9
Acacia bartleana Maslin (ms) (1)	709	20.3	44.8
Acacia bartleana Maslin (ms) (2)	735	17	43.9
Viminaria juncea	436	15	44.7
Agonis flexuosa	620	16	44.6
Gyrostemon ramulosus (1)	384	20.5	44.5
Gyrostemon ramulosus (2)	384	20	44.3
Persoonia elliptica	505	15	44.1
Corymbia calophylla	612	17	43.6
Exocarpus sparteus	593	17.5	43.0
Dryandra arborea	720	16.5	42.7
Banksia prionotes	594	14.5	42.5
Hakea oleifolia	565	22	42.1
Casuarina obesa	613	22	41.8
Melaleuca rhaphiophylla	547	16.5	39.0
Bursaria occidentalis	629	18	38.6
Eucalyptus camaldulensis	576	17	38.3
Eucalyptus todtiana	611	21.8	38.1
Kunzea glabrescens	633	24	37.3
Duboisia hopwoodii	446	25	36.5
Hakea prostrata	552	>22	<43
Acacia rostellifera	697	>24	<42
Alyogyne hakeifolia	600	>25	<39
Pittosporum phylliraeoides	719	>22	<39
Melaleuca preissiana	514	20.5	<37
Actinostrobus arenarius	571	>25	<36
Pittosporum angustifolium	719	>22	<36
Callitris glaucophylla	601	>25	<35

(*)Active Alkali calculated as Na_2O
(<) Resultant yield would be less than value shown due to high fines content.
Note: Some species were pulped twice, using separate wood collections. They are listed together in the table, ranked according to the higher pulp yield.

The species with the better pulp yield results were selected for evaluation of pulp properties.

PAPER QUALITY AND BLEACHING RESULTS

The assessment of pulp quality (from selected species) was conducted on wood chips from the same samples as those used in yield trials some assaying described in the sections above.

Table 5: Pulp testing results and bleaching tests. See **Appendix 2** for complete data set. Brightness determination data are presented in **Appendix 3**.

Species	**Pulp yield**	**Bleaching**	**Paper properties**			
			Freeness	**Density**	**Tear Index**	**Tensile Index**
Taxandria juniperina	excellent	excellent	excellent	excellent	v. good	v. good
Senna pleurocarpa	excellent	good	v. good	poor	v. poor	good
Paraserianthes lophantha	excellent	excellent	v. good	poor	v. poor	poor
Grevillea leucopteris	excellent	v. good	excellent	excellent	good	good
Acacia lasiocalyx	excellent	good	excellent	excellent	v. poor	poor
Anthocercis littorea	v. good	excellent	good	v. poor	v. poor	v. good
Trymalium floribundum	v. good	v. good	v. good	v. good	v. poor	good
Adenanthos stictus	v. good	good	v. good	v. good	v. poor	v. poor
Acacia cyclops	v. good	v. poor	v. good	v. good	v. poor	poor
Lambertia inermis	v. good	-	excellent	excellent	v. poor	poor
Eucalyptus loxophleba ssp. lissophloia	v. good	v. good	poor	v. good	v. poor	v. poor
Acacia murrayana	v. good	excellent	v. good	excellent	v. poor	v. poor
Eucalyptus rudis	v. good	v. good	v. good	poor	v. poor	poor
Eucalyptus astringens	v. good	good	excellent	excellent	v. poor	poor
Eucalyptus occidentalis	v. good	v. poor	good	poor	v. poor	v. poor
Eucalyptus erythrocorys	good	excellent	excellent	v. good	v. poor	v. poor
Eucalyptus kochii ssp. plenissima	good	excellent	v. good	excellent	v. poor	v. poor
Alyogyne huegelii	good	v. good	excellent	excellent	v. good	good
Jacksonia sternbergiana	good	v. good	excellent	excellent	v. poor	v. poor
Acacia aff. redolens	good	v. good	good	excellent	v. poor	v. poor
Acacia microbotrya	good	good	v. good	excellent	v. poor	v. poor
Codonocarpus cotinifolius	good	good	v. good	v. poor	v. poor	poor
Allocasuarina huegeliana	good	good	poor	excellent	v. poor	v. poor
Acacia saligna	good	poor	excellent	excellent	v. poor	poor
Grevillea candelabroides	good	excellent	excellent	excellent	excellent	good
Acacia bartleana Maslin (ms)	poor	poor	excellent	excellent	v. poor	poor
Dryandra sessilis	poor	v. poor	v. good	excellent	v. poor	v. poor
Viminaria juncea	poor	good	excellent	poor	v. poor	poor
Agonis flexuosa	poor	good	excellent	excellent	poor	good
Gyrostemon ramulosus	poor	v. poor	v. good	poor	v. poor	v. poor

To summarise from Table 4 and 5, the species most warranting further study are:
Taxandria juniperina, *Grevillea leucopteris*, *Alyogyne huegelii* and *Grevillea candelabroides*.

A second group of promising species would include: *Senna pleurocarpa, Acacia lasiocalyx, Anthocercis littorea* (at older age), *Trymalium floribundum, Viminaria juncea, Agonis flexuosa.*

MEDIUM DENSITY FIBREBOARD

The mechanical and physical properties of medium density fibreboards (MDF) prepared from selected species are presented over the following pages. The data are based on replicate panels prepared from each of the species listed in Table 6. Attempts to produce six replicate panels for each species were not always possible due to the times needed to stabilise the pilot plant for successful panel production.

Values used in generating the following charts are given in Appendix 4 in summary format.

Table 6: Species fabricated into MDF

Species	No. of panels	Whole Panel Density (kg/m^3)
Acacia lasiocalyx	6	827 (12)
Acacia saligna	5	830 (62)
Alyogyne huegelii	4	756 (18)
Anthocercis littorea	6	766 (19)
Bursaria occidentalis	6	752 (34)
Callitris glaucophylla	6	751 (20)
Casuarina obesa	6	850 (21)
Codonocarpus cotinifolius	6	756 (34)
Dryandra sessilis	6	762 (34)
Eucalyptus loxophleba ssp. lissophloia	6	837 (14)
Eucalyptus rudis	6	795 (16)
Grevillea leucopteris	5	772 (34)
Gyrostemon ramulosus	6	775 (41)
Hakea oleifolia	6	817 (20)
Jacksonia sternbergiana	6	770 (43)
Melaleuca preissiana	3	689 (32)
Pinus radiata	6	780 (59)
Senna pleurocarpa	6	765 (18)
Taxandria juniperina	6	813 (35)
Viminaria juncea	5	835 (22)

MDF – Modulus of Rupture

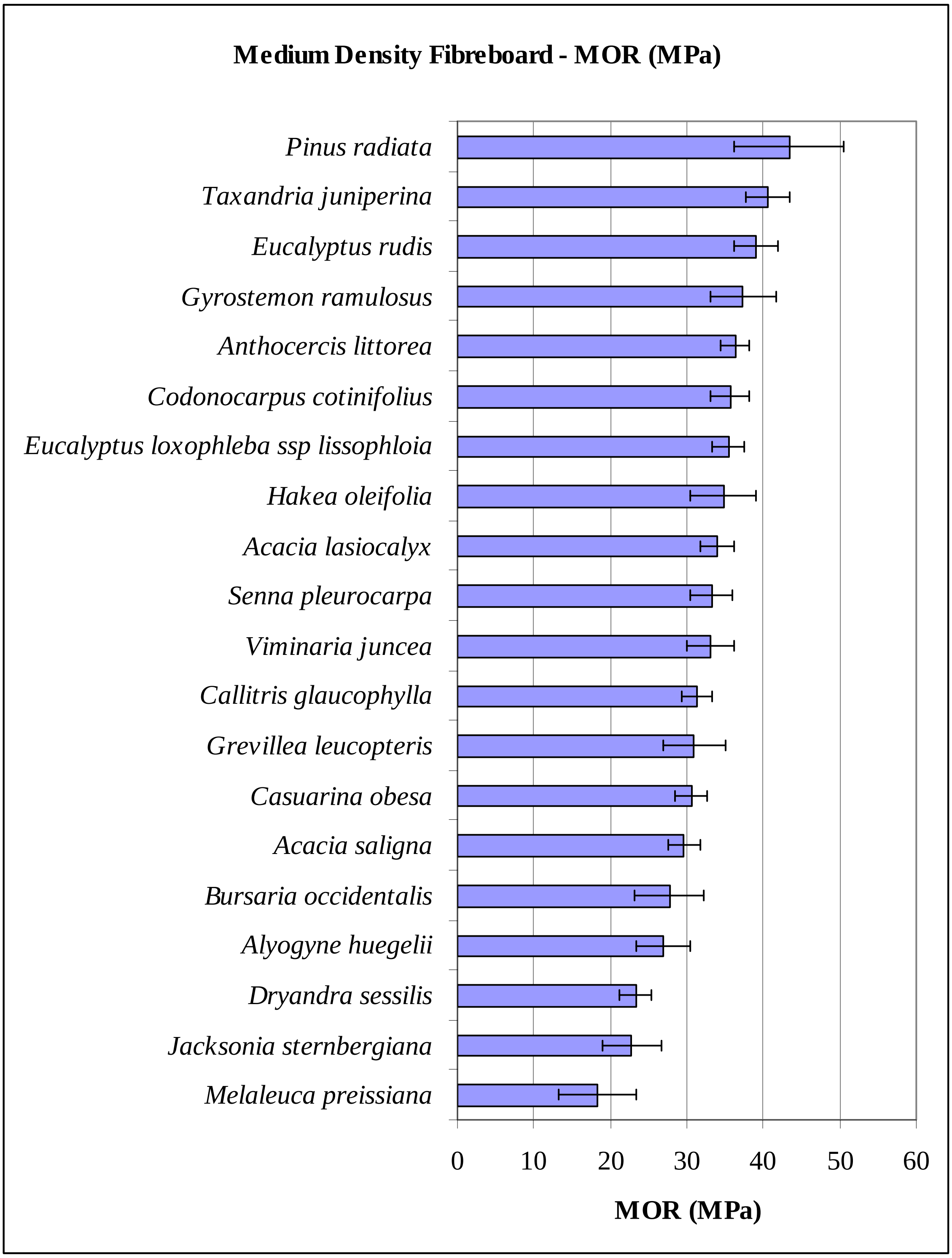


Figure 2: MDF modulus of rupture results from three point flexural testing.

MDF – Modulus of Elasticity (MOE)

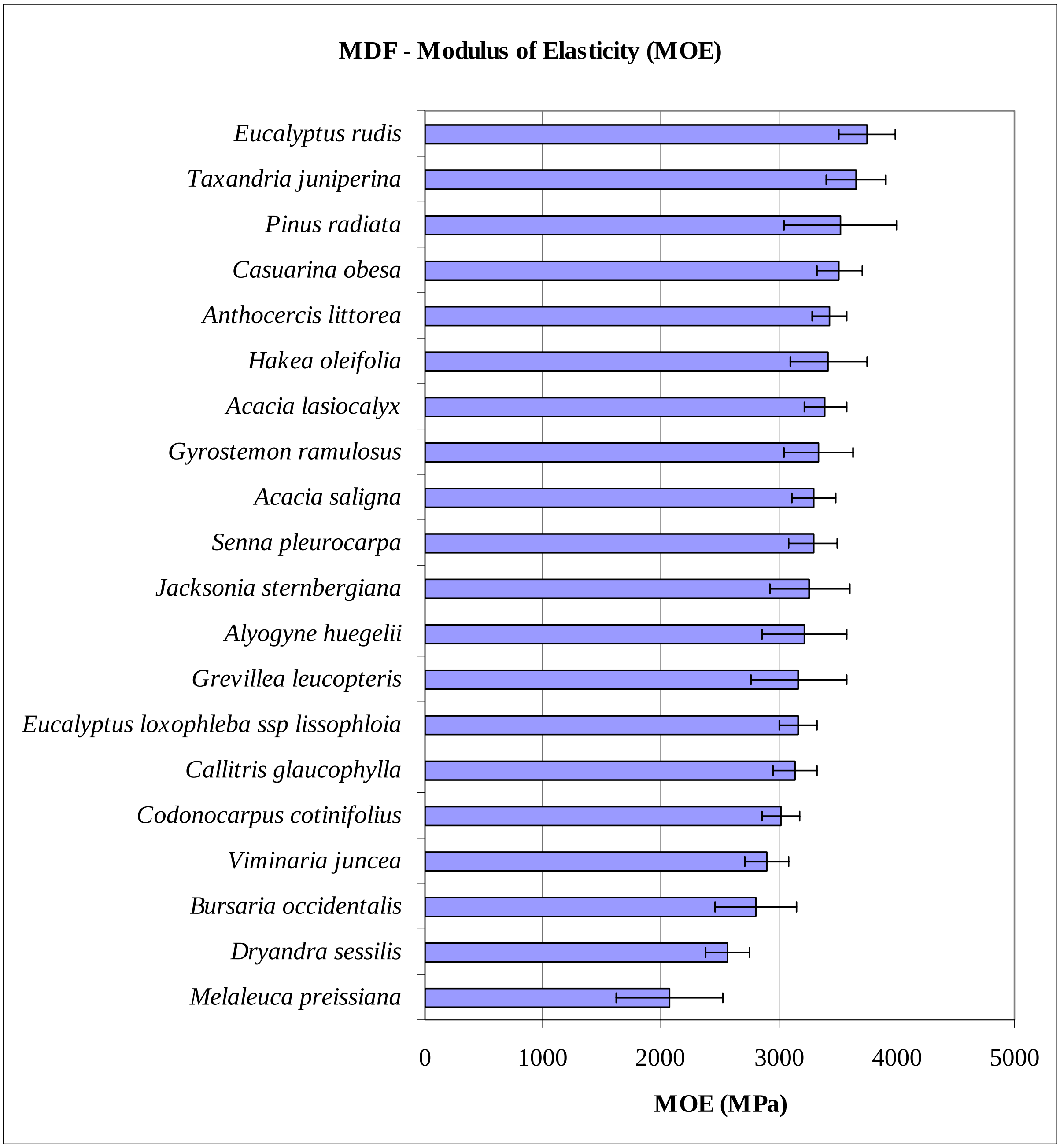


Figure 3: MDF modulus of elasticity results from three point flexural testing.

MDF – Internal Bond Strength

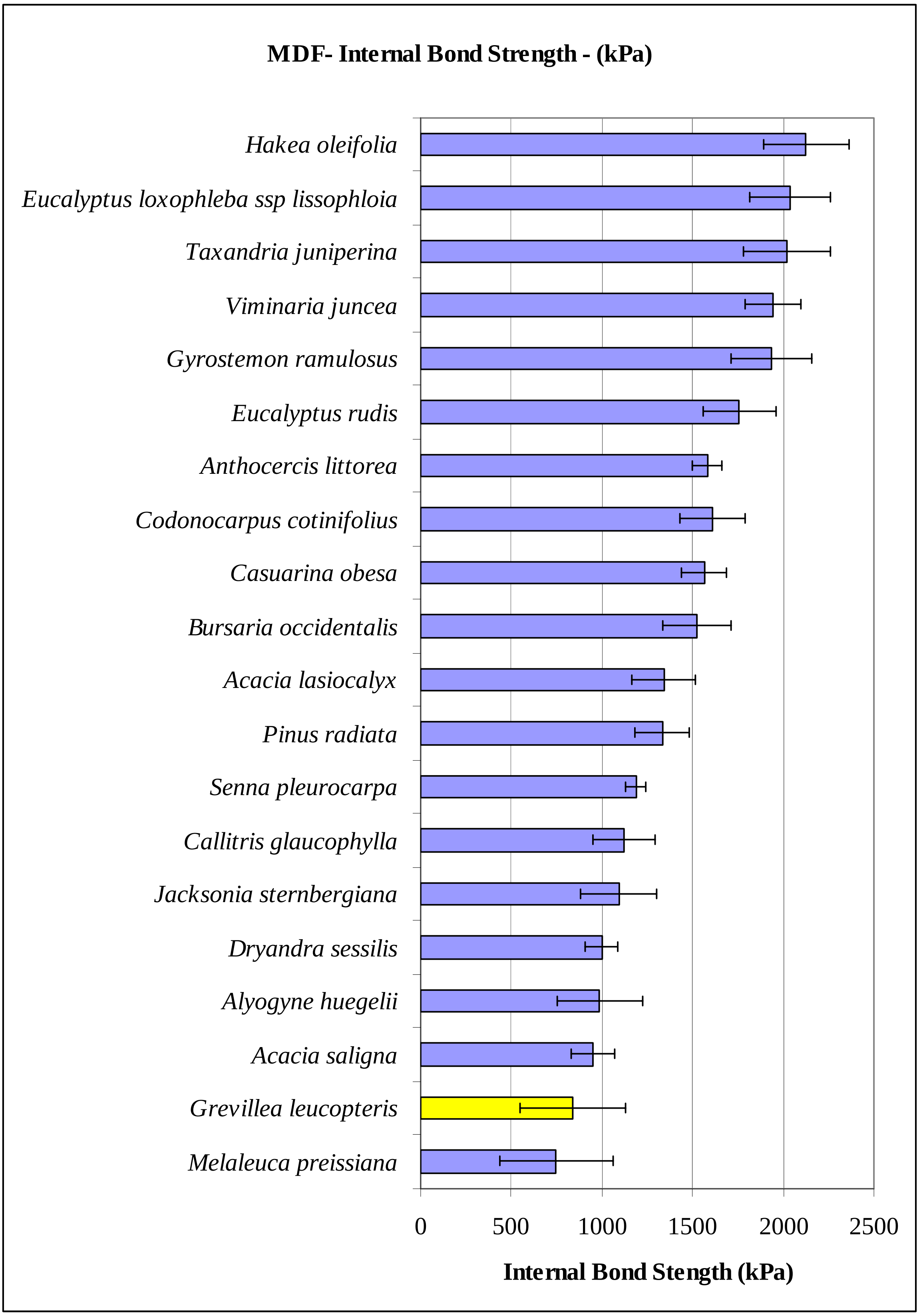


Figure 4: MDF internal bond strength results. Note: Result for *Grevillea leucopteris* is given as a range of two distinct groups of 3 and 2 panels – the chart bar for this species represents a grand mean (840 kPa) and the error bars (±293 kPa) the range.

MDF – Thickness Swell

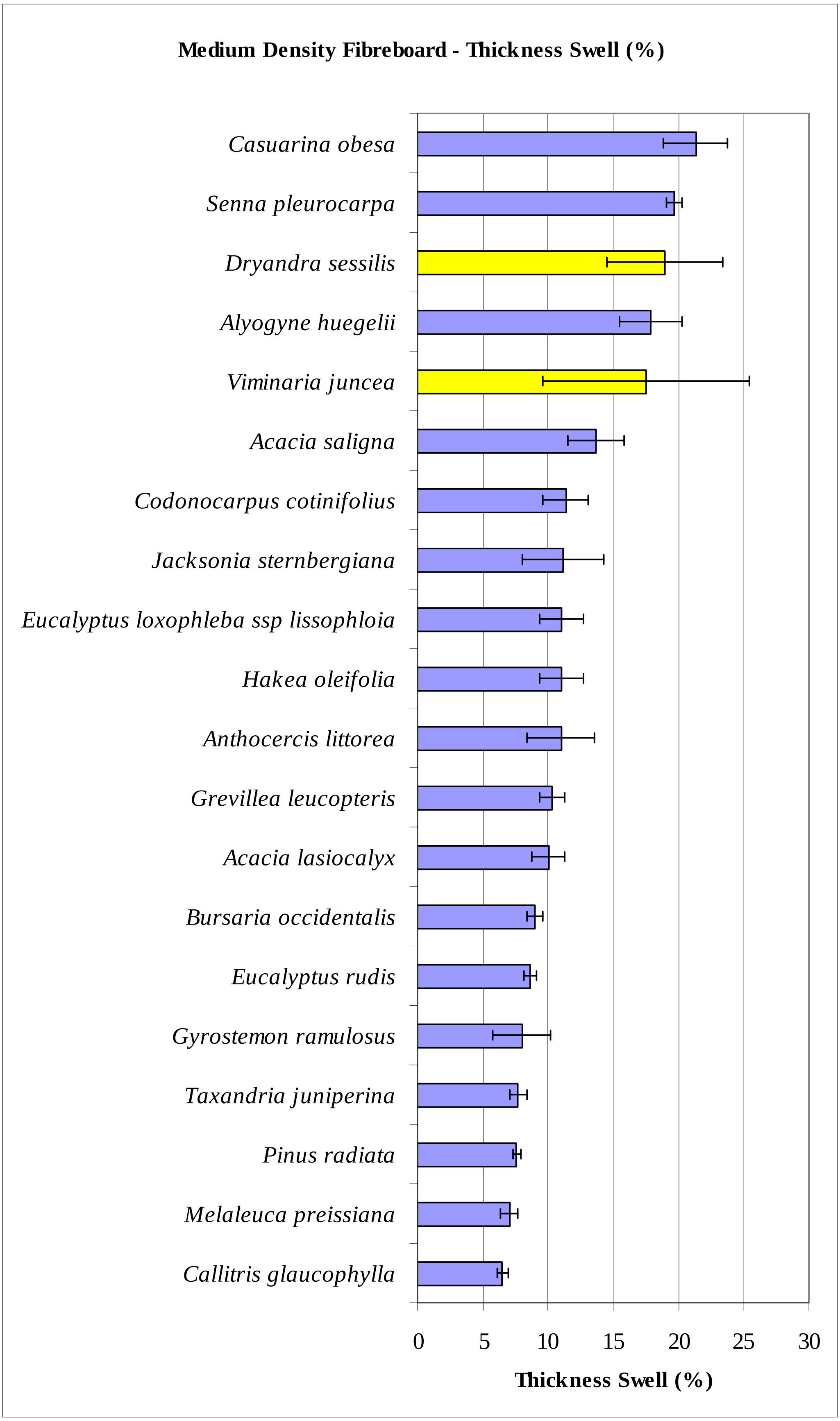


Figure 5: MDF thickness swell results. Note, results for *Viminaria juncea* and *Dryandra sessilis* are presented as mid points of grand means and ranges have been substituted for error bars *V. juncea* – 17.5 ±7.95 and *D. sessilis* – 19.0 ±4.5

Discussion

Many wood species were successfully converted to MDF panels having acceptable mechanical and physical properties. Although the target panel density was 750 kg/m^3 this work program generated a considerable spread of whole-panel densities (Table 6). Due to the limited body of work able to be carried out with respect to process variables this work is very much a screening process. Nonetheless, the flexural properties of many species compared well with those of the pine control. Strength and stiffness dropped away for hardwood species when the panel density fell below 750 kg/m^3. This would expected for MDF prepared from hardwoods species having relatively high basic density.

It should be noted that high pressure refining of hardwoods produces a high ‘fines’ content in the fibrous mass. High fines content would have an effect on compaction and resin distribution leading to high internal bond strengths. Eight species were between 1500 and 2000 kPa whereas 1000 kPa would be considered more typical for a commercial panel. The poorest performing species, *Melaleuca preissiana* also possessed the lowest panel density; this suggests that the species could warrant re-investigation.

Thickness swell after 24 h water immersion were all acceptable for this ‘standard’ grade of MDF panel. Although a thickness swell of ~20% represents an upper limit for commercial acceptability, the majority of species were at ~10%. In Figure 5, two distinct groupings within species were found (not withstanding the spread of data for *Dryandra sessilis* and *Viminaria juncea*). Species above about *Acacia saligna* had relatively high thickness swells compared to those below this level. However, it would be prudent not to read too much into the data at this early stage.

The results show that at a pilot scale level a wide variety of wood species can be successfully processed by high pressure refining and converted to a panel product. Species selection, on those studied here, could best be done on growth rates and ‘form’ in conjunction with their suitability for other products which might be developed on a regional basis. Further consideration could also be made to blending the hardwood species (*Callitris* was the only native softwood studied) with *Pinus radiata* during production.

The species under study here did not greatly outperform the benchmark *P. radiata* species in mechanical or physical performance. Pine panels were at or near the top of flexural strength and stiffness, possessed low thickness swell and had a mid-range of the internal bond strengths. This would suggest more work is needed to optimise the preparation of panels using hardwood species especially the high pressure refining operation and the need to reduce fines. Further studies to benchmark against (high rainfall) plantation hardwoods would also be useful to better estimate the potential of the species studied here.

PARTICLEBOARD

The mechanical and physical properties of particleboard panels prepared from selected species are presented over the following pages. The data are based on replicate panels prepared from each of the species listed in Table 7. An attempt to produce six replicate panels was not always possible due to material and processing constraints.

Values used in generating the following charts are given in Appendix 5 in summary format.

Table 7: Particleboard whole panel densities and the number of panels prepared per species.

Species	Number of Panels	Whole Panel Density (kg/m^3)
Acacia lasiocalyx	6	711 (23)
Acacia saligna	6	714 (33)
Alyogyne huegelii	5	687 (7)
Anthocercis littorea	5	690 (39)
Bursaria occidentalis	6	710 (9)
Callitris glaucophylla	6	741 (8)
Casuarina obesa	6	739 (31)
Codonocarpus cotinifolius	6	680 (29)
Dryandra sessilis	6	668 (20)
Eucalyptus loxophleba ssp lissophloia	5	794 (38)
Eucalyptus occidentalis	6	692 (44)
Eucalyptus rudis	6	727 (31)
Grevillea leucopteris	5	750 (28)
Gyrostemon ramulosus	6	689 (30)
Hakea oleifolia	6	743 (50)
Jacksonia sternbergiana	3	696 (14)
Melaleuca preissiana	6	744 (26)
Pinus radiata	6	733 (11)
Senna pleurocarpa	5	737 (15)
Taxandria juniperina	6	733 (15)
Viminaria juncea	6	713 (14)

Particleboard – Modulus of Rupture (MOR)

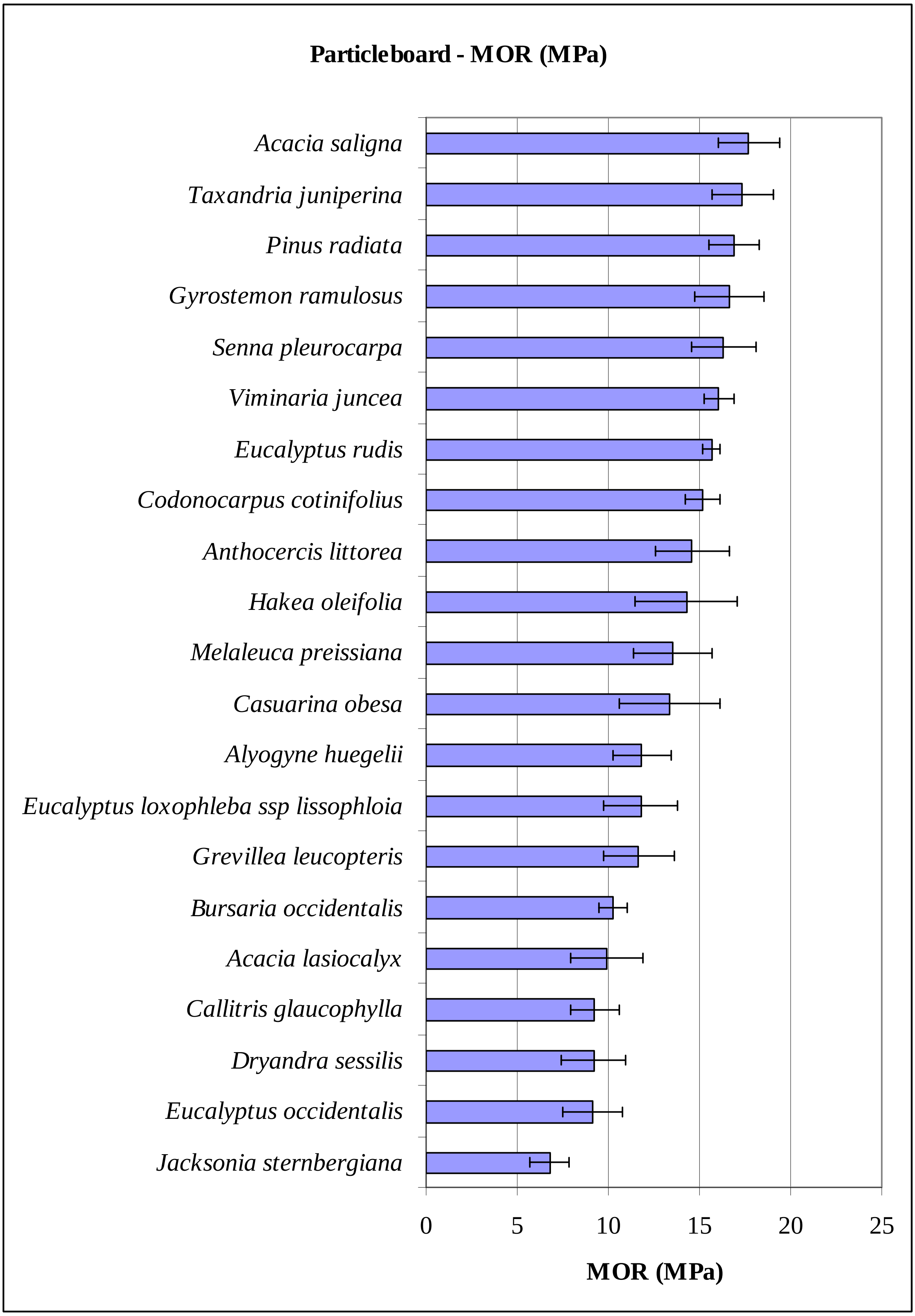


Figure 6: Particleboard modulus of rupture results from three point flexural testing. Note *Eucalyptus rudis* data based on 5 panels.

Particleboard – Modulus of Elasticity (MOE)

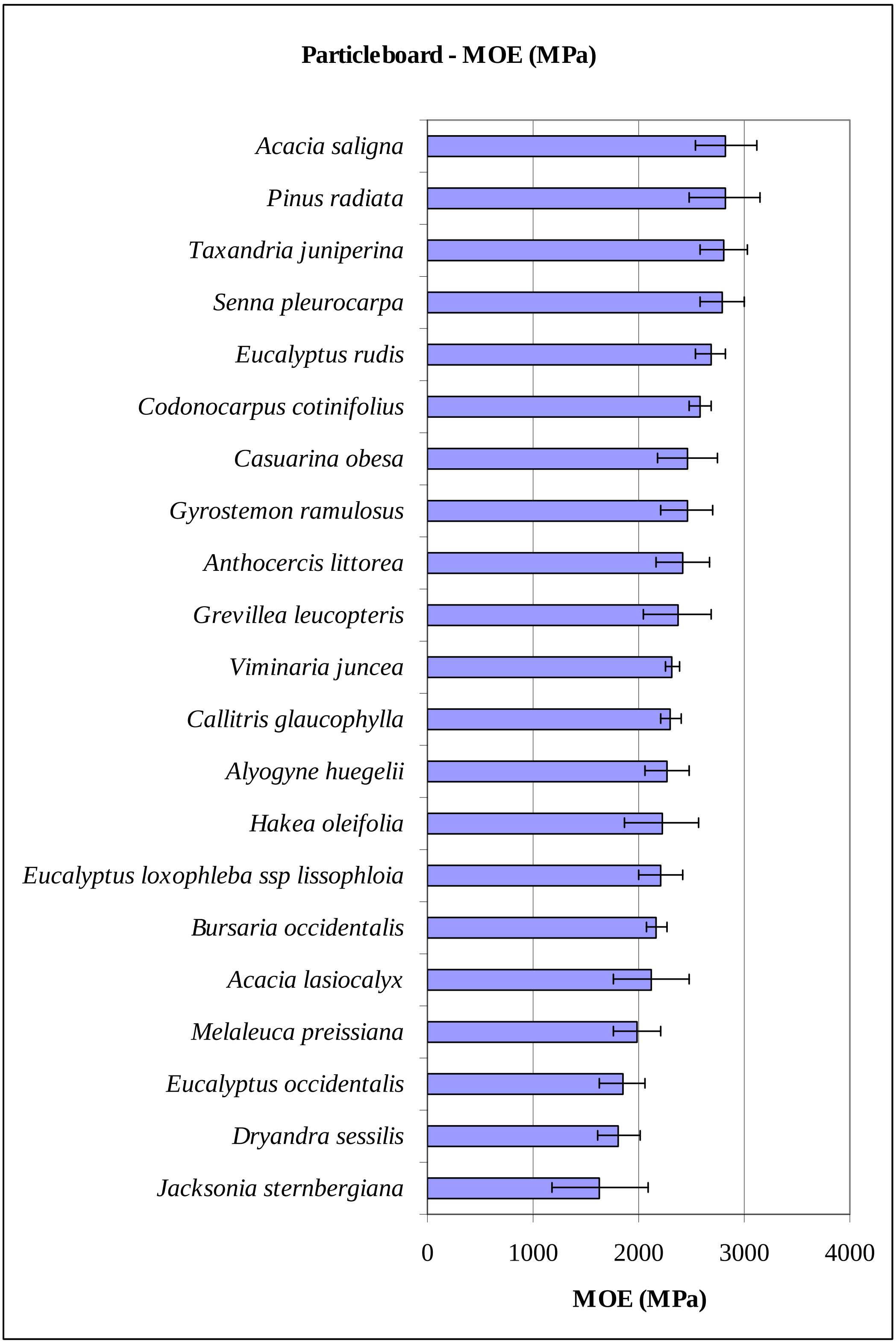


Figure 7: Particleboard modulus of elasticity results from three point flexural testing. Note, *Eucalyptus rudis* data based on 5 panels.

Particleboard – Internal Bond Strength

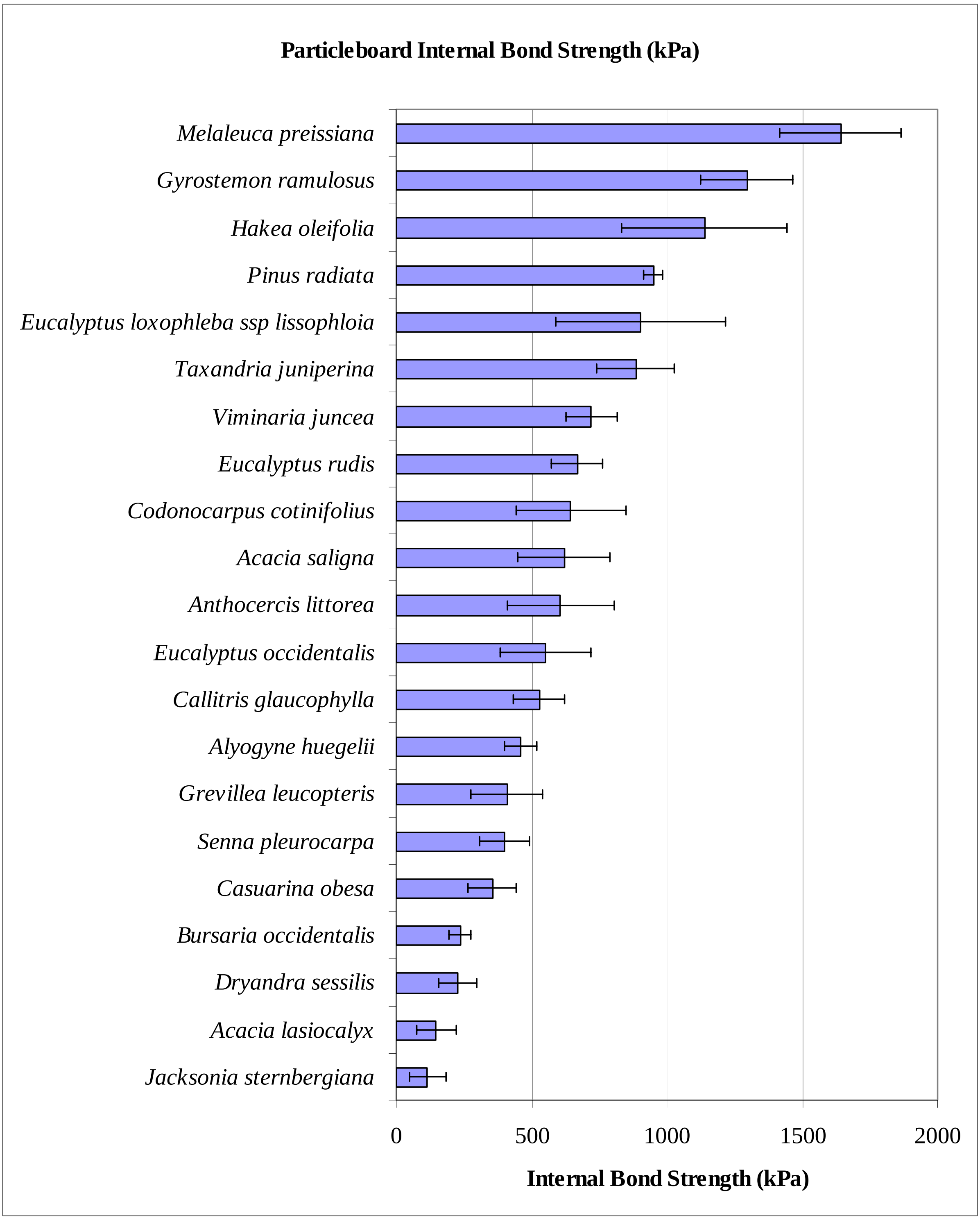


Figure 8: Particleboard internal bond strength results. Note: *Eucalyptus rudis* results based on 5 panels and *Grevillea leucopteris, Eucalyptus occidentalis, Casuarina obesa* results are based on four panels for each species.

Particleboard – Thickness Swell

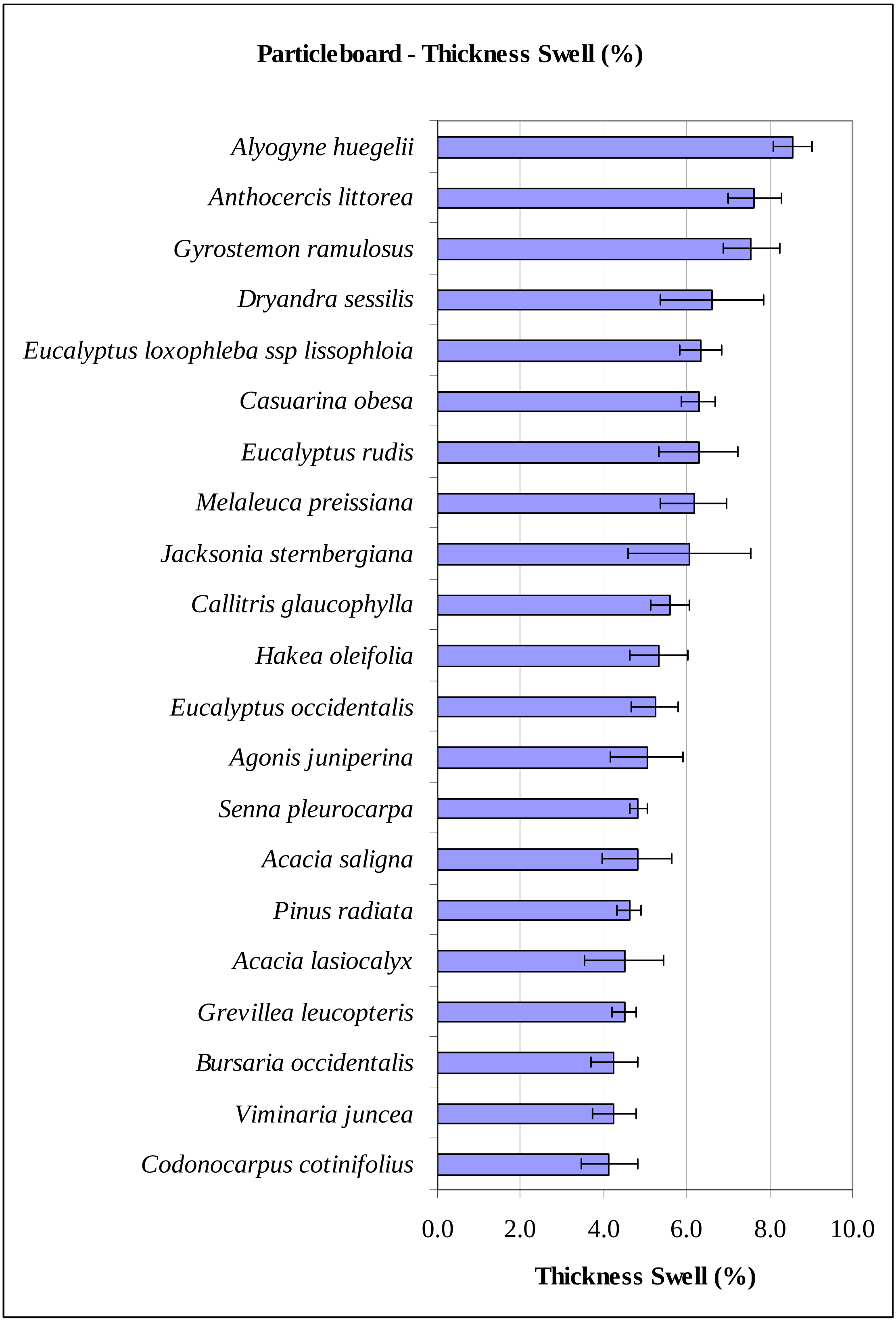


Figure 9: Particleboard thickness swell results.

DISCUSSION

Particleboard flexural properties for all species, including the pine control, were comparable to commercial panels for standard grade boards. Some drop-off in strength and stiffness was seen in some species (Figures 6 and 7) however, they should not be dismissed without further re-assessment.

Internal bond strengths were acceptable for many species and comparable to that of the *P. radiata* control, although results for the lowest three species, with IBS of ~100-250 kPa, suggest a re-investigation might be warranted.

Thickness swells after 1 hour immersion time were well within the limits for standard grade panels and the results for all species, including the *P. radiata* control panels, differed by only about four percentage points.

In general terms the indigenous species performed comparably with that of the pine control. A few exceptions exist with some panels not being fabricated to optimum density, hence having poor performance in flexure and internal bond strength.

An important consideration in the preparation of particleboard is the conformability of the woody material under heat and pressure during panel pressing. This is very evident in processing *P. radiata*. However, many of the species investigated produced panels of an ‘open’ core construction. Two exceptions to this were *Codonocarpus cotinifolius* and *Gyrostemon ramulosus* where the material appeared to be better compacted.

Along with wood conformability the species would also need to be of an acceptable density, below approximately 500 kg/m^3. Heavy panels would not be acceptable in the market place due to handling difficulties and high transport costs. At the time of writing, a small percentage of eucalypt wood is used as core material in some particleboards. This could offer some opportunity commercially if new wood species could be used on a part furnish basis in particleboard manufacture.

MATERIALS AND METHODS

CELLULOSE CONTENT

Wet Chemistry

Diglyme (10 mL) and hydrochloric acid (2 mL) were added to milled wood (1 g) in a reaction vial, sealed with a PTFE lined septum and placed in a shaking water bath at 90°C. After 1h the sample was removed and filtered through a tared, porous alundum crucible. The residue was washed with methanol (50 mL) and then boiling water (500 mL) and the crucible dried overnight at 105°C. Cellulose was calculated as a percentage of OD wood. Results are a mean of duplicate determinations.

Near I-R Analysis

Wood meal was used to generate NIR spectra for each of the species using an FIR Systems 5000 bench top analyser. Spectra from the wood samples were used to establish base-line controls against the results from the wet chemistry results.

The following chemical assays were carried out based on wood meals prepared from random samples of wood chips which were air dried to approximately 5% moisture content and milled in a Wiley Mill through a 1 mm screen.

HOT WATER SOLUBLE EXTRACTIVES

This method was based on the Australian standard: Solubility of wood in boiling water, AS/NZS 1301.004s:1998. Briefly, wood meal was boiled for one hour under reflux conditions with the weight difference before and after boiling being the water soluble content.

pH AND WOOD MEAL BUFFERING CAPACITY

The buffering capacities and pH of wood meals prepared from milled composite samples of wood chips were determined using a modified method described by Johns and Niazi[2]. Air dried wood meal (1 g) was steeped in 100 mL of distilled water until a steady pH was reached, at which point the suspension was titrated against 0.01 N NaOH or H_2SO_4 until a pH of 7 or 3 was reach respectively. Titrating with the base to pH 7 yields the Acid Buffering Capacity (ABC in mmol/g) and titrating with the acid to pH 3 gives the Base Buffering Capacity (BBC in mmol/g). The wood buffering capacity (WBC) is the sum of the two buffering capacities. The initial pH of the suspended wood meal prior to titration was taken to represent the pH of the wood.

FIBRE LENGTH

Fibre length and width were determined on fibres prepared by Kraft cooking process in the pulping program using a Galai CIS-100 image analysis system. Dilute suspensions of fibres were passed in front of an optical lens and video camera allowing digital still frames to be analysed by computer.

CHEMICAL PULPING

Wood Basic Density

Wood density was obtained by boiling wood chip samples to fully saturate the chips with water prior to using the displacement technique to obtain chip volume. The wood chips were then oven dried to obtain the dry weight used in basic density calculations.

---

[2] Johns, W.E and Niazi, K.A. Effect of pH and buffering capacity of wood on the gelation time of urea-formaldehyde resin. *Wood and Fibre* 12(4), 255-263 (1980).

Pulp Yield

Pulp yields were determined by laboratory scale Kraft cooking of wood chips carried out in a multiple digester (triplicate runs per species in 3 L steel ‘bombs’); 400g OD charge, Liquor:Wood ratio of 4:1, percentage Active alkali required, 25% sulfidity, 1.75hrs to 165°C ca 2 hours at temperature, H factor 1300 (an index of ‘area under the curve’ of a time/temperature chart above 100°C). On completion of the cook, bombs were immersed in water and rapidly cooled to room temperature and the cooked chips mechanically disintegrated and then the pulp screened over a 0.25mm Packer screen before being collected in a 50 mesh bag. The pulp was then dewatered and crumbed in a planetary Hobart mixer and sealed in plastic bags prior to evaluation of pulp properties.

Pulp yield was determined as the oven dry equivalent of pulp on the oven dry equivalent of wood starting material for a fibre having a Kappa number of 18. The Kappa number of the pulps were determined as described in AS/NZS 1301.201s:2002.

Pulp Bleaching

Bleaching trials on selected species was carried out in a 3-stage bleach sequence – D (EP) D, described in full below as:

D: Chlorine dioxide charge ca 1.8%+(kappa-15)*0.3/2.63, small amount of sulphuric acid added so that the end pH is 2-2.5, 6% consistency, 1 hour at 60°C duration.

EP: 10% consistency, 1.2- 0.5% NaOH, 1.5 hours at 75°C duration with a final pH of ca 11.

D: 10% consistency, 3 hours at 70°C using 0.3% chlorine dioxide and small amount of sulphuric acid added so that the end pH is 3.8-4.5.

It should be noted that this is not a typical commercial bleaching sequence but gives the same results and is a relatively quick and cost effective method for screening purposes.

Paper Properties

Hand-sheets prepared were preconditioned/conditioned in accordance with Australian Standard AS 1301.P414m - 86. The atmosphere prescribed is as described in AS/NZS 1301.415s:1998 where the temperature and relatively humidity are controlled within the following limits:
– Temperature 23 ±1°C
– Relative humidity: 50 ±2% RH

WOOD-BASED PANELS

Medium Density Fibreboard

A pilot scale Sunds Defibrator CD300 was used to refine the wood chip material into MDF fibre furnish. The unit is a single disc refiner driven by a 105 kW motor running at 3000 rpm. It consists of a PREX screw-feeder, which compresses the feed material (to aid fibre separation) and moves the feed material on a continuous basis into a higher pressure environment. The compression ratio is 1:4. After compression, the material is introduced into the lower part of the impregnation vessel housed within the preheater. Twin screws lift the macerated feed material to the top of the impregnation vessel and into the preheater. The refiner has both disc (300 mm diameter) and conical (100 mm diameter) elements for refining which can be independently adjusted for gap width. The plate pattern used was R3847 (stator and rotor). A schematic of the refiner is shown in Figure 10.

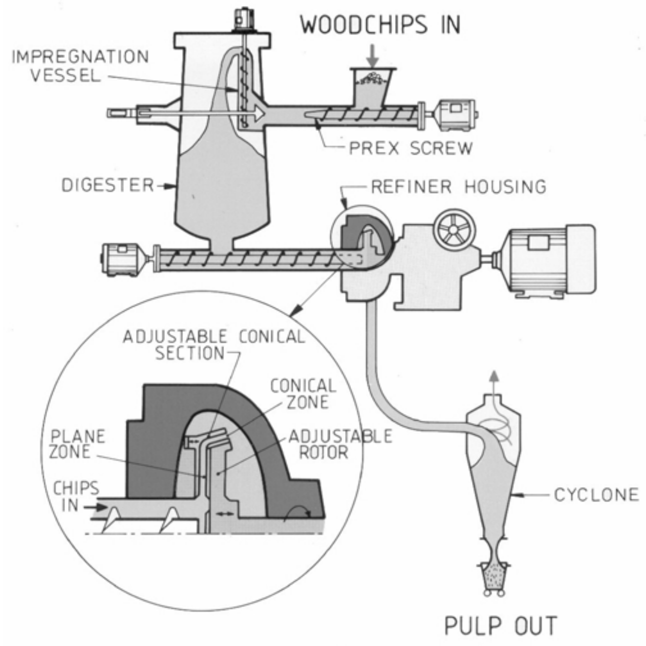


Figure 10: Schematic of high pressure refiner used for the production of MDF furnish

After exiting the refiner housing the fibres are mixed with predetermined weight of resin[3] and forced into the 'blow-line dryer' which reduces the moisture content of the fibres to approximately 10% (wt). A wax emulsion[4] is applied to the fibre furnish in a separate operation whereby the water emulsified wax is injected at the front of the refiner housing as the softened wood chips are fed into the refiner disks. In this series of trials resin addition was 12% (solids on OD wt. of fibre) and wax at 0.6% (solids on OD wt. of fibre).

Resinated fibre was then pre-pressed (cold pressing to reduce fibre mattress height to fit heated platen press) and hot pressed to a target of 13 mm thickness on panel areas of 90×90 cm for a target panel density of 750 kg/m^3. The pressing schedule, using position control, consisted of a temperature of 160°C for a total time of 210 seconds. Once cooled, the panels were trimmed (~100 mm all around) and a 50 mm wide strip was taken from the middle of the panel for the entire length. A 50X50 mm sample was removed from the middle of the strip and a density profile generated to assist in quality control and determining sanding thickness. Approximately 0.5-0.7 mm thickness of material was sanded from each face using a 600 mm wide belt sander.

Particleboard

Wood chips were dried overnight at ~105°C and passed through a Bauer refiner fitted with 'breaker' plates. This reduced the size of wood chips sufficiently for them to be used as 'core' material, as well as allowing the furnish to be screened through 12 mm mesh to supply material for the 'faces' of the particleboard ie a three layered board with 50% of the weight being core and each face having 25% of the total weight. Some species required further milling to produce sufficient face material. This was done by passing processed chips through a Wiley Mill fitted with a 6.3 mm screen.

Sufficient particleboard furnish for three panels (core and face being treated separately) was sprayed with resin/wax/water suspension, with the woody furnish tumbled in a rotating drum. Resin was applied at 10% (on wt. of wood) and wax at 0.6% (on wt. of wood) for a panel target density of 700 kg/m^3. Resinated particles were hand-laid in a 45X45 cm forming box and transferred to the hot press sandwiched between 2.5 mm aluminium caul plates and Teflon release film (0.2 mm thick). Hot pressing was carried out at 160°C for 210 seconds.

---

[3] Urea-Formaldehyde, Cascoresin MBP 1285 from Borden Chemical Australia Pty Ltd
[4] Technimul and Vivashield 9363 from BP Global Special Products (Aust.) Pty Ltd

After cooling, panels were trimmed to 32X32 cm and sanded, removing ~0.5-0.7 mm thickness of material from each face.

Testing Panel Products

Both Particleboard and MDF were tested for the following mechanical and physical properties:

AS/NZS 4266: Method 5 – Modulus of Elasticity and Modulus of Rupture in bending. MDF – five test coupons per panel and three for particleboard per panel.

AS/NZS 4266: Method 6 – Internal bond strength. Six test coupons for MDF and particleboard.

AS/NZS 4266: Method 7 – Thickness swell. MDF – 24 h in water at 20°C. Particleboard – 1 h at 20°C. Six test coupons per panel.

Analysis of Results

Statistical treatment of the data was effected by first applying single-factor ANOVA to each test result for each species for between panel variance to allow the pooling of data for reporting. In many cases the null hypotheses (H_o: all means are equal) was rejected – the data being significant at level 0.05. To present the data in useful format the results for each test (per panel) for each species were treated as a subset of an infinite population to obtain an estimate of the mean test value and an estimate of the reliability of that mean by generating a 95% confidence interval.

The estimate of the mean (μ) was taken to be the grand mean ($\bar{y}$) plus a confidence interval, $\pm t s_P$; where t is the value obtained from t-distribution tables (eg for 6 panels and a 95% confidence interval, $t = 2.571$) and s_P is an estimate of the standard error (subscript ‘p’ is for Panel). The estimate of standard error was obtained from the ANOVA table using the ‘between-panel mean squares’ – (MSB) and calculating s_P using the following equation:

$$s_P = \sqrt{MSB / mn} .$$

Where m = the number of panels and n = the number of test coupons per panel.

APPENDIX 1: WET CHEMISTRY AND NIR RESULTS FOR CELLULOSE CONTENT

Species	NIR code	NIR	Lab
Pinus radiata. Ex NE Victoria	jh-wa-01	53.77	53.49
Eucalyptus nitens. Ex Tasmania	jh-wa-02	42.15	42.26
Acacia lasiocalyx	jh-wa-03	42.72	44.18
Acacia microbotrya	jh-wa-04	39.89	39.95
Acacia murrayana	jh-wa-05	38.92	38.47
Acacia saligna	jh-wa-06	38.31	40.33
Alyogyne huegelii	jh-wa-07	39.58	39.69
Anthocercis littorea	jh-wa-08	42.90	41.92
Bursaria occidentalis	jh-wa-09	36.46	35.29
Casuarina obesa	jh-wa-10	39.04	39.80
Codonocarpus cotinifolius	jh-wa-11	43.67	41.21
Corymbia calophylla	jh-wa-12	37.56	37.95
Eucalyptus camaldulensis	jh-wa-13	35.70	34.67
Eucalyptus loxophleba ssp. lissophloia	jh-wa-14	38.20	39.11
Eucalyptus rudis	jh-wa-15	38.44	37.74
Gyrostemon ramulosus	jh-wa-16	44.52	43.10
Jacksonia sternbergiana	jh-wa-17	41.02	42.28
Senna pleurocarpa	jh-wa-18	43.19	42.33
Viminaria juncea	jh-wa-19	41.80	43.85
Acacia aff. redolens	jh-wa-20	39.36	39.12
Acacia cyclops	jh-wa-21	39.89	40.30
Acacia bartleana Maslin (ms)	jh-wa-22	39.40	38.65
Actinostrobus arenarius	jh-wa-23	46.77	46.38
Adenanthos stictus	jh-wa-24	41.22	39.99
Agonis flexuosa	jh-wa-25	41.93	42.96
Taxandria juniperina	jh-wa-26	44.83	45.15
Allocasuarina huegeliana	jh-wa-27	39.94	40.11
Alyogyne hakeifolia	jh-wa-28	38.78	38.22
Banksia prionotes	jh-wa-29	37.11	36.84
Callitris glaucophylla	jh-wa-30	47.11	46.31
Dryandra arborea	jh-wa-31	39.23	40.52
Dryandra sessilis	jh-wa-32	38.90	39.06
Duboisia hopwoodii	jh-wa-33	41.96	43.93
Eucalyptus erythrocorys	jh-wa-34	39.53	40.57
Eucalyptus todtiana	jh-wa-35	40.12	38.49
Exocarpus sparteus	jh-wa-36	36.07	34.33
Grevillea candelabroides	jh-wa-37	36.89	38.04
Grevillea leucopteris	jh-wa-38	39.79	40.33
Hakea oleifolia	jh-wa-39	36.27	36.36
Hakea prostrata	jh-wa-40	37.45	37.75
Kunzea glabrescens	jh-wa-41	41.67	43.33
Lambertia inermis	jh-wa-42	39.14	41.46
Melaleuca preissiana	jh-wa-43	37.94	38.23
Melaleuca rhaphiophylla	jh-wa-44	38.20	38.40
Paraserianthes lophantha	jh-wa-45	41.27	41.01
Persoonia elliptica	jh-wa-46	38.81	38.37
Pittosporum angustifolium	jh-wa-47	34.20	32.31
Pittosporum phylliraeoides	jh-wa-48	36.76	35.55
Trymalium floribundum	jh-wa-49	43.00	42.58
Acacia rostellifera	jh-wa-50	40.41	43.83

Species	NIR code	NIR	Lab
Eucalyptus astringens	jh-wa-51	38.55	39.65
Eucalyptus kochii ssp plenissima	jh-wa-52	40.22	42.99
Eucalyptus occidentalis	jh-wa-53	38.5	40.47

APPENDIX 2: PULP PROPERTIES

Species	Cook No.	Kappa No.	Ref. No.	Beating (revs)	Freeness (csf)	Density (kg/m^3)	Tear Index (mNm^2/g)	Tensile Index (Nm/g)	Stretch (%)	Tensile Stiffness (kNm/g)	TEA (J/g)	Burst Index ($kPam^2/g$)	Air Resistance (sec)
Acacia aff. redolens	29b	16.7	2003-038	0	402	613	3.6	37	1.5	5.6	0.4	1.7	2.4
				250	370	630	4.3	45	2.1	6	0.7	2.4	3
				400	350	645	4.8	50	2.4	6.1	0.9	2.6	4
				1750	250	720	6.5	70	3.3	7	1.6	4.4	12
Acacia bartleana Maslin (ms)	82c	19.9	2003-078	0	524	585	3.5	35	1.3	5.6	0.3	1.5	1.2
				250	480	630	5.6	44	1.8	6.2	0.6	2	2.4
				1350	350	710	6.9	67	3	7.2	1.4	4.1	4
				1600	330	720	7.1	70	3.3	7.3	1.6	4.4	5
Acacia cyclops	23e	17	2003-002	0	471	631	3.9	39	1.4	6	0.4	1.7	1.8
				250	440	670	4.8	48	1.9	6.3	0.7	2.4	2.5
				900	350	730	5.6	63	2.7	7.2	1.3	3.7	7.9
				1450	300	750	5.9	70	2.8	7.8	1.4	4.3	14
Acacia lasiocalyx	02c21a	16.4	2003-072	0	513	553	3.1	30	1.1	5.1	0.2	1.2	1
				250	490	582	4.5	37	1.5	5.3	0.3	1.8	1.2
				1700	350	700	7.1	61	3.5	6.2	1.5	4	3.9
				3000	238	738	7.3	70	4.1	6.5	2	4.9	8.5
Acacia microbotrya	14e	17.6	2003-040	0	498	573	2.6	31	1.2	4.8	0.2	1.2	0.9
				250	460	600	3.8	39	1.6	5.2	0.4	1.7	1
				1150	350	670	5.7	52	2.6	6	1	3	3.8
				2650	240	740	6.6	70	3.8	6.7	1.8	4.6	15
Acacia murrayana	83e	19.6	2003-082	0	492	608	3.3	32	1.4	4.8	0.3	1.4	2
				250	430	635	4.2	39	2	5.2	0.5	2	3.5
				625	350	675	5.3	49	2.6	5.6	0.9	2.8	6
				2200	180	748	7.1	70	3.9	6.2	1.9	4.8	37

Species	Cook No.	Kappa No.	Ref. No.	Beating (revs)	Freeness (csf)	Density (kg/m^3)	Tear Index (mNm^2/g)	Tensile Index (Nm/g)	Stretch (%)	Tensile Stiffness (kNm/g)	TEA (J/g)	Burst Index (kPam^2/g)	Air Resistance (sec)
Acacia saligna	14f	14.9	2003-041	0	506	616	4.1	36	1.5	5.1	0.4	1.6	3.2
				250	450	690	5.6	45	2.4	6.1	0.8	2.5	8.5
				350	350	755	6.9	63	3.4	7.0	1.6	3.9	18
				650	310	785	7.2	70	3.9	7.1	2.1	4.7	28
Adenanthos stictus	5e	16.4	2003-005	0	475	631	2.4	32	0.9	5.5	0.2	1.1	2.6
				250	405	650	3	38	1.3	6.1	0.3	1.6	6
				450	350	670	3.4	43	1.4	6.3	0.4	1.9	9.9
				2650	95	800	5.8	70	2.8	7.7	1.3	3.9	430
Agonis flexuosa	5f	17.7	2003-020	0	543	571	3.4	36	1.1	5.8	0.2	1.3	1.4
				250	495	615	4.8	43	1.5	6.1	0.8	2	2.5
				1850	350	715	7.9	70	3.3	7.3	1.7	4.3	10
				1850	350	715	7.9	70	3.3	7.3	1.7	4.3	10
Allocasuarina huegeliana	29d	16.5	2003-039	0	385	590	3.5	39	1.3	6.1	0.3	1.7	2
				250	350	610	4.2	45	1.5	6.1	0.4	2	2.5
				250	350	610	4.2	45	1.5	6.1	0.4	2	2.5
				2050	170	710	6.6	70	2.9	7.2	1.4	4	23
Alyogyne huegelii	21f	20.3	2003-043	0	528	603	3.1	41	1.5	6.4	0.4	1.8	1.7
				250	460	635	7.6	50	2	6.8	0.8	2.5	4
				900	350	695	8.7	72	3	7.4	1.5	4.2	11
				800	365	690	8.6	70	2.9	7.3	1.4	4	9.5
Anthocercis littorea	02c23b	16.6	2003-001	0	443	797	6.1	54	2.2	7	0.9	2.7	15
				250	405	840	6.3	67	2.6	7.4	1.1	4.5	25
				650	350	890	6.7	80	3.4	7.8	1.2	4.9	100
				350	390	855	6.4	70	2.9	7.5	1.9	3.9	50

Species	Cook No.	Kappa No.	Ref. No.	Beating (revs)	Freeness (csf)	Density (kg/m^3)	Tear Index (mNm^2/g)	Tensile Index (Nm/g)	Stretch (%)	Tensile Stiffness (kNm/g)	TEA (J/g)	Burst Index ($kPam^2/g$)	Air Resistance (sec)
Codonocarpus cotinifolius	17f	20	2003-044	0	460	744	4.9	42	1.5	6.5	0.4	1.9	14
				250	380	785	6.2	55	2.2	7	1	3	51
				350	350	805	6.5	60	2.5	7.2	1.1	3.2	70
				650	275	840	6.8	70	3	7.7	1.5	4.4	125
Dryandra sessilis	15b	18.2	2003-021	0	471	564	2.8	33	1	5.8	0.2	1.1	1.7
				250	420	595	3.6	39	1.2	6	0.4	1.5	4
				500	350	625	4.3	45	1.5	6.4	0.5	1.8	6
				2650	95	735	6.9	70	2.7	7.7	1.2	3.9	45
Eucalyptus astringens	83a	16.2	2003-083	0	514	609	3.1	37	1.3	5.5	0.3	1.6	1.1
				250	460	630	3.9	46	1.7	5.9	0.6	2.2	1.5
				850	350	690	5.1	62	2.7	6.7	1.2	3.6	3.9
				1300	290	710	7	70	3.4	7.1	1.6	4.5	8
Eucalyptus erythrocorys	80e	18.9	2003-073	0	504	626	3.1	38	1.3	5.9	0.3	1.6	1.9
				250	425	645	4.3	45	1.8	6.2	0.6	2.5	3
				550	350	670	5.6	53	2.3	6.5	0.9	3.1	5
				1800	225	725	7.2	70	3.4	7.2	1.7	4.1	17
Eucalyptus kochii ssp plenissima	83b	17.8	2003-081	0	453	534	1.8	32	0.9	5.8	0.2	1	0.8
				250	420	550	2.2	35	1.1	5.9	0.3	1.3	1.1
				825	350	585	3	43	1.7	6.1	0.5	2	1.7
				2750	250	645	4.9	(60)	2.7	6.9	1.2	3.4	5.7
Eucalyptus occidentalis	83c	16.2	2003-084	0	420	702	3.4	40	1.5	5.7	0.4	1.8	4.3
				250	385	735	4.4	49	2.3	6.2	0.8	2.3	8
				600	350	780	5.3	60	3	6.6	1.3	3.5	14
				1150	300	820	5.8	70	3.7	7.1	1.8	4.6	30

Species	Cook No.	Kappa No.	Ref. No.	Beating (revs)	Freeness (csf)	Density (kg/m^3)	Tear Index (mNm^2/g)	Tensile Index (Nm/g)	Stretch (%)	Tensile Stiffness (kNm/g)	TEA (J/g)	Burst Index ($kPam^2/g$)	Air Resistance (sec)
Eucalyptus rudis	80f	19.2	2003-076	0	471	709	4.9	50	1.7	6.9	0.6	2.3	6.4
				250	410	725	5.6	58	2.1	7.3	0.9	3.2	11
				450	350	738	6.2	65	2.5	7.6	1.2	3.9	16
				650	310	748	6.6	70	2.7	7.8	1.4	4.3	20
Eucalyptus loxophleba spp lissophloia	02c16e	16.7	2002-070	0	388	629	3.4	39	1.8		0.5	1.9	2.4
				250	370	650	3.6	43	1.9		0.6	2.3	3
				740	350	670	4	50	2.6		0.9	3	4.5
				2750	305	745	5.2	70	4.2	6.8	2	4.8	19
Grevillea candelabroides	15c	21.3	2003-037	0	600	575	6.9	36	1.5	3.5	0.4	1.6	1.3
				250	550	620	8.9	48	2	5.9	0.7	2.2	2
				1800	350	710	8.9	75	3.4	7.4	1.8	4.9	12
				1350	400	690	9.1	70	3.2	7.1	1.5	4.4	7
Grevillea leucopteris	31e	17.6	2003-004	0	558	606	6.1	36	2	4.8	0.5	2	2.2
				250	530	660	7	45	2.3	5.4	0.7	2.8	3.5
				2650	350	760	8.1	70	3.7	6.8	1.8	4.8	28
				2650	350	760	8.1	70	3.7	6.8	1.8	4.8	28
Gyrostemon ramulosus	80d	18.7	2003-071	0	496	701	4	34	1.4	5.5	0.3	1.5	10
				250	400	755	5.1	53	1.9	7.1	0.6	2.5	30
				450	350	795	5.8	46	2.8	7.4	0.9	3.1	50
				1500	220	871	6.8	70	3.5	7.6	1.8	4.4	208
Jacksonia sternbergiana	16a	17	2003-042	0	526	588	3.8	31	1.1	5.3	0.2	1.2	1.6
				250	445	615	4.5	38	1.5	5.8	0.3	2	3.5
				650	350	660	5.4	47	1.9	6.3	0.7	2.7	7
				2650	175	765	6.7	70	3.5	7.5	1.8	4.4	63

Species	Cook No.	Kappa No.	Ref. No.	Beating (revs)	Freeness (csf)	Density (kg/m^3)	Tear Index (mNm^2/g)	Tensile Index (Nm/g)	Stretch (%)	Tensile Stiffness (kNm/g)	TEA (J/g)	Burst Index (kPam^2/g)	Air Resistance (sec)
Lambertia inermis	10f	17.3	2003-022	0	609	574	3.1	27	0.9	5	0.1	0.9	0.9
				250	535	610	3.5	35	1.3	5.8	0.4	1.6	2.1
				1250	350	780	6.3	63	2.7	7.2	1.1	3.4	10
				1700	285	808	6.8	70	3.1	7.6	1.4	4	18
Paraserianthes lophantha	7a	19.9	2003-018	0	494	703	3.6	39	1.7	5.2	0.5	1.8	5.8
				250	440	752	4.1	54	2.4	6.1	1.1	2.8	15
				745	350	820	5	65	3.2	6.9	1.6	3.8	35
				1350	290	860	5.6	70	3.6	7.3	1.9	4.6	92
Senna pleurocarpa	02c18a	16.4	2002-071	0	498	694	4.3	46	1.7	6.2	0.5	2.5	4.3
				250	450	740	5.7	56	2.3	6.6	0.9	3.2	8.5
				1100	350	862	6.6	77	3.7	7.5	2	5.4	25
				700	385	794	6.6	70	3.1	7.2	1.7	4.4	14
Taxandria juniperina	6a	16.3	2003-006	0	583	619	6	50	1.3	7.5	0.4	1.9	1.5
				250	540	645	7.7	59	1.8	7.6	0.7	2.8	2.2
				1900	350	760	8.8	87	3.2	8.4	1.9	5.6	24
				600	500	685	8.7	70	2.4	7.9	1.2	4.1	4
Trymalium floribundum	24e	20.8	2003-003	0	485	629	4.1	45	1.3	6.8	0.4	1.9	1.8
				250	455	660	4.6	53	1.7	7.2	0.6	2.6	3
				1125	350	700	6	71	2.5	8.1	1.3	4.2	12
				1050	355	700	6.1	70	2.5	8	1.2	4.1	10
Viminaria juncea	15e	18.7	2003-019	0	505	706	5.2	44	1.8	5.9	0.5	1.9	8.2
				250	420	735	6	52	2.4	6.4	0.9	3	22
				560	350	770	6.6	60	3	7	1.2	3.9	38
				1100	295	820	6.9	70	3.6	7.4	1.8	4.6	70

APPENDIX 3: PAPER BRIGHTNESS VALUES

Species	Brightness	Brightness after 1 h at 105°C	Comment
Acacia murrayana	89.95	87.59	excellent
Acacia bartleana Maslin (ms)	88.12	84.58	poor
Eucalyptus erythrocorys	90.12	87.13	excellent
Eucalyptus rudis	89.21	86.88	very good
Eucalyptus astringens	87.54	85.16	good
Eucalyptus kochii ssp plenissima	89.67	87.13	excellent
Eucalyptus occidentalis	86.18	83.19	very poor
Gyrostemon ramulosus	85.65	82.74	very poor
Taxandria juniperina	89.9	87.1	excellent
Senna pleurocarpa	87.1	85.1	good
Paraserianthes lophantha	89.1	87.1	excellent
Grevillea leucopteris	89.1	86.9	very good
Acacia lasiocalyx	87.4	85.2	good
Anthocercis littorea	90.8	88.8	excellent
Trymalium floribundum	88.9	86.8	very good
Adenanthos stictus	87.8	85.1	good
Acacia cyclops	85.5*	83.3	very poor
Eucalyptus loxophleba ssp lissophloia	88.2	86.3	very good
Alyogyne huegelii	89.2	86.8	very good
Jacksonia sternbergiana	89.7	86.2	very good
Acacia aff. redolens	88.5	86.6	very good
Acacia microbotrya	87.4	85	good
Codonocarpus cotinifolius	88.5	85.1	good
Allocasuarina huegeliana	87.4	85.6	good
Acacia saligna	87.8*	83.1	poor
Grevillea candelabroides	89.4	87.9	excellent
Dryandra sessilis	84.8*	82.4	very poor
Viminaria juncea	87.6	85.4	good
Agonis flexuosa	87.9	85.1	good

* Will require more chemicals than others for bleaching.

APPENDIX 4: SUMMARY OF MDF PROPERTIES

Species	Panel No.	Whole Panel Density (kg/m^3)	Flexural Strength - MOR (MPa)	Flexural Modulus - MOE (MPa)	Internal Bond Strength (kPa)	Thickness Swell (%)
Acacia lasiocalyx	6	827 (12)	34.03 (2.24)	3396 (181)	1340 (176)	10.1 (1.3)
Acacia saligna	5	830 (62)	29.66 (2.07)	3298 (190)	953 (121)	13.7 (2.2)
Alyogyne huegelii	4	756 (18)	26.94 (3.47)	3218 (355)	989 (236)	17.9 (2.4)
Anthocercis littorea	6	766 (19)	36.30 (1.82)	3429 (147)	1582 (83)	11.0 (2.6)
Bursaria occidentalis	6	752 (32)	27.75 (4.55)	2804 (345)	1523 (191)	9.0 (0.6)
Callitris glaucophylla	6	751 (20)	31.36 (2.00)	3135 (184)	1124 (170)	6.5 (0.4)
Casuarina obesa	6	850 (21)	30.64 (2.09)	3513 (195)	1563 (124)	21.3 (2.5)
Codonocarpus cotinifolius	6	756 (34)	35.63 (2.63)	3017 (156)	1608 (179)	11.4 (1.7)
Dryandra sessilis	6	762 (34)	23.32 (2.13)	2564 (182)	997 (91)	14.5-23.4
Eucalyptus loxophleba ssp lissophloia	6	837 (14)	35.42 (2.09)	3167 (163)	2040 (222)	11.1 (1.7)
Eucalyptus rudis	6	795 (16)	39.06 (2.78)	3750 (242)	1758 (204)	8.6 (0.5)
Grevillea leucopteris	5	772 (34)	30.91 (4.09)	3171 (409)	547-1133	10.3 (0.9)
Gyrostemon ramulosus	6	775 (41)	37.35 (4.28)	3337 (298)	1938 (222)	8.0 (2.2)
Hakea oleifolia	6	817 (20)	34.80 (4.35)	3422 (330)	2124 (235)	11.0 (1.7)
Jacksonia sternbergiana	6	770 (43)	22.76 (3.89)	3262 (339)	1093 (211)	11.2 (3.1)
Melaleuca preissiana	3	689 (32)	18.24 (5.05)	2072 (453)	746 (312)	7.0 (0.6)
Pinus radiata	6	780 (59)	43.40 (7.16)	3525 (481)	1334 (150)	7.6 (0.3)
Senna pleurocarpa	6	765 (18)	33.23 (2.80)	3295 (206)	1188 (54)	19.7 (0.6)
Taxandria juniperina	6	813 (35)	40.64 (2.91)	3659 (252)	2022 (239)	7.7 (0.7)
Viminaria juncea	5	835 (22)	33.03 (3.06)	2894 (185)	1946 (153)	9.7-25.6

Result of IBS for *Grevillea leucopteris* is given as a range of two distinct groups of 3 and 2 panels. Results of thickness swell for *Viminaria juncea* and *Dryandra sessilis* are given as ranges of grand means.

APPENDIX 5: SUMMARY OF PARTICLEBOARD PROPERTIES

Species	Panel No.	Whole Panel Density (kg/m^3)	Flexural Strength - MOR (MPa)	Flexural Modulus - MOE (MPa)	Internal Bond Strength (kPa)	Thickness Swell (%)
Acacia lasiocalyx	6	711 (23)	9.93 (1.98)	2119 (354)	147 (73)	4.5 (0.9)
Acacia saligna	6	714 (33)	17.71 (1.66)	2825 (293)	619 (170)	4.8 (0.8)
Alyogyne huegelii	5	687 (7)	11.85 (1.59)	2268 (205)	461 (59)	8.6 (0.5)
Bursaria occidentalis	6	710 (9)	10.25 (0.77)	2166 (37)	235 (40)	4.3 (0.6)
Anthocercis littorea	5	690 (39)	14.59 (2.03)	2415 (254)	607 (198)	7.6 (0.6)
Casuarina obesa	6	739 (31)	13.35 (2.77)	2460 (112)	354 (88)	6.3 (0.4)
Callitris glaucophylla	6	741 (8)	9.25 (1.36)	2306 (99)	527 (96)	5.6 (0.5)
Codonocarpus cotinifolius	6	680 (29)	15.18 (0.95)	2586 (105)	645 (203)	4.1 (0.7)
Dryandra sessilis	6	668 (20)	9.20 (1.76)	1813 (201)	227 (73)	6.6 (1.3)
Eucalyptus loxophleba ssp lissophloia	5	794 (38)	11.79 (2.04)	2209 (210)	902 (315)	6.3 (0.5)
Eucalyptus occidentalis	6	692 (44)	9.11 (1.63)	1846 (220)	552 (167)	5.2 (0.6)
Eucalyptus rudis	6	727 (31)	15.66 (0.48)	2680 (140)	668 (95)	6.3 (1.0)
Grevillea leucopteris	5	750 (28)	11.67 (1.96)	2368 (325)	408 (133)	4.5 (0.3)
Gyrostemon ramulosus	6	689 (30)	16.66 (1.90)	2460 (244)	1296 (170)	7.6 (0.7)
Hakea oleifolia	6	743 (50)	14.27 (2.83)	2216 (345)	1138 (307)	5.3 (0.7)
Jacksonia sternbergiana	3	696 (14)	6.79 (1.09)	1634 (460)	115 (67)	6.1 (1.5)
Melaleuca preissiana	6	744 (26)	13.55 (2.15)	1990 (226)	1642 (225)	6.2 (0.8)
Pinus radiata	6	733 (11)	16.89 (1.37)	2816 (332)	950 (35)	4.6 (0.3)
Senna pleurocarpa	5	737 (15)	16.32 (1.79)	2794 (211)	398 (91)	4.8 (0.2)
Taxandria juniperina	6	733 (15)	17.37 (1.69)	2806 (219)	884 (144)	5.0 (0.9)
Viminaria juncea	6	713 (14)	16.05 (0.82)	2314 (67)	720 (96)	4.2 (0.5)

Note: *Eucalyptus rudis* MOR and MOE and IBS based on 5 panels.

Search Report

Appendix 3

Investigation of combustion properties of selected Western Australian species

CSIRO Energy Technology

CSIRO Energy Technology

Combustion properties of Search Project species

20 July 2004

Introduction

Perhaps the single major determinant in the viability of a bioenergy project is the feedstock, not only in terms of its location, extent and ability to be collected, but also in relation to its energy characteristics.

Any solid carbonaceous material when subjected to high temperatures and sufficient oxygen will thermally decompose to carbon dioxide and water (the water being due to hydrogen in the fuel). The ideal biomass fuel would consist of just carbon, hydrogen and oxygen. However in practice biomass as delivered to the boiler will also have free moisture (which lowers the available energy content of the fuel), and inorganic elements which when subjected to high temperatures form compounds that can cause corrosion and fouling of boiler tubes and heat exchanger surfaces. These compounds are very difficult to predict from merely knowing the constituents of the biomass, as they depend on many chemical interactions within the boiler, boiler temperature, and the passage of the compounds through the boiler and economiser surfaces.

CSIRO therefore developed predictor tests where samples of biomass are combusted in a lab scale furnace, and fouling deposits and high temperature corrosion measured on metal samples placed in the flue gas stream. This is believed to provide a reasonable indication of the propensity for these combustion characteristics to take place in practice, however it is not an absolute nor exact measure. This testing, for example, provides a true indication of the characteristics of that particular sample under the particular lab scale furnace conditions. However in say a 10MWelectrical boiler and steam turbine plant, approximately 100,000 tonnes of biomass will pass through every year, and biomass is usually a highly variable fuel compared to say coal.

Sampling

Samples were selected in as representative a way as possible. In a commercial operation, bioenergy will generally tend to use the residue biomass material, with higher value products using the higher value material. For the purposes of this analysis, samples were made up from ⅓ wood, ⅓ bark and ⅓ leaves and twigs. The chemical constitution of each part of the tree tends to vary, so the component make-up is important.

Species

Twenty-six species were tested for standard combustion properties (detailed results in Appendix 1), and of those, 20 were tested for fouling and corrosion (detailed results in Appendix 2). The species tested are listed in Table 1.

Table 1. Species tested for combustion properties.

Species	Standard combustion	Fouling and corrosion
Acacia bartleana Maslin (ms)	✓	
Acacia lasiocalyx	✓	✓
Acacia murrayana	✓	
Acacia rostellifera	✓	
Acacia saligna	✓	✓
Agonis flexuosa	✓	✓
Alyogyne huegelii	✓	✓
Anthocercis littorea	✓	✓
Bursaria occidentalis	✓	✓
Codonocarpus cotinifolius	✓	✓
Eucalyptus astringens	✓	
Eucalyptus erythrocorys	✓	
Eucalyptus kochii ssp plenissima	✓	
Eucalyptus loxophleba ssp lissophloia	✓	✓
Eucalyptus occidentalis	✓	✓
Eucalyptus rudis	✓	✓
Grevillea candelabroides	✓	✓
Grevillea leucopteris	✓	✓
Gyrostemon ramulosus	✓	✓
Hakea oleifolia	✓	✓
Jacksonia sternbergiana	✓	✓
Melaleuca preissiana	✓	✓
Senna pleurocarpa	✓	✓
Taxandria juniperina	✓	✓
Trymalium floribundum	✓	✓
Viminaria juncea	✓	✓

Method

Combustion fouling and corrosion properties were analysed according to Table 2 and the schematic in Figure 1.

Table 2. Combustion and analysis methods.

Purpose	To quantitatively estimate the fouling and corrosion propensity under simple combustion conditions
Method	Biomass is slowly burnt at temperatures up to 800°C with convective air passing over the sample. A mild steel plate is positioned close to the burning fuel, so that corrosion can occur on both surfaces at 800°C. A polished stainless steel stub, suitable for scanning electron microscopy (SEM), is positioned in the outlet air, where the temperature is 400°C. Volatile components from the fuel and vapours formed during combustion are able to corrode / foul the mild steel plate and stainless steel stub, respectively. In a simple way, this test can simulate the initiation of fouling or corrosion on variable surfaces at different temperatures in a conventional boiler.

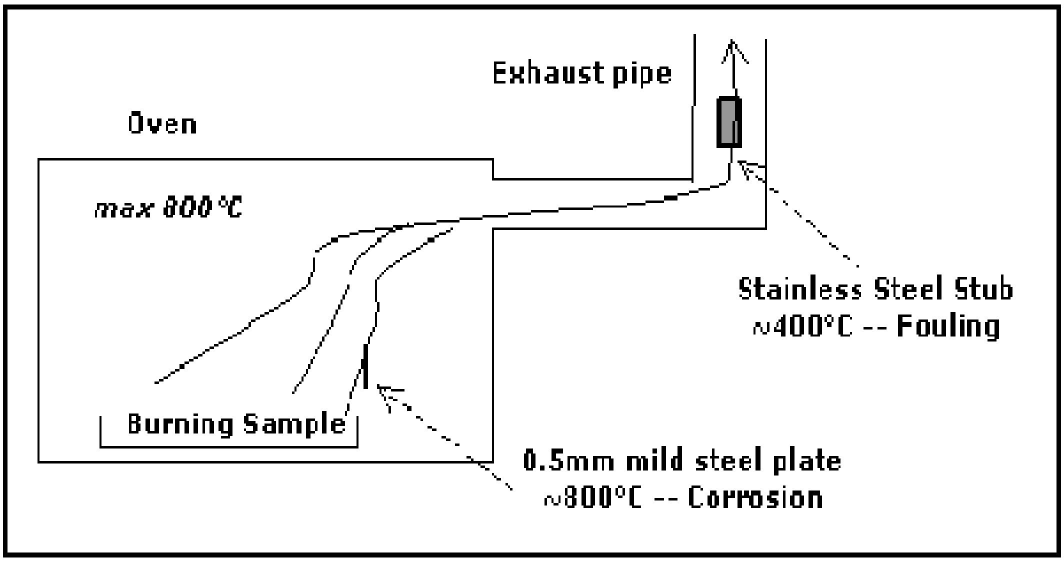


Figure 1. Laboratory set-up for combustion-related fouling and corrosion prediction.

Fouling and corrosion results for each species are contained in Appendix 2. The following discussion uses results for *Alyogyne huegelii* as an example.

Fouling

The fouling deposit is then examined under a scanning electron microscope. The deposit left on the metal stub by *Alyogyne huegelii* is shown below (Figure 2). Most importantly, the deposit from a sample area is analysed for major elements. This particular sample showed sodium, chlorine and potassium to be the major elements in the ash deposit (Figure 3). These particular elements are commonly associated with compounds that tend to lower ash fusion temperature and cause deposition and fouling.

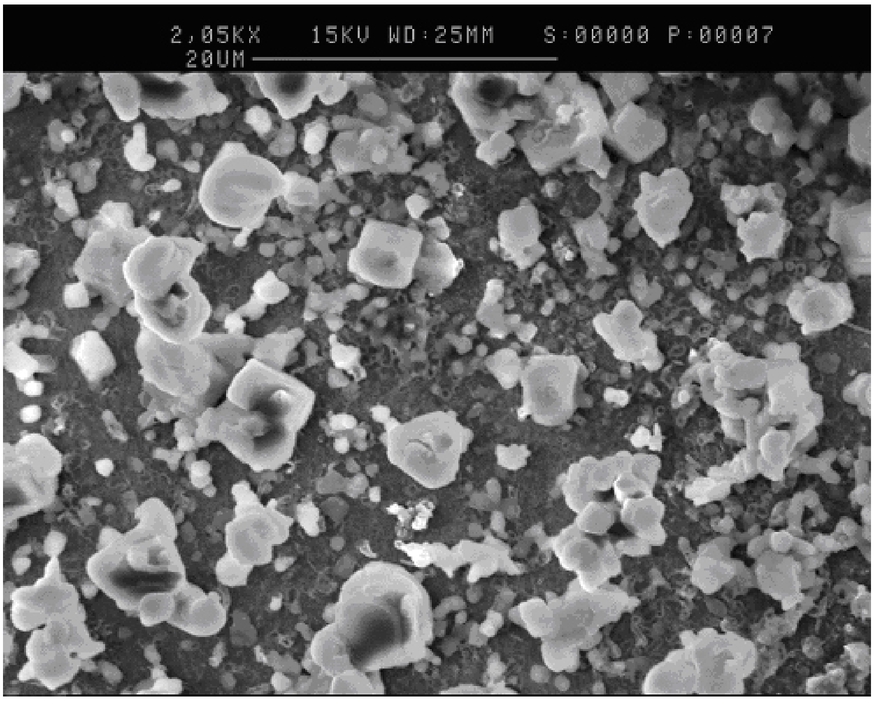


Figure 2. ***Alyogyne huegelii* – Stub deposit**

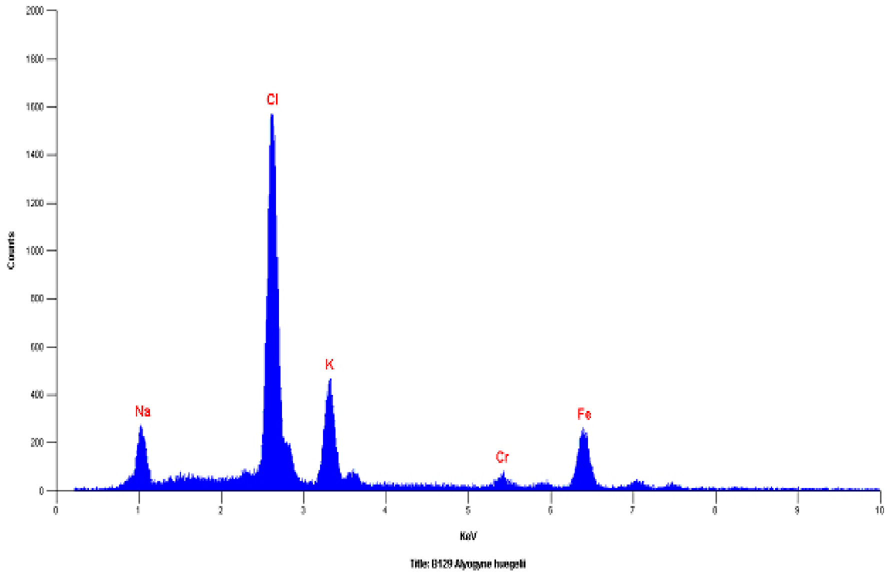


Figure 3. **Elemental analysis of a typical area of fouling deposit from Alyogyne huegelii**

Corrosion

The other combustion property that is tested for is the potential for high temperature corrosion. The metal stub, having been subjected to the flue gas from the combusted sample, is examined under the electron microscope for "before and after" effects of corrosion. The photos (Figure 4) show the results of this analysis for *Alyogyne huegelii*. By comparison with other biomass samples, this sample was rated as moderate.

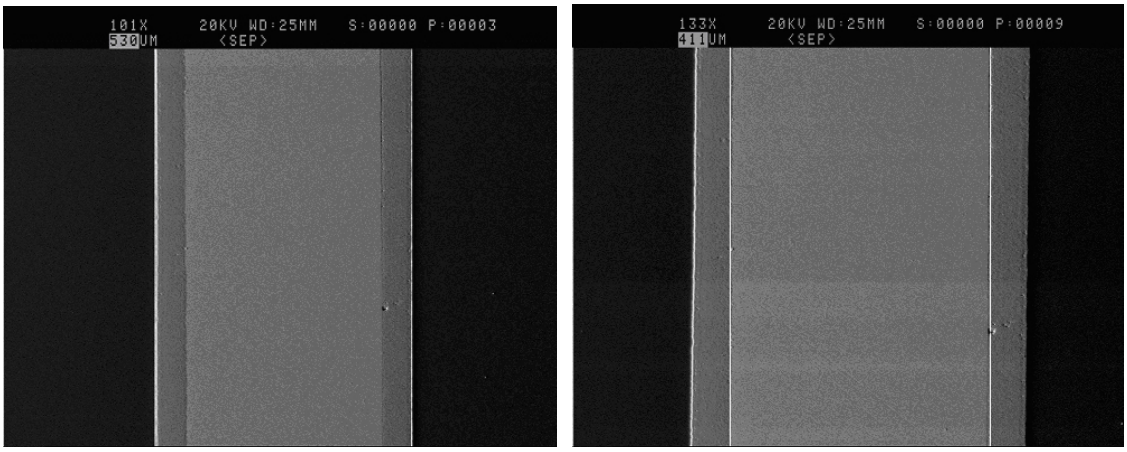


Figure 4. **Before and after SEM images of corrosion resulting from combustion of *Alyogyne huegelii***

Other combustion characteristics

A number of other fuel-related parameters were analysed. These included the level of ash, level of moisture, and the gross calorific value (GCV). Each of these parameters depend on the basis on which they are evaluated. The condition in which the material arrives is called "as-received". This is an important basis for measurement because as-received is generally the condition of the material when it is burnt. In practice however, moisture in particular, and ash content to a smaller degree, are variable properties and can significantly alter some of the fuel properties. To attempt to consider the fuel without such influences the sample material is air-dried to remove free moisture. This causes measures such as the level of ash and calorific value to change as a percentage of the remaining material. The material is also assessed on a "dry, ash-free basis" meaning the ash component is also removed. This is particularly useful for gross calorific value, as it gives a measure of the underlying energy content of the fuel (ash and moisture both working to dilute energy value). See Appendix 1 for analysis results for each of the 26 species tested.

Figure 5 shows the variation of gross calorific value on an as-received basis. Biomass has a lower GCV than black coal due to the basic constituents of the fuels (for example biomass has around 40% oxygen, bituminous coal 10% or less). Taking ash and moisture out of the equation, biomass material generally has a gross calorific value of 19 to 20.5 MJ/kg on a dry, ash-free basis. This was found to be the case for the samples analysed in this study, except for *Taxandria juniperina*, which had a surprisingly high GCVdaf of 23.1 MJ/kg. Usually this is due to some level of oil content, for example macadamia shells exhibit a higher than average GCV due to oily residues from the kernel. The reason for an elevated GCV in this case is uncertain, and may warrant further investigation. The effect is of course a good one.

Figure 6, Figure 7 and Figure 8 show moisture, ash and wastage, all on an as-received basis. Moisture content of "green" biomass is usually closer to 50%, as is the case with the blue gum whole tree chips. The generally low level of moisture in each of the samples tested is perhaps not indicative of what would be received in practice unless an active drying process was carried out. For materials with a low ash content, moisture has a roughly linear effect on calorific value. For example dry biomass with a GCV of 20MJ/kg would have a GCV of around 10MJ/kg at 50% moisture.

Figure 9 shows ash fusion temperature, which is one measure of the likelihood of ash creating fouling problems by softening and sticking to boiler surfaces. Most combustors dedicated to biomass operate below the lowest ash fusion temperature measured for these samples, however coal-fired boilers do operate at higher furnace temperatures and so biomass co-firing with coal may present a fouling issue for those samples with lower ash fusion temperatures.

Overall, no samples were rated as having a high propensity to cause high temperature corrosion. *Alyogyne huegelii* and *Gyrostemon ramulosus* were higher than average, however still within a moderate range compared with other biomass fuels.

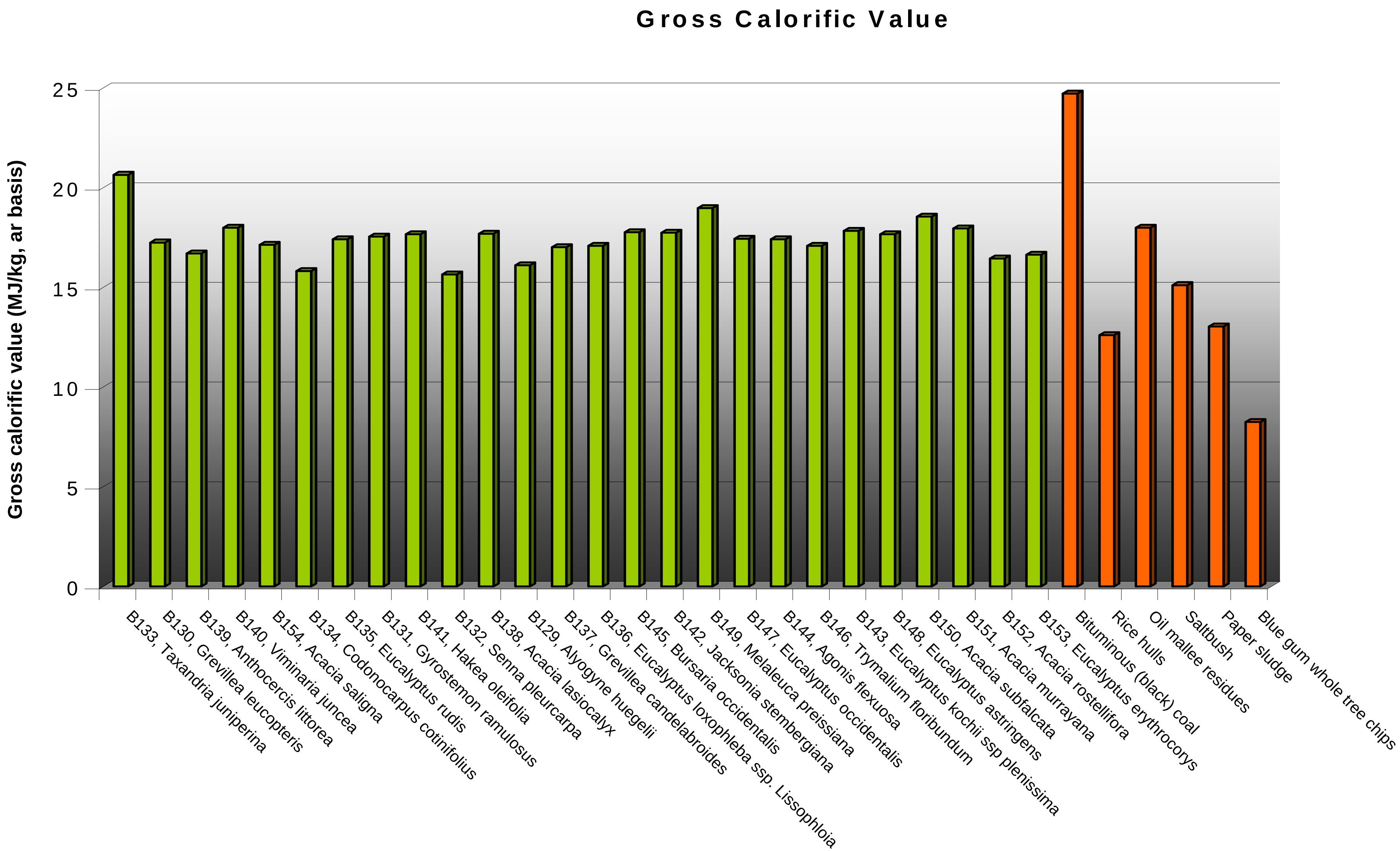


Figure 5. Gross calorific value (as-received basis).

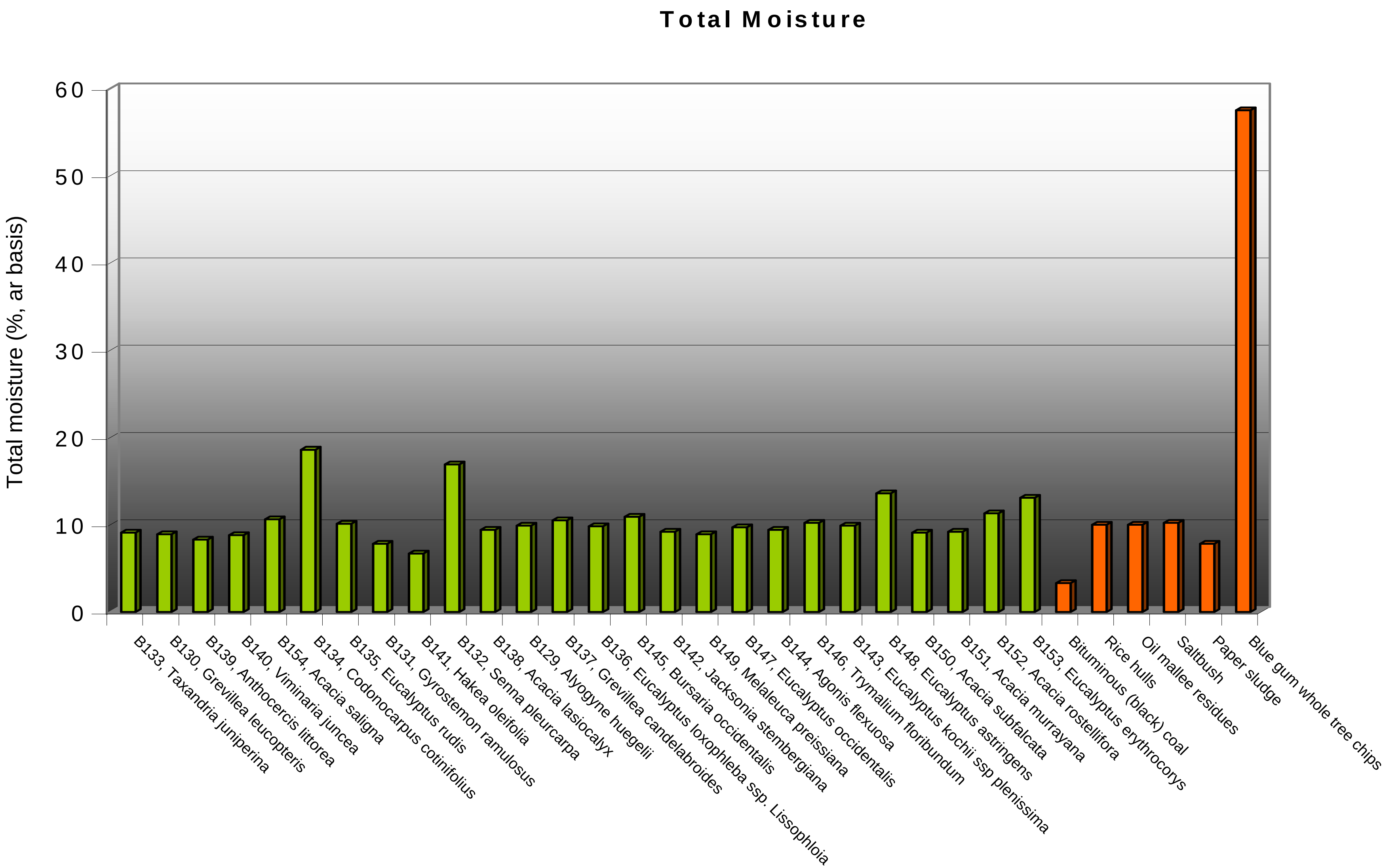


Figure 6. Total moisture content (as received basis).

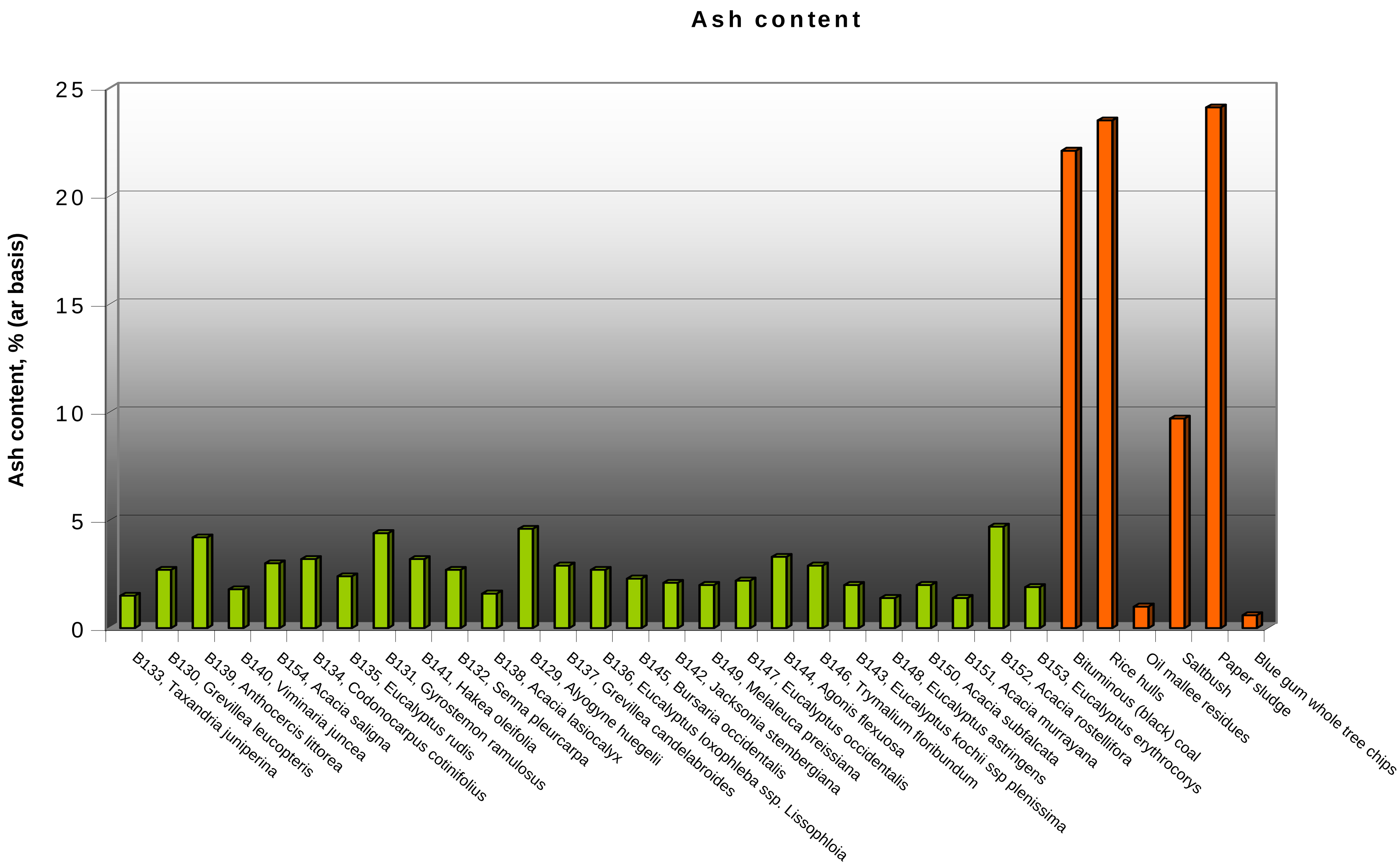


Figure 7. **Ash content (as received basis).**

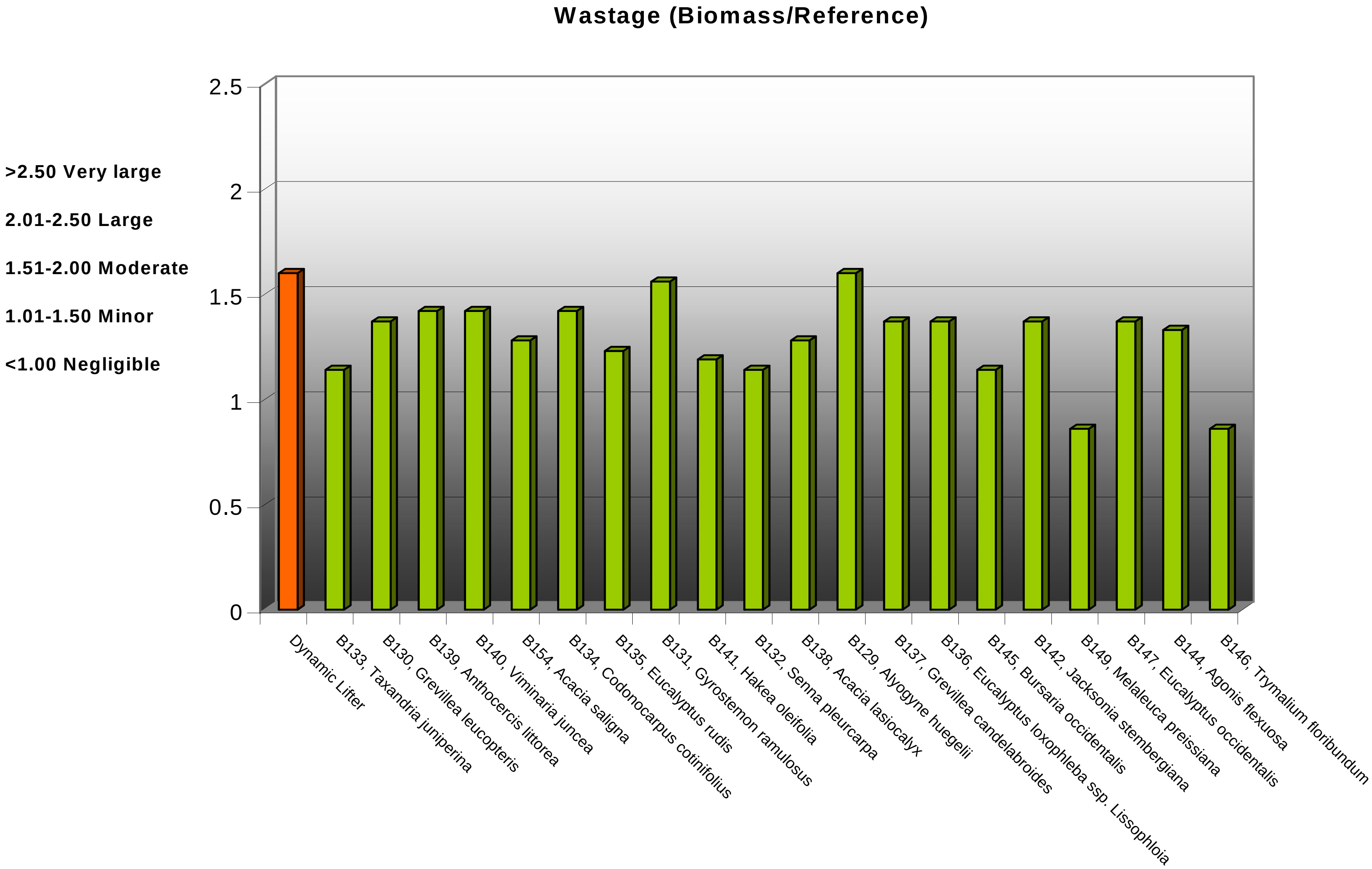


Figure 8. Wastage of metal stub (on a relative basis) as a result of high temperature corrosion.

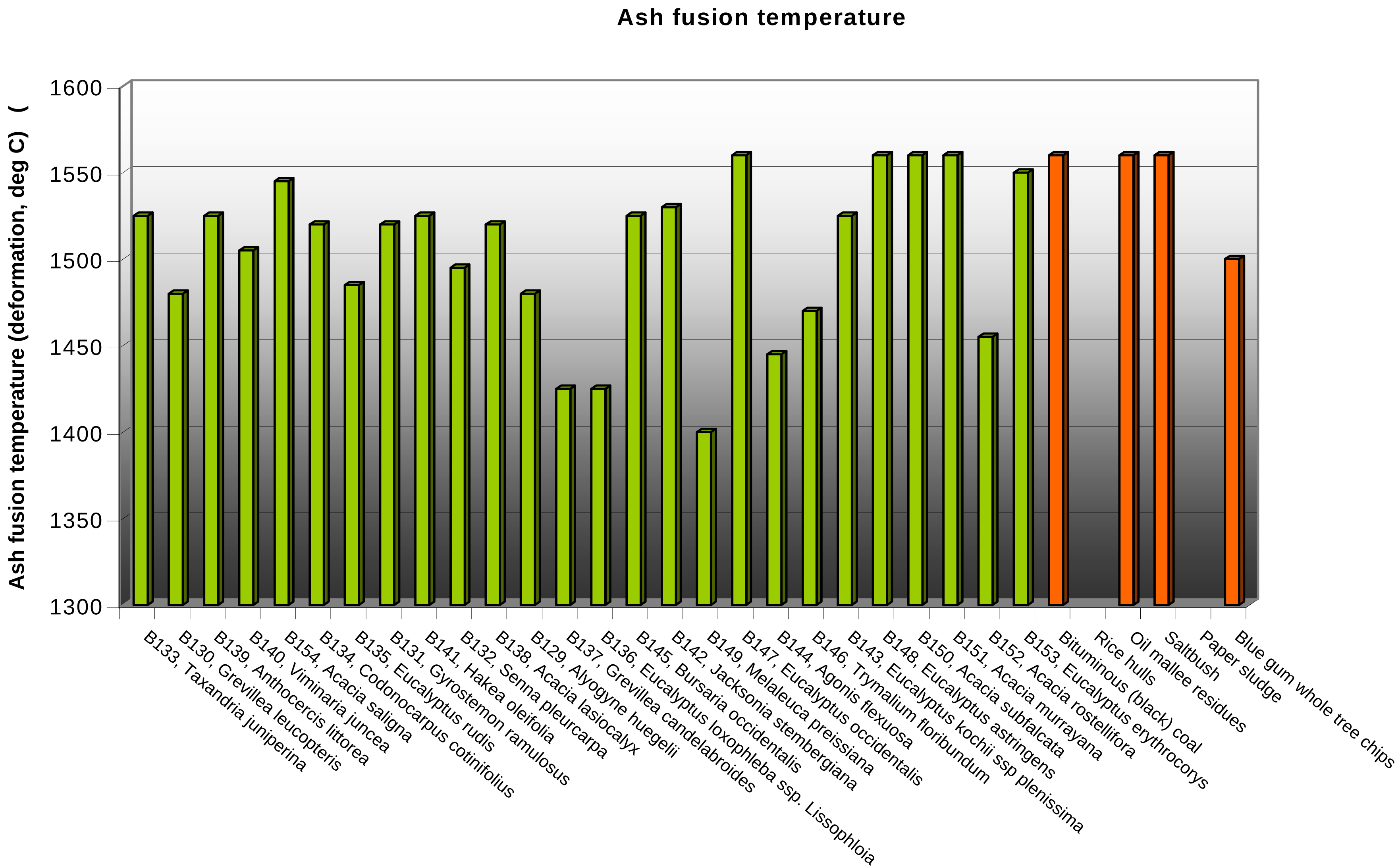


Figure 9. Ash fusion temperature.

Appendix 1

Standard combustion tests on 26 Search Project species

The following pages include results of standard combustion tests carried out by CCI Australia Pty Ltd for CSIRO Energy Technology. Tests were carried out on mixed samples in the proportion of 1/3 wood (W), 1/3 bark (B) and 1/3 leaf and twig (LT).

Twenty-six species were tested:

Acacia bartleana Maslin (ms)

Acacia lasiocalyx

Acacia murrayana

Acacia rostellifera

Acacia saligna

Agonis flexuosa

Alyogyne huegelii

Anthocercis littorea

Bursaria occidentalis

Codonocarpus cotinifolius

Eucalyptus astringens

Eucalyptus erythrocorys

Eucalyptus kochii ssp plenissima

Eucalyptus loxophleba ssp lissophloia

Eucalyptus occidentalis

Eucalyptus rudis

Grevillea candelabroides

Grevillea leucopteris

Gyrostemon ramulosus

Hakea oleifolia

Jacksonia sternbergiana

Melaleuca preissiana

Senna pleurocarpa

Taxandria juniperina

Trymalium floribundum

Viminaria juncea

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN : CSIRO Energy Technology **CCI REF. NO. :** N3392

DESCRIPTION : Supplied Biomass Samples for Analysis **DATE REC'D :** 14/08/2003

REPORTED TO : Mr Owen Farrell

Listing of Received Biomass Samples

CSIRO Sample Description		CCI Sample Number	Mass Received (g)	Free Moisture (%ad)	Ash (%db)
B129	*Alyogyne huegelii*	**M07919**	7667.0	5.12	5.1
B130	*Grevillea leucopteris*	**M07920**	8191.0	4.98	3.0
B131	*Gyrostemon ramulsosus*	**M07921**	7683.0	2.88	4.8
B132	*Senna pleurocarpa*	**M07922**	7559.0	11.36	3.3
B133	*Taxandria juniperina*	**M07923**	8301.0	3.08	1.6
B134	*Codonocarpus cotinifolius*	**M07924**	9937.0	13.57	4.0
B135	*Eucalyptus rudis*	**M07925**	8070.0	3.86	2.7
B136	*Eucalyptus loxophleba ssp lissophloia*	**M07926**	9950.0	2.09	3.0
B137	*Grevillea candelabroides*	**M07927**	8302.0	7.67	3.2
B138	*Acacia lasiocalyx*	**M07928**	9525.0	4.50	1.8
B139	*Anthocercis littorea*	**M07929**	5758.0	3.59	4.5
B140	*Viminaria juncea*	**M07930**	6926.0	3.13	2.0
B141	*Hakea oleifolia*	**M07931**	7819.0	2.73	3.5
B142	*Jacksonia sternbergiana*	**M07932**	6057.0	2.45	2.3
B143	*Eucalyptus kochii ssp plenissima*	**M07933**	6250.0	2.97	2.2
B144	*Agonis flexuosa*	**M07934**	7163.0	4.94	3.7
B145	*Bursaria occidentalis*	**M07935**	10944.0	4.77	2.6
B146	*Trymalium floribundum*	**M07936**	6462.0	4.08	3.2
B147	*Eucalyptus occidentalis*	**M07937**	6362.0	6.14	2.4
B148	*Eucalyptus astringens*	**M07938**	8463.0	10.00	1.6
B149	*Melaleuca preissiana*	**M07939**	8853.0	1.87	2.2
B150	*Acacia bartleana Maslin (ms)*	**M07940**	7486.0	1.99	2.2
B151	*Acacia murrayana*	**M07941**	6301.0	2.36	1.5
B152	*Acacia rostellifera*	**M07942**	7418.0	4.58	5.3
B153	*Eucalyptus erythrocorys*	**M07943**	7021.0	4.08	2.2
B154	*Acacia saligna*	**M07944**	1247.0	7.23	3.3

Prepared splits of all samples have been returned to CSIRO - September 2003

Reported By: J. England Provisional **Date:** *September 22, 2003*

CCI AUSTRALIA

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN : CSIRO Energy Technology **CCI REF. NO. :** N3392

DESCRIPTION : Supplied Biomass Samples for Analysis **DATE REC'D :** 14/08/2003

REPORTED TO : Mr Owen Farrell

Listing of Received Biomass Samples

CSIRO Sample Description		CCI Sample Number	Mass Received (g)	Air Dried Mass (g)	Free Moisture (%ad)
B129-W	*Alyogyne huegelii*	**M07841**	2709.0	2594.0	4.2
B129-B	*Alyogyne huegelii*	**M07842**	2140.0	2030.0	5.1
B129-LT	*Alyogyne huegelii*	**M07843**	2818.0	2650.0	6.0
B130-W	*Grevillea leucopteris*	**M07844**	2183.0	2075.0	4.9
B130-B	*Grevillea leucopteris*	**M07845**	3312.0	3105.0	6.3
B130-LT	*Grevillea leucopteris*	**M07846**	2696.0	2595.0	3.7
B131-W	*Gyrostemon ramulosus*	**M07847**	3007.0	2929.0	2.6
B131-B	*Gyrostemon ramulosus*	**M07848**	3647.0	3543.0	2.9
B131-LT	*Gyrostemon ramulosus*	**M07849**	1029.0	996.0	3.2
B132-W	*Senna pleurocarpa*	**M07850**	2109.0	2056.0	2.5
B132-B	*Senna pleurocarpa*	**M07851**	3876.0	2754.0	28.9
B132-LT	*Senna pleurocarpa*	**M07852**	1574.0	1533.0	2.6
B133-W	*Taxandria juniperina*	**M07853**	3103.0	2984.0	3.8
B133-B	*Taxandria juniperina*	**M07854**	2693.0	2666.0	1.0
B133-LT	*Taxandria juniperina*	**M07855**	2505.0	2395.0	4.4
B134-W	*Codonocarpus cotinifolius*	**M07856**	3065.0	2993.0	2.3
B134-B	*Codonocarpus cotinifolius*	**M07857**	4613.0	3997.0	13.4
B134-LT	*Codonocarpus cotinifolius*	**M07858**	2259.0	1694.0	25.0
B135-W	*Eucalyptus rudis*	**M07859**	3073.0	2950.0	4.0
B135-B	*Eucalyptus rudis*	**M07860**	3188.0	3050.0	4.3
B135-LT	*Eucalyptus rudis*	**M07861**	1809.0	1750.0	3.3
B136-W	*Eucalyptus loxophleba ssp lissophloia*	**M07862**	3200.0	3138.0	1.9
B136-B	*Eucalyptus loxophleba ssp lissophloia*	**M07863**	3500.0	3434.0	1.9
B136-LT	*Eucalyptus loxophleba ssp lissophloia*	**M07864**	3250.0	3170.0	2.5

Prepared splits of all samples have been returned to CSIRO - September 2003

Reported By: J. England Provisional **Date:** *September 22, 2003*

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN : CSIRO Energy Technology **CCI REF. NO. :** N3392

DESCRIPTION : Supplied Biomass Samples for Analysis **DATE REC'D :** 14/08/2003

REPORTED TO : Mr Owen Farrell

Listing of Received Biomass Samples

CSIRO Sample Description		CCI Sample Number	Mass Received (g)	Air Dried Mass (g)	Free Moisture (%ad)
B137-W	*Grevillea candelabroides*	**M07865**	2908.0	2620.0	9.9
B137-B	*Grevillea candelabroides*	**M07866**	2401.0	2239.0	6.7
B137-LT	*Grevillea candelabroides*	**M07867**	2993.0	2803.0	6.3
B138-W	*Acacia lasiocalyx*	**M07868**	3408.0	3300.0	3.2
B138-B	*Acacia lasiocalyx*	**M07869**	3098.0	2900.0	6.4
B138-LT	*Acacia lasiocalyx*	**M07870**	3019.0	2900.0	3.9
B139-W	*Anthocercis littorea*	**M07871**	2937.0	2925.0	0.4
B139-B	*Anthocercis littorea*	**M07872**	1566.0	1481.0	5.4
B139-LT	*Anthocercis littorea*	**M07873**	1255.0	1193.0	4.9
B140-W	*Viminaria juncea*	**M07874**	3099.0	3028.0	2.3
B140-B	*Viminaria juncea*	**M07875**	2108.0	2059.0	2.3
B140-LT	*Viminaria juncea*	**M07876**	1719.0	1637.0	4.8
B141-W	*Hakea oleifolia*	**M07877**	2009.0	2000.0	0.4
B141-B	*Hakea oleifolia*	**M07878**	3088.0	2876.0	6.9
B141-LT	*Hakea oleifolia*	**M07879**	2722.0	2698.0	0.9
B142-W	*Jacksonia sternbergiana*	**M07880**	2271.0	2217.0	2.4
B142-B	*Jacksonia sternbergiana*	**M07881**	2083.0	2026.0	2.7
B142-LT	*Jacksonia sternbergiana*	**M07882**	1703.0	1665.0	2.2
B143-W	*Eucalyptus kochii ssp plenissima*	**M07883**	1690.0	1628.0	3.7
B143-B	*Eucalyptus kochii ssp plenissima*	**M07884**	1793.0	1737.0	3.1
B143-LT	*Eucalyptus kochii ssp plenissima*	**M07885**	2767.0	2708.0	2.1
B144-W	*Agonis flexuosa*	**M07886**	2829.0	2692.0	4.8
B144-B	*Agonis flexuosa*	**M07887**	1942.0	1818.0	6.4
B144-LT	*Agonis flexuosa*	**M07888**	2392.0	2306.0	3.6

Prepared splits of all samples have been returned to CSIRO - September 2003

Reported By: J. England Provisional **Date:** *September 22, 2003*

AUSTRALIA

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN : CSIRO Energy Technology **CCI REF. NO. :** N3392

DESCRIPTION : Supplied Biomass Samples for Analysis **DATE REC'D :** 14/08/2003

REPORTED TO : Mr Owen Farrell

Listing of Received Biomass Samples

CSIRO Sample Description		CCI Sample Number	Mass Received (g)	Air Dried Mass (g)	Free Moisture (%ad)
B145-W	*Bursaria occidentalis*	**M07889**	5760.0	5385.0	6.5
B145-B	*Bursaria occidentalis*	**M07890**	3265.0	3135.0	4.0
B145-LT	*Bursaria occidentalis*	**M07891**	1919.0	1846.0	3.8
B146-W	*Trymalium floribundum*	**M07892**	3126.0	2997.0	4.1
B146-B	*Trymalium floribundum*	**M07893**	1473.0	1408.0	4.4
B146-LT	*Trymalium floribundum*	**M07894**	1863.0	1794.0	3.7
B147-W	*Eucalyptus occidentalis*	**M07895**	2238.0	2051.0	8.4
B147-B	*Eucalyptus occidentalis*	**M07896**	1693.0	1622.0	4.2
B147-LT	*Eucalyptus occidentalis*	**M07897**	2431.0	2288.0	5.9
B148-W	*Eucalyptus astringens*	**M07898**	2839.0	2613.0	8.0
B148-B	*Eucalyptus astringens*	**M07899**	2835.0	2393.0	15.6
B148-LT	*Eucalyptus astringens*	**M07900**	2789.0	2609.0	6.5
B149-W	*Melaleuca preissiana*	**M07901**	3657.0	3555.0	2.8
B149-B	*Melaleuca preissiana*	**M07902**	2522.0	2488.0	1.3
B149-LT	*Melaleuca preissiana*	**M07903**	2674.0	2635.0	1.5
B150-W	*Acacia bartleana Maslin (ms)*	**M07904**	2941.0	2895.0	1.6
B150-B	*Acacia bartleana Maslin (ms)*	**M07905**	2492.0	2439.0	2.1
B150-LT	*Acacia bartleana Maslin (ms)*	**M07906**	2053.0	2006.0	2.3
B151-W	*Acacia murrayana*	**M07907**	2009.0	1946.0	3.1
B151-B	*Acacia murrayana*	**M07908**	2010.0	1972.0	1.9
B151-LT	*Acacia murrayana*	**M07909**	2282.0	2235.0	2.1
B152-W	*Acacia rostellifera*	**M07910**	2260.0	2168.0	4.1
B152-B	*Acacia rostellifera*	**M07911**	3138.0	2974.0	5.2
B152-LT	*Acacia rostellifera*	**M07912**	2020.0	1930.0	4.5

Prepared splits of all samples have been returned to CSIRO - September 2003

Reported By: J. England Provisional **Date:** *September 22, 2003*

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN : CSIRO Energy Technology **CCI REF. NO. :** N3392

DESCRIPTION : Supplied Biomass Samples for Analysis **DATE REC'D :** 14/08/2003

REPORTED TO : Mr Owen Farrell

Listing of Received Biomass Samples

CSIRO Sample Description		CCI Sample Number	Mass Received (g)	Air Dried Mass (g)	Free Moisture (%ad)
B153-W	*Eucalyptus erythrocorys*	**M07913**	1952.0	1891.0	3.1
B153-B	*Eucalyptus erythrocorys*	**M07914**	2366.0	2207.0	6.7
B153-LT	*Eucalyptus erythrocorys*	**M07915**	2703.0	2638.0	2.4
B79-W	*Acacia saligna*	**M07916**	492.0	456.0	7.3
B80-B	*Acacia saligna*	**M07917**	261.0	242.0	7.3
B81-LT	*Acacia saligna*	**M07918**	494.0	459.0	7.1

Prepared splits of all samples have been returned to CSIRO - September 2003

Reported By: J. England Provisional **Date:** *September 22, 2003*

AUSTRALIA

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN :	CSIRO Energy Technology	**CCI REF. NO. :**	N3392
DESCRIPTION :	Supplied Biomass Sample for Analysis	**DATE REC'D :**	14/08/2003
REPORTED TO :	Mr Owen Farrell		

BIOMASS SAMPLE - B150

Acacia bartleana Maslin (ms)

CCI Sample Number		M07940
Mass Received	(g)	7486.0
Free Moisture	(%ar)	2.0

Analysis Basis		(ar)	(ad)	(db)	(daf)
Total Moisture	(%)	9.1			
Proximate Analysis					
Air Dried Moisture	(%)		7.5		
Ash *(@ 815 °C)*	(%)	2.0	2.0	2.2	
Volatile Matter	(%)	67.3	68.5	74.1	75.7
Fixed Carbon	(%)	21.6	22.0	23.7	24.3
Gross Calorific Value	(MJ/kg)	18.56	18.89	20.42	20.87
	(kcal/kg)	4432	4512	4878	4984
Ultimate Analysis					
Carbon	(%)	46.8	47.6	51.5	52.6
Hydrogen	(%)	5.40	5.49	5.94	6.07
Nitrogen	(%)	1.25	1.27	1.37	1.40
Total Sulfur	(%)	0.11	0.11	0.12	
Oxygen *(by difference)*	(%)	35.3	36.0	38.9	

Ash Fusion Temperatures		(Oxidising Atm)
Deformation	(°C)	+1560
Sphere	(°C)	+1560
Hemisphere	(°C)	+1560
Flow	(°C)	+1560

(ar) = "as received" basis, (ad) = "air dried" basis, (db) = "dry basis", (daf) = "dry, ash free" basis

Analysed at CCI Newcastle in accordance with Australian Standard Methods
AS1038.1, AS1038.3, AS1038.5, AS1038.6.3.3, AS1038.7 (draft) and AS1038.15.

Reported By: J. England Provisional **Date:** *September 22, 2003*

CCI AUSTRALIA

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN : CSIRO Energy Technology — **CCI REF. NO. :** N3392

DESCRIPTION : Supplied Biomass Sample for Analysis — **DATE REC'D :** 14/08/2003

REPORTED TO : Mr Owen Farrell

BIOMASS SAMPLE - B138

Acacia lasiocalyx

CCI Sample Number		M07928
Mass Received	(g)	9525.0
Free Moisture	(%ar)	4.5

Analysis Basis		(ar)	(ad)	(db)	(daf)
Total Moisture	(%)	9.4			
Proximate Analysis					
Air Dried Moisture	(%)		6.6		
Ash *(@ 815 °C)*	(%)	1.6	1.7	1.8	
Volatile Matter	(%)	72.6	74.8	80.1	81.6
Fixed Carbon	(%)	16.4	16.9	18.1	18.4
Gross Calorific Value	(MJ/kg)	17.70	18.25	19.54	19.90
	(kcal/kg)	4228	4358	4668	4754
Ultimate Analysis					
Carbon	(%)	44.6	46.0	49.3	50.2
Hydrogen	(%)	5.40	5.57	5.96	6.07
Nitrogen	(%)	0.91	0.94	1.01	1.03
Total Sulfur	(%)	0.11	0.11	0.12	
Oxygen *(by difference)*	(%)	38.0	39.1	41.8	

Ash Fusion Temperatures		(Oxidising Atm)
Deformation	(°C)	1520
Sphere	(°C)	1525
Hemisphere	(°C)	1530
Flow	(°C)	1535

(ar) = "as received" basis, (ad) = "air dried" basis, (db) = "dry basis", (daf) = "dry, ash free" basis

Analysed at CCI Newcastle in accordance with Australian Standard Methods
AS1038.1, AS1038.3, AS1038.5, AS1038.6.3.3, AS1038.7 (draft) and AS1038.15.

Reported By: J. England Provisional **Date:** *September 22, 2003*

AUSTRALIA

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN : CSIRO Energy Technology **CCI REF. NO. :** N3392

DESCRIPTION : Supplied Biomass Sample for Analysis **DATE REC'D :** 14/08/2003

REPORTED TO : Mr Owen Farrell

BIOMASS SAMPLE - B151
Acacia murrayana

CCI Sample Number		M07941
Mass Received	(g)	6301.0
Free Moisture	(%ar)	2.4

Analysis Basis		(ar)	(ad)	(db)	(daf)
Total Moisture	(%)	9.2			
Proximate Analysis					
Air Dried Moisture	(%)		6.8		
Ash *(@ 815 °C)*	(%)	1.4	1.4	1.5	
Volatile Matter	(%)	71.0	72.9	78.2	79.4
Fixed Carbon	(%)	18.4	18.9	20.3	20.6
Gross Calorific Value	(MJ/kg)	17.97	18.45	19.80	20.10
	(kcal/kg)	4292	4406	4730	4800
Ultimate Analysis					
Carbon	(%)	45.3	46.5	49.9	50.7
Hydrogen	(%)	5.51	5.66	6.07	6.17
Nitrogen	(%)	1.73	1.78	1.91	1.94
Total Sulfur	(%)	0.09	0.09	0.10	
Oxygen *(by difference)*	(%)	36.8	37.8	40.5	

Ash Fusion Temperatures		(Oxidising Atm)
Deformation	(°C)	+1560
Sphere	(°C)	+1560
Hemisphere	(°C)	+1560
Flow	(°C)	+1560

(ar) = "as received" basis, (ad) = "air dried" basis, (db) = "dry basis", (daf) = "dry, ash free" basis

Analysed at CCI Newcastle in accordance with Australian Standard Methods
AS1038.1, AS1038.3, AS1038.5, AS1038.6.3.3, AS1038.7 (draft) and AS1038.15.

Reported By: J. England Provisional **Date:** *September 22, 2003*

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN : CSIRO Energy Technology **CCI REF. NO. :** N3392

DESCRIPTION : Supplied Biomass Sample for Analysis **DATE REC'D :** 14/08/2003

REPORTED TO : Mr Owen Farrell

BIOMASS SAMPLE - B152
Acacia rostellifera

CCI Sample Number		M07942
Mass Received	(g)	7418.0
Free Moisture	(%ar)	4.6

Analysis Basis		(ar)	(ad)	(db)	(daf)
Total Moisture	(%)	11.3			
Proximate Analysis					
Air Dried Moisture	(%)		7.3		
Ash *(@ 815 °C)*	(%)	4.7	4.9	5.3	
Volatile Matter	(%)	66.8	69.8	75.3	79.5
Fixed Carbon	(%)	17.2	18.0	19.4	20.5
Gross Calorific Value	(MJ/kg)	16.46	17.20	18.55	19.59
	(kcal/kg)	3932	4108	4430	4678
Ultimate Analysis					
Carbon	(%)	42.4	44.3	47.8	50.5
Hydrogen	(%)	4.90	5.12	5.52	5.83
Nitrogen	(%)	0.78	0.82	0.88	0.93
Total Sulfur	(%)	0.29	0.30	0.32	
Oxygen *(by difference)*	(%)	35.6	37.3	40.2	

Ash Fusion Temperatures		(Oxidising Atm)
Deformation	(°C)	1455
Sphere	(°C)	1460
Hemisphere	(°C)	1465
Flow	(°C)	1470

(ar) = "as received" basis, (ad) = "air dried" basis, (db) = "dry basis", (daf) = "dry, ash free" basis

Analysed at CCI Newcastle in accordance with Australian Standard Methods
AS1038.1, AS1038.3, AS1038.5, AS1038.6.3.3, AS1038.7 (draft) and AS1038.15.

Reported By: J. England Provisional **Date:** *September 22, 2003*

AUSTRALIA

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN :	CSIRO Energy Technology	**CCI REF. NO. :**	N3392
DESCRIPTION :	Supplied Biomass Sample for Analysis	**DATE REC'D :**	14/08/2003
REPORTED TO :	Mr Owen Farrell		

BIOMASS SAMPLE - B154

Acacia saligna

CCI Sample Number		M07944
Mass Received	(g)	1247.0
Free Moisture	(%ar)	7.2

Analysis Basis		(ar)	(ad)	(db)	(daf)
Total Moisture	(%)	10.6			
Proximate Analysis					
Air Dried Moisture	(%)		6.2		
Ash *(@ 815 °C)*	(%)	3.0	3.1	3.3	
Volatile Matter	(%)	68.1	71.4	76.1	78.7
Fixed Carbon	(%)	18.3	19.3	20.6	21.3
Gross Calorific Value	(MJ/kg)	17.15	17.99	19.18	19.83
	(kcal/kg)	4096	4296	4582	4736
Ultimate Analysis					
Carbon	(%)	43.7	45.8	48.8	50.5
Hydrogen	(%)	5.13	5.38	5.74	5.93
Nitrogen	(%)	1.08	1.13	1.20	1.25
Total Sulfur	(%)	0.19	0.20	0.21	
Oxygen *(by difference)*	(%)	36.3	38.2	40.8	

Ash Fusion Temperatures		(Oxidising Atm)
Deformation	(°C)	1545
Sphere	(°C)	1550
Hemisphere	(°C)	1555
Flow	(°C)	1560

(ar) = "as received" basis, (ad) = "air dried" basis, (db) = "dry basis", (daf) = "dry, ash free" basis

Analysed at CCI Newcastle in accordance with Australian Standard Methods
AS1038.1, AS1038.3, AS1038.5, AS1038.6.3.3, AS1038.7 (draft) and AS1038.15.

Reported By: J. England Provisional **Date:** *September 22, 2003*

AUSTRALIA

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN : CSIRO Energy Technology **CCI REF. NO. :** N3392

DESCRIPTION : Supplied Biomass Sample for Analysis **DATE REC'D :** 14/08/2003

REPORTED TO : Mr Owen Farrell

BIOMASS SAMPLE - B144

Agonis flexuosa

CCI Sample Number		M07934
Mass Received	(g)	7163.0
Free Moisture	(%ar)	4.9

Analysis Basis		(ar)	(ad)	(db)	(daf)
Total Moisture	(%)	9.4			
Proximate Analysis					
Air Dried Moisture	(%)		7.4		
Ash *(@ 815 °C)*	(%)	3.3	3.4	3.7	
Volatile Matter	(%)	70.1	71.6	77.3	80.3
Fixed Carbon	(%)	17.2	17.6	19.0	19.7
Gross Calorific Value	(MJ/kg)	17.42	17.80	19.22	19.96
	(kcal/kg)	4160	4252	4590	4768
Ultimate Analysis					
Carbon	(%)	44.4	45.4	49.0	50.9
Hydrogen	(%)	5.17	5.28	5.70	5.92
Nitrogen	(%)	0.45	0.46	0.50	0.52
Total Sulfur	(%)	0.08	0.08	0.09	
Oxygen *(by difference)*	(%)	37.2	38.0	41.0	

Ash Fusion Temperatures		(Oxidising Atm)
Deformation	(°C)	1445
Sphere	(°C)	1450
Hemisphere	(°C)	1455
Flow	(°C)	1470

(ar) = "as received" basis, (ad) = "air dried" basis, (db) = "dry basis", (daf) = "dry, ash free" basis

Analysed at CCI Newcastle in accordance with Australian Standard Methods AS1038.1, AS1038.3, AS1038.5, AS1038.6.3.3, AS1038.7 (draft) and AS1038.15.

Reported By: J. England Provisional **Date:** *September 22, 2003*

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN :	CSIRO Energy Technology	**CCI REF. NO. :**	N3392
DESCRIPTION :	Supplied Biomass Sample for Analysis	**DATE REC'D :**	14/08/2003
REPORTED TO :	Mr Owen Farrell		

BIOMASS SAMPLE - B129

Alyogyne huegelii

CCI Sample Number		M07919
Mass Received	(g)	7667.0
Free Moisture	(%ar)	5.1

Analysis Basis		(ar)	(ad)	(db)	(daf)
Total Moisture	(%)	9.9			
Proximate Analysis					
Air Dried Moisture	(%)		7.7		
Ash *(@ 815 °C)*	(%)	4.6	4.7	5.1	
Volatile Matter	(%)	64.9	66.5	72.0	75.9
Fixed Carbon	(%)	20.6	21.1	22.9	24.1
Gross Calorific Value	(MJ/kg)	16.12	16.51	17.89	18.85
	(kcal/kg)	3850	3944	4272	4502
Ultimate Analysis					
Carbon	(%)	41.9	42.9	46.5	49.0
Hydrogen	(%)	4.94	5.06	5.48	5.78
Nitrogen	(%)	0.54	0.55	0.60	0.63
Total Sulfur	(%)	0.25	0.26	0.28	
Oxygen *(by difference)*	(%)	37.9	38.8	42.0	
Ash Fusion Temperatures			(Oxidising Atm)		
Deformation	(°C)		1480		
Sphere	(°C)		1500		
Hemisphere	(°C)		1510		
Flow	(°C)		1520		

(ar) = "as received" basis, (ad) = "air dried" basis, (db) = "dry basis", (daf) = "dry, ash free" basis

Analysed at CCI Newcastle in accordance with Australian Standard Methods
AS1038.1, AS1038.3, AS1038.5, AS1038.6.3.3, AS1038.7 (draft) and AS1038.15.

Reported By: J. England Provisional **Date:** *September 22, 2003*

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN :	CSIRO Energy Technology	**CCI REF. NO. :**	N3392
DESCRIPTION :	Supplied Biomass Sample for Analysis	**DATE REC'D :**	14/08/2003
REPORTED TO :	Mr Owen Farrell		

BIOMASS SAMPLE - B139
Anthocercis littorea

CCI Sample Number		M07929
Mass Received	(g)	5758.0
Free Moisture	(%ar)	3.6

Analysis Basis		(ar)	(ad)	(db)	(daf)
Total Moisture	(%)	8.3			
Proximate Analysis					
Air Dried Moisture	(%)		7.6		
Ash *(@ 815 °C)*	(%)	4.2	4.2	4.5	
Volatile Matter	(%)	71.4	71.9	77.8	81.5
Fixed Carbon	(%)	16.1	16.3	17.7	18.5
Gross Calorific Value	(MJ/kg)	16.71	16.84	18.23	19.09
	(kcal/kg)	3992	4022	4354	4560
Ultimate Analysis					
Carbon	(%)	42.8	43.1	46.6	48.9
Hydrogen	(%)	5.26	5.30	5.74	6.01
Nitrogen	(%)	1.07	1.08	1.17	1.22
Total Sulfur	(%)	0.15	0.15	0.16	
Oxygen *(by difference)*	(%)	38.2	38.6	41.8	

Ash Fusion Temperatures		(Oxidising Atm)
Deformation	(°C)	1525
Sphere	(°C)	1530
Hemisphere	(°C)	1535
Flow	(°C)	1540

(ar) = "as received" basis, (ad) = "air dried" basis, (db) = "dry basis", (daf) = "dry, ash free" basis

Analysed at CCI Newcastle in accordance with Australian Standard Methods
AS1038.1, AS1038.3, AS1038.5, AS1038.6.3.3, AS1038.7 (draft) and AS1038.15.

Reported By: J. England Provisional **Date:** *September 22, 2003*

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN :	CSIRO Energy Technology	**CCI REF. NO. :**	N3392
DESCRIPTION :	Supplied Biomass Sample for Analysis	**DATE REC'D :**	14/08/2003
REPORTED TO :	Mr Owen Farrell		

BIOMASS SAMPLE - B145

Bursaria occidentalis

CCI Sample Number		M07935
Mass Received	(g)	10944.0
Free Moisture	(%ar)	4.8

Analysis Basis		(ar)	(ad)	(db)	(daf)
Total Moisture	(%)	10.9			
Proximate Analysis					
Air Dried Moisture	(%)		7.2		
Ash *(@ 815 °C)*	(%)	2.3	2.4	2.6	
Volatile Matter	(%)	70.3	73.2	78.9	81.0
Fixed Carbon	(%)	16.5	17.2	18.5	19.0
Gross Calorific Value	(MJ/kg)	17.77	18.51	19.95	20.48
	(kcal/kg)	4244	4422	4764	4892
Ultimate Analysis					
Carbon	(%)	44.5	46.3	49.9	51.2
Hydrogen	(%)	5.36	5.58	6.01	6.17
Nitrogen	(%)	0.56	0.58	0.63	0.64
Total Sulfur	(%)	0.06	0.06	0.06	
Oxygen *(by difference)*	(%)	36.3	37.9	40.8	

Ash Fusion Temperatures		(Oxidising Atm)
Deformation	(°C)	1525
Sphere	(°C)	1530
Hemisphere	(°C)	1535
Flow	(°C)	1540

(ar) = "as received" basis, (ad) = "air dried" basis, (db) = "dry basis", (daf) = "dry, ash free" basis

Analysed at CCI Newcastle in accordance with Australian Standard Methods
AS1038.1, AS1038.3, AS1038.5, AS1038.6.3.3, AS1038.7 (draft) and AS1038.15.

Reported By: J. England Provisional **Date:** *September 22, 2003*

CCi AUSTRALIA

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN : CSIRO Energy Technology | **CCI REF. NO. :** N3392

DESCRIPTION : Supplied Biomass Sample for Analysis | **DATE REC'D :** 14/08/2003

REPORTED TO : Mr Owen Farrell

BIOMASS SAMPLE - B134
Codonocarpus cotinifolius

CCI Sample Number		M07924
Mass Received	(g)	9937.0
Free Moisture	(%ar)	13.6

Analysis Basis		(ar)	(ad)	(db)	(daf)
Total Moisture	(%)	18.6			
Proximate Analysis					
Air Dried Moisture	(%)		6.4		
Ash *(@ 815 °C)*	(%)	3.2	3.7	4.0	
Volatile Matter	(%)	64.8	74.5	79.6	82.9
Fixed Carbon	(%)	13.4	15.4	16.4	17.1
Gross Calorific Value	(MJ/kg)	15.83	18.20	19.44	20.24
	(kcal/kg)	3780	4346	4644	4834
Ultimate Analysis					
Carbon	(%)	39.4	45.3	48.4	50.4
Hydrogen	(%)	4.09	4.70	5.02	5.23
Nitrogen	(%)	1.13	1.30	1.39	1.45
Total Sulfur	(%)	0.54	0.62	0.66	
Oxygen *(by difference)*	(%)	33.0	38.0	40.5	

Ash Fusion Temperatures		(Oxidising Atm)
Deformation	(°C)	1520
Sphere	(°C)	1525
Hemisphere	(°C)	1530
Flow	(°C)	1540

(ar) = "as received" basis, (ad) = "air dried" basis, (db) = "dry basis", (daf) = "dry, ash free" basis

Analysed at CCI Newcastle in accordance with Australian Standard Methods
AS1038.1, AS1038.3, AS1038.5, AS1038.6.3.3, AS1038.7 (draft) and AS1038.15.

Reported By: J. England Provisional **Date:** *September 22, 2003*

CCI AUSTRALIA

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN : CSIRO Energy Technology **CCI REF. NO. :** N3392
DESCRIPTION : Supplied Biomass Sample for Analysis **DATE REC'D :** 14/08/2003
REPORTED TO : Mr Owen Farrell

BIOMASS SAMPLE - B148
Eucalyptus astringens

CCI Sample Number		M07938
Mass Received	(g)	8463.0
Free Moisture	(%ar)	10.0

Analysis Basis		(ar)	(ad)	(db)	(daf)
Total Moisture	(%)	13.6			
Proximate Analysis					
Air Dried Moisture	(%)		7.3		
Ash *(@ 815 °C)*	(%)	1.4	1.5	1.6	
Volatile Matter	(%)	65.1	69.8	75.3	76.5
Fixed Carbon	(%)	19.9	21.4	23.1	23.5
Gross Calorific Value	(MJ/kg)	17.68	18.97	20.46	20.80
	(kcal/kg)	4222	4530	4886	4968
Ultimate Analysis					
Carbon	(%)	44.4	47.6	51.3	52.2
Hydrogen	(%)	5.07	5.44	5.87	5.96
Nitrogen	(%)	0.39	0.42	0.45	0.46
Total Sulfur	(%)	0.06	0.06	0.06	
Oxygen *(by difference)*	(%)	35.1	37.7	40.7	
Ash Fusion Temperatures			(Oxidising Atm)		
Deformation	(°C)		+1560		
Sphere	(°C)		+1560		
Hemisphere	(°C)		+1560		
Flow	(°C)		+1560		

(ar) = "as received" basis, (ad) = "air dried" basis, (db) = "dry basis", (daf) = "dry, ash free" basis

Analysed at CCI Newcastle in accordance with Australian Standard Methods
AS1038.1, AS1038.3, AS1038.5, AS1038.6.3.3, AS1038.7 (draft) and AS1038.15.

Reported By: J. England Provisional **Date:** *September 22, 2003*

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN :	CSIRO Energy Technology	**CCI REF. NO. :**	N3392
DESCRIPTION :	Supplied Biomass Sample for Analysis	**DATE REC'D :**	14/08/2003
REPORTED TO :	Mr Owen Farrell		

BIOMASS SAMPLE - B153
Eucalyptus erythrocorys

CCI Sample Number		M07943
Mass Received	(g)	7021.0
Free Moisture	(%ar)	4.1

Analysis Basis		(ar)	(ad)	(db)	(daf)
Total Moisture	(%)	13.1			
Proximate Analysis					
Air Dried Moisture	(%)		7.6		
Ash *(@ 815 °C)*	(%)	1.9	2.0	2.2	
Volatile Matter	(%)	69.4	73.8	79.9	81.6
Fixed Carbon	(%)	15.6	16.6	17.9	18.4
Gross Calorific Value	(MJ/kg)	16.65	17.70	19.16	19.58
	(kcal/kg)	3976	4228	4576	4676
Ultimate Analysis					
Carbon	(%)	42.3	45.0	48.7	49.8
Hydrogen	(%)	4.98	5.30	5.74	5.86
Nitrogen	(%)	0.36	0.38	0.41	0.42
Total Sulfur	(%)	0.05	0.05	0.05	
Oxygen *(by difference)*	(%)	37.3	39.7	42.9	

Ash Fusion Temperatures		(Oxidising Atm)
Deformation	(°C)	1550
Sphere	(°C)	1555
Hemisphere	(°C)	1560
Flow	(°C)	+1560

(ar) = "as received" basis, (ad) = "air dried" basis, (db) = "dry basis", (daf) = "dry, ash free" basis

Analysed at CCI Newcastle in accordance with Australian Standard Methods
AS1038.1, AS1038.3, AS1038.5, AS1038.6.3.3, AS1038.7 (draft) and AS1038.15.

Reported By: J. England Provisional **Date:** *September 22, 2003*

CCI AUSTRALIA

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN : CSIRO Energy Technology — **CCI REF. NO. :** N3392

DESCRIPTION : Supplied Biomass Sample for Analysis — **DATE REC'D :** 14/08/2003

REPORTED TO : Mr Owen Farrell

BIOMASS SAMPLE - B143

Eucalyptus kochii ssp plenissima

CCI Sample Number		M07933
Mass Received	(g)	6250.0
Free Moisture	(%ar)	3.0

Analysis Basis		(ar)	(ad)	(db)	(daf)
Total Moisture	(%)	9.9			
Proximate Analysis					
Air Dried Moisture	(%)		8.2		
Ash *(@ 815 °C)*	(%)	2.0	2.0	2.2	
Volatile Matter	(%)	71.9	73.3	79.8	81.6
Fixed Carbon	(%)	16.2	16.5	18.0	18.4
Gross Calorific Value	(MJ/kg)	17.85	18.19	19.81	20.26
	(kcal/kg)	4264	4344	4732	4840
Ultimate Analysis					
Carbon	(%)	45.2	46.1	50.2	51.3
Hydrogen	(%)	5.44	5.54	6.03	6.17
Nitrogen	(%)	0.51	0.52	0.57	0.58
Total Sulfur	(%)	0.07	0.07	0.08	
Oxygen *(by difference)*	(%)	36.9	37.6	40.9	

Ash Fusion Temperatures		(Oxidising Atm)
Deformation	(°C)	1525
Sphere	(°C)	1530
Hemisphere	(°C)	1535
Flow	(°C)	1550

(ar) = "as received" basis, (ad) = "air dried" basis, (db) = "dry basis", (daf) = "dry, ash free" basis

Analysed at CCI Newcastle in accordance with Australian Standard Methods
AS1038.1, AS1038.3, AS1038.5, AS1038.6.3.3, AS1038.7 (draft) and AS1038.15.

Reported By: J. England Provisional **Date:** *September 22, 2003*

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN :	CSIRO Energy Technology	**CCI REF. NO. :**	N3392
DESCRIPTION :	Supplied Biomass Sample for Analysis	**DATE REC'D :**	14/08/2003
REPORTED TO :	Mr Owen Farrell		

BIOMASS SAMPLE - B136
Eucalyptus loxophleba ssp lissophloia

CCI Sample Number		M07926
Mass Received	(g)	9950.0
Free Moisture	(%ar)	2.1

Analysis Basis		(ar)	(ad)	(db)	(daf)
Total Moisture	(%)	9.8			
Proximate Analysis					
Air Dried Moisture	(%)		7.1		
Ash *(@ 815 °C)*	(%)	2.7	2.8	3.0	
Volatile Matter	(%)	69.1	71.2	76.6	79.0
Fixed Carbon	(%)	18.4	18.9	20.4	21.0
Gross Calorific Value	(MJ/kg)	17.10	17.61	18.96	19.54
	(kcal/kg)	4084	4206	4528	4668
Ultimate Analysis					
Carbon	(%)	44.0	45.3	48.8	50.3
Hydrogen	(%)	5.22	5.38	5.79	5.97
Nitrogen	(%)	0.40	0.41	0.44	0.46
Total Sulfur	(%)	0.06	0.06	0.06	
Oxygen *(by difference)*	(%)	37.8	39.0	41.9	

Ash Fusion Temperatures		(Oxidising Atm)
Deformation	(°C)	1425
Sphere	(°C)	1430
Hemisphere	(°C)	1435
Flow	(°C)	1440

(ar) = "as received" basis, (ad) = "air dried" basis, (db) = "dry basis", (daf) = "dry, ash free" basis

Analysed at CCI Newcastle in accordance with Australian Standard Methods
AS1038.1, AS1038.3, AS1038.5, AS1038.6.3.3, AS1038.7 (draft) and AS1038.15.

Reported By: J. England Provisional **Date:** *September 22, 2003*

CCI AUSTRALIA

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN :	CSIRO Energy Technology	**CCI REF. NO. :**	N3392
DESCRIPTION :	Supplied Biomass Sample for Analysis	**DATE REC'D :**	14/08/2003
REPORTED TO :	Mr Owen Farrell		

BIOMASS SAMPLE - B147
Eucalyptus occidentalis

CCI Sample Number		M07937
Mass Received	(g)	6362.0
Free Moisture	(%ar)	6.1

Analysis Basis		(ar)	(ad)	(db)	(daf)
Total Moisture	(%)	9.7			
Proximate Analysis					
Air Dried Moisture	(%)		7.7		
Ash *(@ 815 °C)*	(%)	2.2	2.2	2.4	
Volatile Matter	(%)	70.6	72.2	78.2	80.1
Fixed Carbon	(%)	17.5	17.9	19.4	19.9
Gross Calorific Value	(MJ/kg)	17.45	17.84	19.33	19.80
	(kcal/kg)	4168	4262	4616	4730
Ultimate Analysis					
Carbon	(%)	44.6	45.6	49.4	50.6
Hydrogen	(%)	5.25	5.37	5.82	5.96
Nitrogen	(%)	0.46	0.47	0.51	0.52
Total Sulfur	(%)	0.06	0.06	0.07	
Oxygen *(by difference)*	(%)	37.7	38.6	41.8	

Ash Fusion Temperatures		(Oxidising Atm)
Deformation	(°C)	+1560
Sphere	(°C)	+1560
Hemisphere	(°C)	+1560
Flow	(°C)	+1560

(ar) = "as received" basis, (ad) = "air dried" basis, (db) = "dry basis", (daf) = "dry, ash free" basis

Analysed at CCI Newcastle in accordance with Australian Standard Methods
AS1038.1, AS1038.3, AS1038.5, AS1038.6.3.3, AS1038.7 (draft) and AS1038.15.

Reported By: J. England Provisional **Date:** *September 22, 2003*

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN :	CSIRO Energy Technology	**CCI REF. NO. :**	N3392
DESCRIPTION :	Supplied Biomass Sample for Analysis	**DATE REC'D :**	14/08/2003
REPORTED TO :	Mr Owen Farrell		

BIOMASS SAMPLE - B135
Eucalyptus rudis

CCI Sample Number		M07925
Mass Received	(g)	8070.0
Free Moisture	(%ar)	3.9

Analysis Basis		(ar)	(ad)	(db)	(daf)
Total Moisture	(%)	10.1			
Proximate Analysis					
Air Dried Moisture	(%)		7.4		
Ash *(@ 815 °C)*	(%)	2.4	2.5	2.7	
Volatile Matter	(%)	72.2	74.4	80.3	82.6
Fixed Carbon	(%)	15.3	15.7	17.0	17.4
Gross Calorific Value	(MJ/kg)	17.42	17.94	19.37	19.91
	(kcal/kg)	4160	4284	4626	4756
Ultimate Analysis					
Carbon	(%)	44.0	45.3	48.9	50.3
Hydrogen	(%)	5.37	5.53	5.97	6.14
Nitrogen	(%)	0.59	0.61	0.66	0.68
Total Sulfur	(%)	0.07	0.07	0.08	
Oxygen *(by difference)*	(%)	37.5	38.6	41.7	

Ash Fusion Temperatures		(Oxidising Atm)
Deformation	(°C)	1485
Sphere	(°C)	1490
Hemisphere	(°C)	1495
Flow	(°C)	1500

(ar) = "as received" basis, (ad) = "air dried" basis, (db) = "dry basis", (daf) = "dry, ash free" basis

Analysed at CCI Newcastle in accordance with Australian Standard Methods
AS1038.1, AS1038.3, AS1038.5, AS1038.6.3.3, AS1038.7 (draft) and AS1038.15.

Reported By: J. England Provisional **Date:** *September 22, 2003*

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN : CSIRO Energy Technology **CCI REF. NO. :** N3392
DESCRIPTION : Supplied Biomass Sample for Analysis **DATE REC'D :** 14/08/2003
REPORTED TO : Mr Owen Farrell

BIOMASS SAMPLE - B137
Grevillea candelabroides

CCI Sample Number		M07927
Mass Received	(g)	8302.0
Free Moisture	(%ar)	7.7

Analysis Basis		(ar)	(ad)	(db)	(daf)
Total Moisture	(%)	10.5			
Proximate Analysis					
Air Dried Moisture	(%)		7.2		
Ash *(@ 815 °C)*	(%)	2.9	3.0	3.2	
Volatile Matter	(%)	70.6	73.2	78.9	81.5
Fixed Carbon	(%)	16.0	16.6	17.9	18.5
Gross Calorific Value	(MJ/kg)	17.02	17.65	19.02	19.65
	(kcal/kg)	4066	4216	4542	4694
Ultimate Analysis					
Carbon	(%)	43.1	44.7	48.2	49.8
Hydrogen	(%)	5.27	5.46	5.88	6.08
Nitrogen	(%)	0.37	0.38	0.41	0.42
Total Sulfur	(%)	0.17	0.18	0.19	
Oxygen *(by difference)*	(%)	37.7	39.1	42.1	

Ash Fusion Temperatures		(Oxidising Atm)
Deformation	(°C)	1425
Sphere	(°C)	1430
Hemisphere	(°C)	1435
Flow	(°C)	1440

(ar) = "as received" basis, (ad) = "air dried" basis, (db) = "dry basis", (daf) = "dry, ash free" basis

Analysed at CCI Newcastle in accordance with Australian Standard Methods
AS1038.1, AS1038.3, AS1038.5, AS1038.6.3.3, AS1038.7 (draft) and AS1038.15.

Reported By: J. England Provisional **Date:** *September 22, 2003*

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN :	CSIRO Energy Technology	**CCI REF. NO. :**	N3392
DESCRIPTION :	Supplied Biomass Sample for Analysis	**DATE REC'D :**	14/08/2003
REPORTED TO :	Mr Owen Farrell		

BIOMASS SAMPLE - B130
Grevillea leucopteris

CCI Sample Number		M07920
Mass Received	(g)	8191.0
Free Moisture	(%ar)	5.0

Analysis Basis		(ar)	(ad)	(db)	(daf)
Total Moisture	(%)	8.9			
Proximate Analysis					
Air Dried Moisture	(%)		6.8		
Ash *(@ 815 °C)*	(%)	2.7	2.8	3.0	
Volatile Matter	(%)	71.0	72.6	77.9	80.3
Fixed Carbon	(%)	17.4	17.8	19.1	19.7
Gross Calorific Value	(MJ/kg)	17.26	17.66	18.95	19.54
	(kcal/kg)	4122	4218	4526	4668
Ultimate Analysis					
Carbon	(%)	44.4	45.4	48.7	50.2
Hydrogen	(%)	5.32	5.44	5.84	6.02
Nitrogen	(%)	0.30	0.31	0.33	0.34
Total Sulfur	(%)	0.10	0.10	0.11	
Oxygen *(by difference)*	(%)	38.3	39.2	42.0	

Ash Fusion Temperatures		(Oxidising Atm)
Deformation	(°C)	1480
Sphere	(°C)	1485
Hemisphere	(°C)	1490
Flow	(°C)	1500

(ar) = "as received" basis, (ad) = "air dried" basis, (db) = "dry basis", (daf) = "dry, ash free" basis

Analysed at CCI Newcastle in accordance with Australian Standard Methods
AS1038.1, AS1038.3, AS1038.5, AS1038.6.3.3, AS1038.7 (draft) and AS1038.15.

Reported By: J. England Provisional **Date:** *September 22, 2003*

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN : CSIRO Energy Technology **CCI REF. NO. :** N3392

DESCRIPTION : Supplied Biomass Sample for Analysis **DATE REC'D :** 14/08/2003

REPORTED TO : Mr Owen Farrell

BIOMASS SAMPLE - B131

Gyrostemon ramulosus

CCI Sample Number		M07921
Mass Received	(g)	7683.0
Free Moisture	(%ar)	2.9

Analysis Basis		(ar)	(ad)	(db)	(daf)
Total Moisture	(%)	7.8			
Proximate Analysis					
Air Dried Moisture	(%)		6.2		
Ash *(@ 815 °C)*	(%)	4.4	4.5	4.8	
Volatile Matter	(%)	70.2	71.4	76.1	80.0
Fixed Carbon	(%)	17.6	17.9	19.1	20.0
Gross Calorific Value	(MJ/kg)	17.56	17.86	19.04	20.00
	(kcal/kg)	4194	4266	4548	4776
Ultimate Analysis					
Carbon	(%)	44.4	45.2	48.2	50.6
Hydrogen	(%)	5.47	5.57	5.94	6.24
Nitrogen	(%)	1.58	1.61	1.72	1.80
Total Sulfur	(%)	0.78	0.79	0.84	
Oxygen *(by difference)*	(%)	35.6	36.1	38.5	

Ash Fusion Temperatures		(Oxidising Atm)
Deformation	(°C)	1520
Sphere	(°C)	1530
Hemisphere	(°C)	1550
Flow	(°C)	1560

(ar) = "as received" basis, (ad) = "air dried" basis, (db) = "dry basis", (daf) = "dry, ash free" basis

Analysed at CCI Newcastle in accordance with Australian Standard Methods
AS1038.1, AS1038.3, AS1038.5, AS1038.6.3.3, AS1038.7 (draft) and AS1038.15.

Reported By: J. England Provisional **Date:** *September 22, 2003*

AUSTRALIA

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN :	CSIRO Energy Technology	**CCI REF. NO. :**	N3392
DESCRIPTION :	Supplied Biomass Sample for Analysis	**DATE REC'D :**	14/08/2003
REPORTED TO :	Mr Owen Farrell		

BIOMASS SAMPLE - B141
Hakea oleifolia

CCI Sample Number		M07931
Mass Received	(g)	7819.0
Free Moisture	(%ar)	2.7

Analysis Basis		(ar)	(ad)	(db)	(daf)
Total Moisture	(%)	6.7			
Proximate Analysis					
Air Dried Moisture	(%)		7.6		
Ash *(@ 815 °C)*	(%)	3.2	3.2	3.5	
Volatile Matter	(%)	70.8	70.1	75.9	78.6
Fixed Carbon	(%)	19.3	19.1	20.6	21.4
Gross Calorific Value	(MJ/kg)	17.68	17.51	18.95	19.63
	(kcal/kg)	4222	4182	4526	4688
Ultimate Analysis					
Carbon	(%)	44.9	44.5	48.2	49.9
Hydrogen	(%)	5.36	5.31	5.75	5.95
Nitrogen	(%)	0.29	0.29	0.31	0.33
Total Sulfur	(%)	0.27	0.27	0.29	
Oxygen *(by difference)*	(%)	39.3	38.8	42.0	

Ash Fusion Temperatures		(Oxidising Atm)
Deformation	(°C)	1525
Sphere	(°C)	1530
Hemisphere	(°C)	1535
Flow	(°C)	1540

(ar) = "as received" basis, (ad) = "air dried" basis, (db) = "dry basis", (daf) = "dry, ash free" basis

Analysed at CCI Newcastle in accordance with Australian Standard Methods
AS1038.1, AS1038.3, AS1038.5, AS1038.6.3.3, AS1038.7 (draft) and AS1038.15.

Reported By: J. England Provisional **Date:** *September 22, 2003*

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN :	CSIRO Energy Technology	**CCI REF. NO. :**	N3392
DESCRIPTION :	Supplied Biomass Sample for Analysis	**DATE REC'D :**	14/08/2003
REPORTED TO :	Mr Owen Farrell		

BIOMASS SAMPLE - B142
Jacksonia sternbergiana

CCI Sample Number		M07932
Mass Received	(g)	6057.0
Free Moisture	(%ar)	2.4

Analysis Basis		(ar)	(ad)	(db)	(daf)
Total Moisture	(%)	9.2			
Proximate Analysis					
Air Dried Moisture	(%)		7.4		
Ash *(@ 815 °C)*	(%)	2.1	2.1	2.3	
Volatile Matter	(%)	68.9	70.3	75.9	77.7
Fixed Carbon	(%)	19.8	20.2	21.8	22.3
Gross Calorific Value	(MJ/kg)	17.75	18.10	19.55	20.00
	(kcal/kg)	4240	4324	4670	4776
Ultimate Analysis					
Carbon	(%)	45.8	46.7	50.4	51.6
Hydrogen	(%)	5.27	5.37	5.80	5.93
Nitrogen	(%)	1.16	1.18	1.27	1.30
Total Sulfur	(%)	0.09	0.09	0.10	
Oxygen *(by difference)*	(%)	36.4	37.2	40.1	

Ash Fusion Temperatures		(Oxidising Atm)
Deformation	(°C)	1530
Sphere	(°C)	1535
Hemisphere	(°C)	1540
Flow	(°C)	1550

(ar) = "as received" basis, (ad) = "air dried" basis, (db) = "dry basis", (daf) = "dry, ash free" basis

Analysed at CCI Newcastle in accordance with Australian Standard Methods
AS1038.1, AS1038.3, AS1038.5, AS1038.6.3.3, AS1038.7 (draft) and AS1038.15.

Reported By: J. England Provisional **Date:** *September 22, 2003*

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN : CSIRO Energy Technology **CCI REF. NO. :** N3392
DESCRIPTION : Supplied Biomass Sample for Analysis **DATE REC'D :** 14/08/2003
REPORTED TO : Mr Owen Farrell

BIOMASS SAMPLE - B149
Melaleuca preissiana

CCI Sample Number		M07939
Mass Received	(g)	8853.0
Free Moisture	(%ar)	1.9

Analysis Basis		(ar)	(ad)	(db)	(daf)
Total Moisture	(%)	8.9			
Proximate Analysis					
Air Dried Moisture	(%)		7.2		
Ash *(@ 815 °C)*	(%)	2.0	2.0	2.2	
Volatile Matter	(%)	73.4	74.8	80.6	82.4
Fixed Carbon	(%)	15.7	16.0	17.2	17.6
Gross Calorific Value	(MJ/kg)	18.98	19.33	20.83	21.29
	(kcal/kg)	4534	4616	4976	5086
Ultimate Analysis					
Carbon	(%)	47.0	47.9	51.6	52.8
Hydrogen	(%)	5.67	5.78	6.23	6.37
Nitrogen	(%)	0.62	0.63	0.68	0.69
Total Sulfur	(%)	0.18	0.18	0.19	
Oxygen *(by difference)*	(%)	35.6	36.3	39.1	

Ash Fusion Temperatures		(Oxidising Atm)
Deformation	(°C)	1400
Sphere	(°C)	1405
Hemisphere	(°C)	1410
Flow	(°C)	+1560

(ar) = "as received" basis, (ad) = "air dried" basis, (db) = "dry basis", (daf) = "dry, ash free" basis

Analysed at CCI Newcastle in accordance with Australian Standard Methods
AS1038.1, AS1038.3, AS1038.5, AS1038.6.3.3, AS1038.7 (draft) and AS1038.15.

Reported By: J. England Provisional **Date:** *September 22, 2003*

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN : CSIRO Energy Technology **CCI REF. NO. :** N3392
DESCRIPTION : Supplied Biomass Sample for Analysis **DATE REC'D :** 14/08/2003
REPORTED TO : Mr Owen Farrell

BIOMASS SAMPLE - B132
Senna pleurocarpa

CCI Sample Number		M07922
Mass Received	(g)	7559.0
Free Moisture	(%ar)	11.4

Analysis Basis		(ar)	(ad)	(db)	(daf)
Total Moisture	(%)	16.9			
Proximate Analysis					
Air Dried Moisture	(%)		6.0		
Ash *(@ 815 °C)*	(%)	2.7	3.1	3.3	
Volatile Matter	(%)	64.5	73.0	77.7	80.3
Fixed Carbon	(%)	15.9	17.9	19.0	19.7
Gross Calorific Value	(MJ/kg)	15.66	17.71	18.84	19.48
	(kcal/kg)	3740	4230	4500	4652
Ultimate Analysis					
Carbon	(%)	40.0	45.3	48.2	49.8
Hydrogen	(%)	4.90	5.54	5.89	6.09
Nitrogen	(%)	0.88	0.99	1.05	1.09
Total Sulfur	(%)	0.07	0.08	0.09	
Oxygen *(by difference)*	(%)	34.6	39.0	41.5	

Ash Fusion Temperatures		(Oxidising Atm)
Deformation	(°C)	1495
Sphere	(°C)	1500
Hemisphere	(°C)	1505
Flow	(°C)	1510

(ar) = "as received" basis, (ad) = "air dried" basis, (db) = "dry basis", (daf) = "dry, ash free" basis

Analysed at CCI Newcastle in accordance with Australian Standard Methods
AS1038.1, AS1038.3, AS1038.5, AS1038.6.3.3, AS1038.7 (draft) and AS1038.15.

Reported By: J. England Provisional **Date:** *September 22, 2003*

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN :	CSIRO Energy Technology	**CCI REF. NO. :**	N3392
DESCRIPTION :	Supplied Biomass Sample for Analysis	**DATE REC'D :**	14/08/2003
REPORTED TO :	Mr Owen Farrell		

BIOMASS SAMPLE - B133
Taxandria juniperina

CCI Sample Number		M07923
Mass Received	(g)	8301.0
Free Moisture	(%ar)	3.1

Analysis Basis		(ar)	(ad)	(db)	(daf)
Total Moisture	(%)	9.1			
Proximate Analysis					
Air Dried Moisture	(%)		6.4		
Ash *(@ 815 °C)*	(%)	1.5	1.5	1.6	
Volatile Matter	(%)	71.7	73.8	78.8	80.1
Fixed Carbon	(%)	17.7	18.3	19.6	19.9
Gross Calorific Value	(MJ/kg)	20.66	21.27	22.72	23.09
	(kcal/kg)	4934	5080	5426	5514
Ultimate Analysis					
Carbon	(%)	46.0	47.4	50.6	51.5
Hydrogen	(%)	5.44	5.60	5.98	6.08
Nitrogen	(%)	0.33	0.34	0.36	0.37
Total Sulfur	(%)	0.08	0.08	0.09	
Oxygen *(by difference)*	(%)	37.6	38.7	41.4	

Ash Fusion Temperatures		(Oxidising Atm)
Deformation	(°C)	1525
Sphere	(°C)	1530
Hemisphere	(°C)	1535
Flow	(°C)	1540

(ar) = "as received" basis, (ad) = "air dried" basis, (db) = "dry basis", (daf) = "dry, ash free" basis

Analysed at CCI Newcastle in accordance with Australian Standard Methods
AS1038.1, AS1038.3, AS1038.5, AS1038.6.3.3, AS1038.7 (draft) and AS1038.15.

Reported By: J. England Provisional **Date:** *September 23, 2003*

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN : CSIRO Energy Technology **CCI REF. NO. :** N3392

DESCRIPTION : Supplied Biomass Sample for Analysis **DATE REC'D :** 14/08/2003

REPORTED TO : Mr Owen Farrell

BIOMASS SAMPLE - B146
Trymalium floribundum

CCI Sample Number		M07936
Mass Received	(g)	6462.0
Free Moisture	(%ar)	4.1

Analysis Basis		(ar)	(ad)	(db)	(daf)
Total Moisture	(%)	10.2			
Proximate Analysis					
Air Dried Moisture	(%)		7.5		
Ash *(@ 815 °C)*	(%)	2.9	3.0	3.2	
Volatile Matter	(%)	69.5	71.6	77.4	80.0
Fixed Carbon	(%)	17.4	17.9	19.4	20.0
Gross Calorific Value	(MJ/kg)	17.10	17.61	19.04	19.68
	(kcal/kg)	4084	4206	4548	4700
Ultimate Analysis					
Carbon	(%)	43.7	45.0	48.6	50.3
Hydrogen	(%)	5.21	5.37	5.81	6.00
Nitrogen	(%)	0.51	0.53	0.57	0.59
Total Sulfur	(%)	0.00	0.00	0.00	
Oxygen *(by difference)*	(%)	37.5	38.6	41.8	

Ash Fusion Temperatures		(Oxidising Atm)
Deformation	(°C)	1470
Sphere	(°C)	1475
Hemisphere	(°C)	1480
Flow	(°C)	1500

(ar) = "as received" basis, (ad) = "air dried" basis, (db) = "dry basis", (daf) = "dry, ash free" basis

Analysed at CCI Newcastle in accordance with Australian Standard Methods
AS1038.1, AS1038.3, AS1038.5, AS1038.6.3.3, AS1038.7 (draft) and AS1038.15.

Reported By: J. England Provisional **Date:** *September 22, 2003*

CCI AUSTRALIA PTY LTD ABN: 64 001 285 927
6 Callistemon Close WARABROOK NSW 2304
Box 281 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA
TEL: (02) 49674477 FAX: (02) 49681534
E-MAIL: cciadmin@ccipl.com.au

ORIGIN : CSIRO Energy Technology **CCI REF. NO. :** N3392

DESCRIPTION : Supplied Biomass Sample for Analysis **DATE REC'D :** 14/08/2003

REPORTED TO : Mr Owen Farrell

BIOMASS SAMPLE - B140

Viminaria juncea

CCI Sample Number		M07930
Mass Received	(g)	6926.0
Free Moisture	(%ar)	3.1

Analysis Basis		(ar)	(ad)	(db)	(daf)
Total Moisture	(%)	8.8			
Proximate Analysis					
Air Dried Moisture	(%)		8.5		
Ash *(@ 815 °C)*	(%)	1.8	1.8	2.0	
Volatile Matter	(%)	66.4	66.6	72.8	74.2
Fixed Carbon	(%)	23.0	23.1	25.2	25.8
Gross Calorific Value	(MJ/kg)	18.00	18.06	19.74	20.13
	(kcal/kg)	4300	4314	4714	4808
Ultimate Analysis					
Carbon	(%)	47.2	47.4	51.8	52.8
Hydrogen	(%)	5.33	5.35	5.85	5.96
Nitrogen	(%)	1.02	1.02	1.11	1.14
Total Sulfur	(%)	0.09	0.09	0.10	
Oxygen *(by difference)*	(%)	35.8	35.8	39.1	

Ash Fusion Temperatures		(Oxidising Atm)
Deformation	(°C)	1505
Sphere	(°C)	1510
Hemisphere	(°C)	1515
Flow	(°C)	1525

(ar) = "as received" basis, (ad) = "air dried" basis, (db) = "dry basis", (daf) = "dry, ash free" basis

Analysed at CCI Newcastle in accordance with Australian Standard Methods
AS1038.1, AS1038.3, AS1038.5, AS1038.6.3.3, AS1038.7 (draft) and AS1038.15.

Reported By: J. England Provisional **Date:** *September 22, 2003*

Appendix 2

Initiation of Fouling Deposits During Biomass / Coal Combustion

Results of Test on Biomass Ash

Species tested

The following pages include test results for the 20 species listed below.

In each case, tests were carried out on samples that were mixed in the proportion of 1/3 wood, 1/3 bark and 1/3 leaf and twig.

Acacia lasiocalyx

Acacia saligna

Agonis flexuosa

Alyogyne huegelii

Anthocercis littorea

Bursaria occidentalis

Codonocarpus cotinifolius

Eucalyptus loxophleba ssp lissophloia

Eucalyptus occidentalis

Eucalyptus rudis

Grevillea candelabroides

Grevillea leucopteris

Gyrostemon ramulosus

Hakea oleifolia

Jacksonia sternbergiana

Melaleuca preissiana

Senna pleurocarpa

Taxandria juniperina

Trymalium floribundum

Viminaria juncea

Acacia lasiocalyx

Ash B138

Principle

Biomass / coal is slowly burnt at temperatures up to 800°C with convective air passing over the sample. A mild steel plate is positioned close to the burning fuel so that corrosion can occur on both surfaces at 800°C. A polished stainless steel stub, suitable for scanning electron microscopy (SEM), is positioned up side down in the outlet air, where the temperature is 400°C. Volatile components from the fuel and vapours formed during combustion are able to foul / corrode the mild steel and the stainless steel at 800°C and 400°C respectively. In a simple way, this test simulates the initiation of fouling or corrosion on variable surfaces at different temperatures in a conventional boiler.

The thinning of the mild steel plate and the thickness of corrosion deposits can be related to the fuel being burnt (see Figure). Fouling deposits on the stainless steel stub are examined by SEM. Energy dispersive X-ray (EDX) spectroscopy enables elements from the fuel contributing to the deposits to be identified (see Figure).

Analytical results

Sample combusted (as received basis)	**200g**
Ash (dry basis)	**1.90%**
Estimate of fouling deposit (at 400°C)	**minor**
Estimate of corrosion of steel (at 800°C)	**minor**

Summary

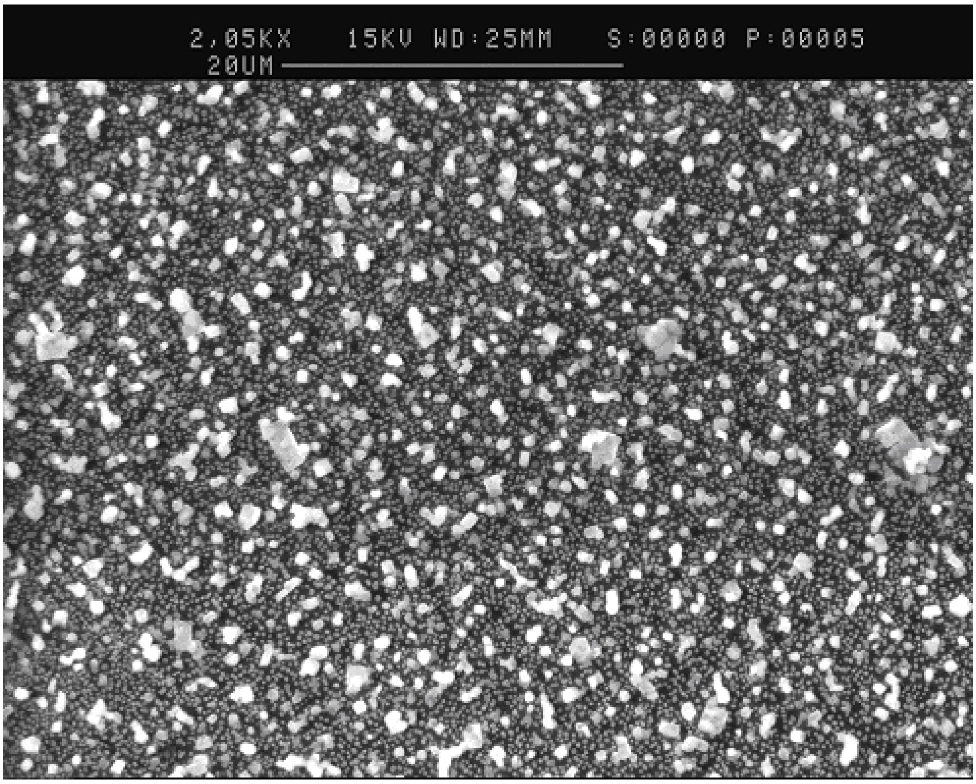
Combustion of ***Acacia lasiocalyx*** causes a **minor** increase in corrosion of mild steel at 800°C above that caused by air alone.

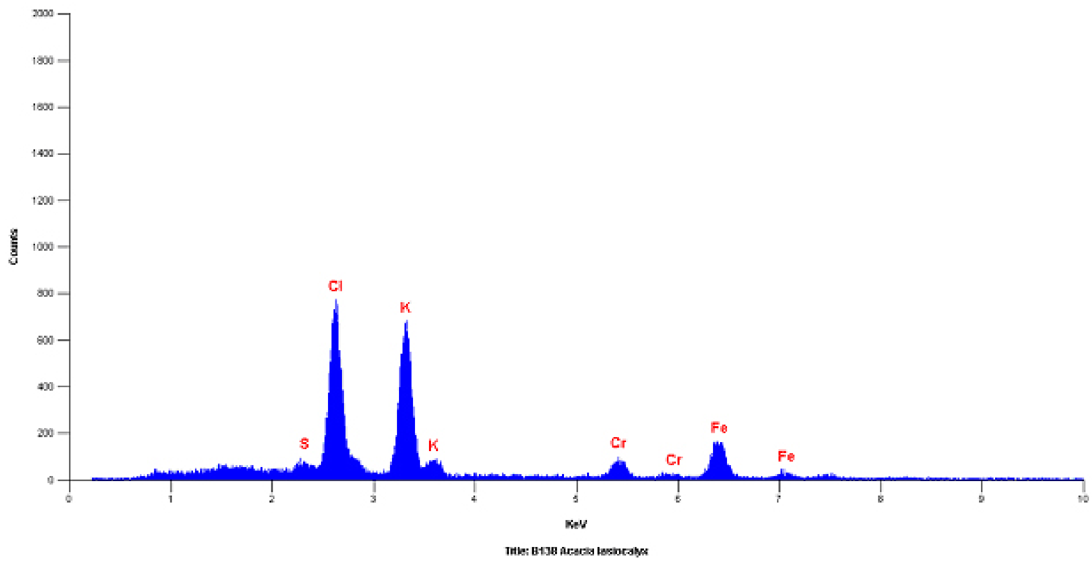
Acacia lasiocalyx ash produces a **minor** amount of fouling deposit by condensation at 400°C on a steel surface.

The dominant elements in the deposit are **potassium and chlorine**.

Negligible corrosion of the stainless steel at 400°C could be detected.

Acacia lasiocalyx B138– Stub deposit

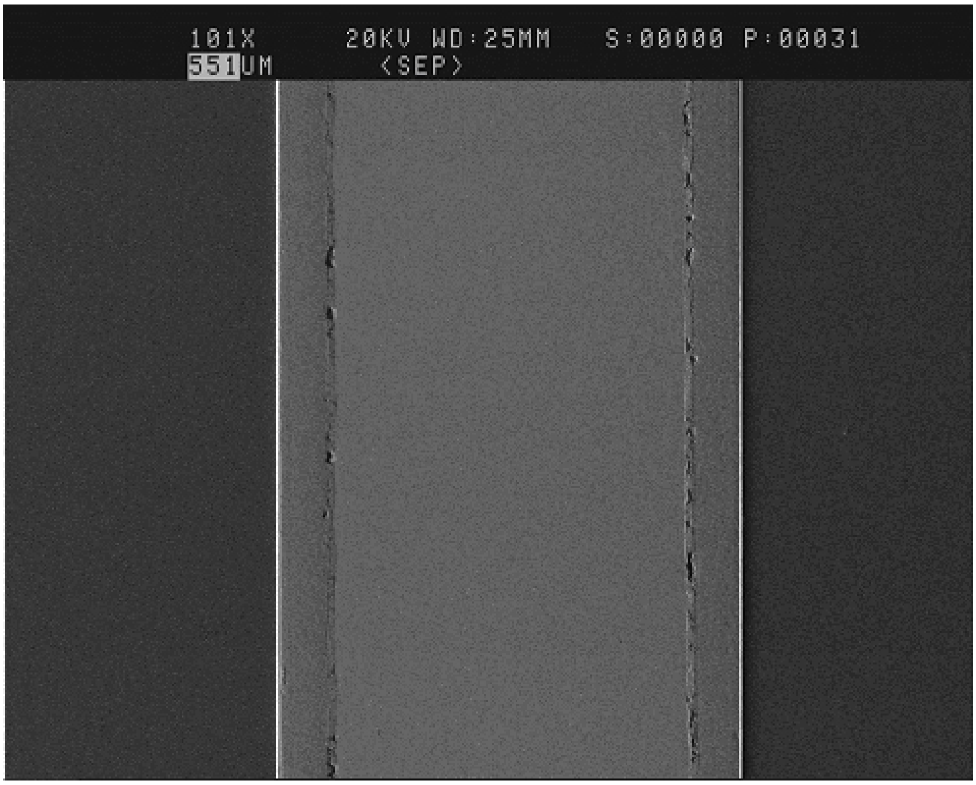


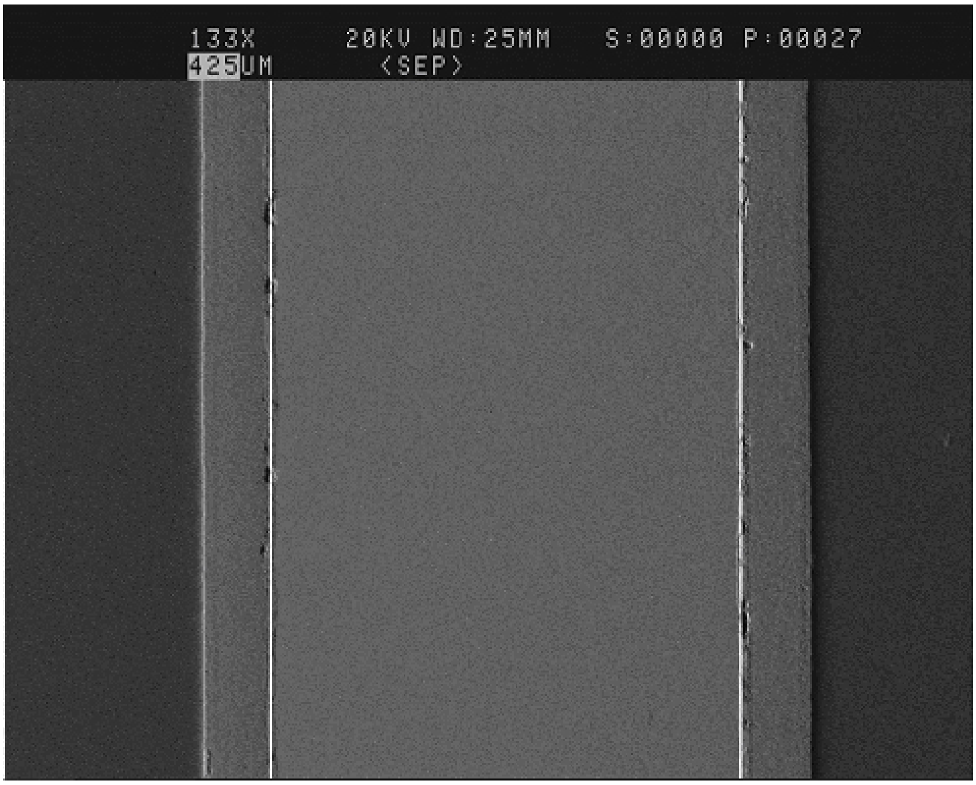


Elemental analysis of a typical particle of *Acacia lasiocalyx.*

Acacia lasiocalyx B138

Mild steel plate @ 800°C
(Please note measuring cursors)





Acacia saligna

Ash B154

Principle

Biomass / coal is slowly burnt at temperatures up to 800°C with convective air passing over the sample. A mild steel plate is positioned close to the burning fuel so that corrosion can occur on both surfaces at 800°C. A polished stainless steel stub, suitable for scanning electron microscopy (SEM), is positioned up side down in the outlet air, where the temperature is 400°C. Volatile components from the fuel and vapours formed during combustion are able to foul / corrode the mild steel and the stainless steel at 800°C and 400°C respectively. In a simple way, this test simulates the initiation of fouling or corrosion on variable surfaces at different temperatures in a conventional boiler.

The thinning of the mild steel plate and the thickness of corrosion deposits can be related to the fuel being burnt (see Figure). Fouling deposits on the stainless steel stub are examined by SEM. Energy dispersive X-ray (EDX) spectroscopy enables elements from the fuel contributing to the deposits to be identified (see Figure).

Analytical Results

Sample combusted (as received basis)	**150g**
Ash (dry basis)	**2.40%**
Estimate of fouling Deposit (at 400°C)	**minor**
Estimate of corrosion of steel (at 800°C)	**minor**

Summary

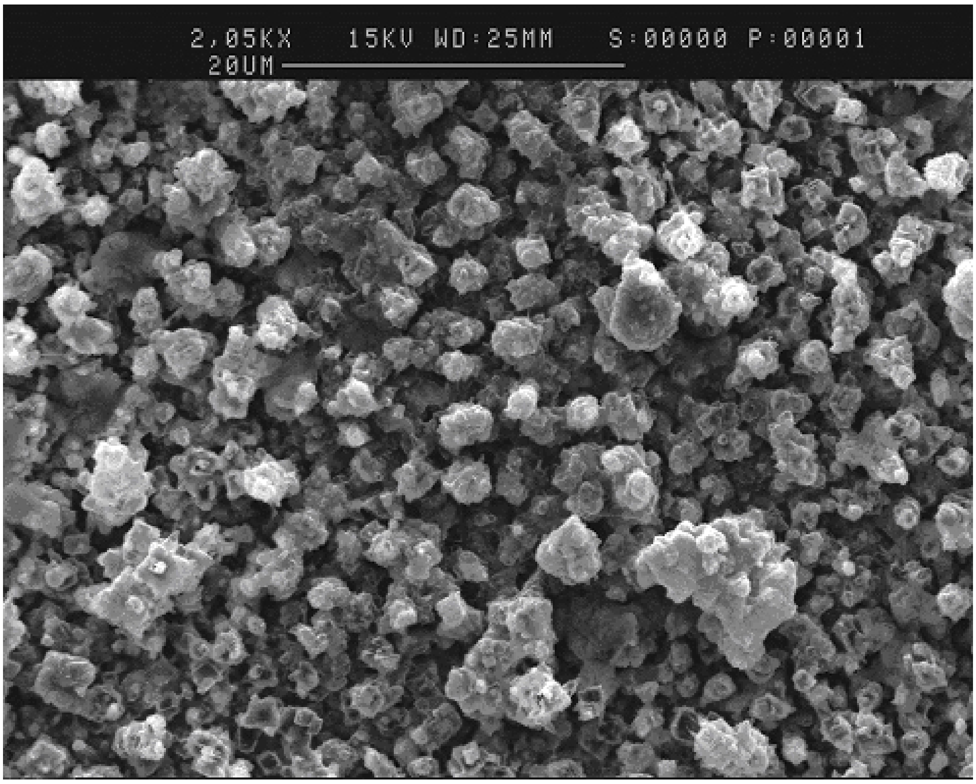
Combustion of ***Acacia saligna*** causes a **minor** increase in corrosion of mild steel at 800°C above that caused by air alone.

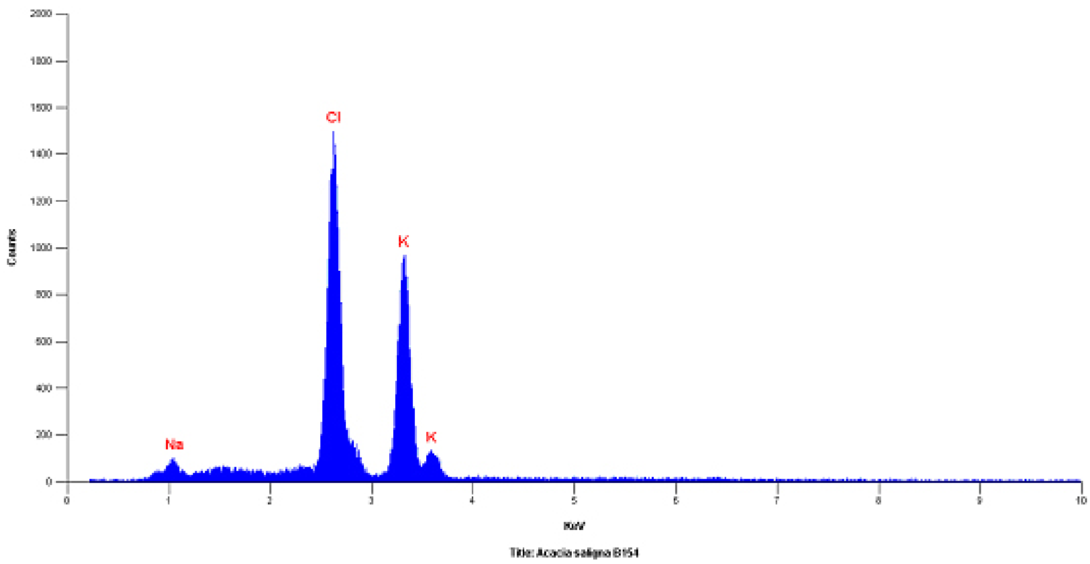
Acacia saligna ash produces a **minor** amount of fouling deposit by condensation at 400°C on a steel surface.

The dominant elements in the deposit are **potassium and chlorine**.

Minor corrosion of the stainless steel at 400°C could be detected.

Acacia saligna B154– Stub deposit

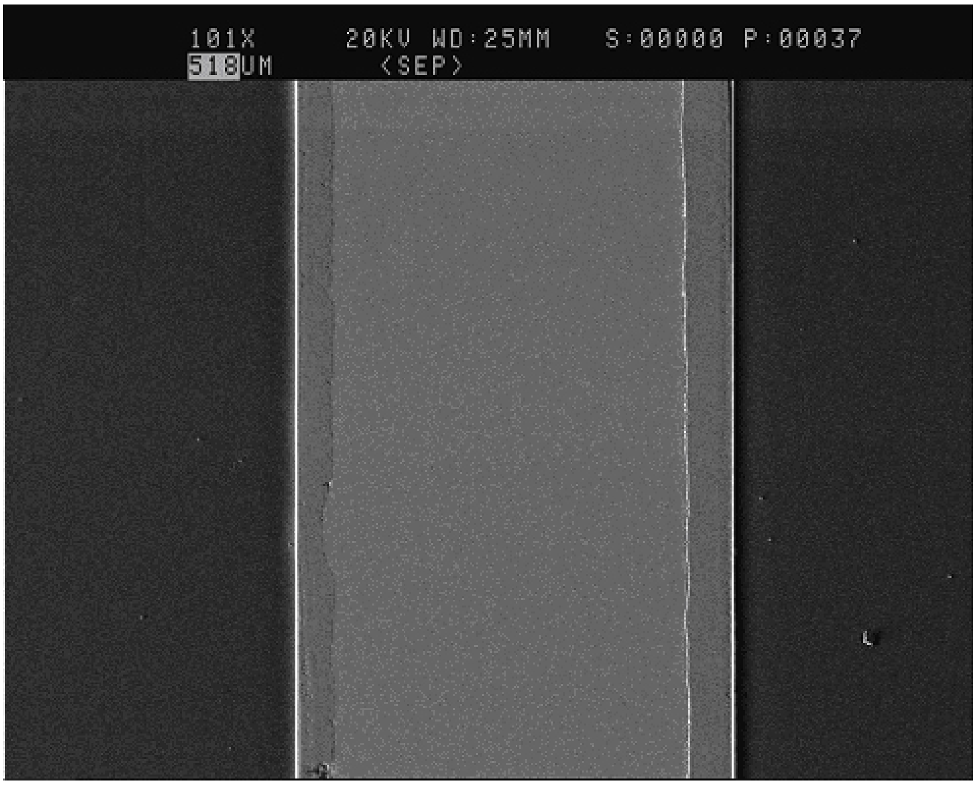


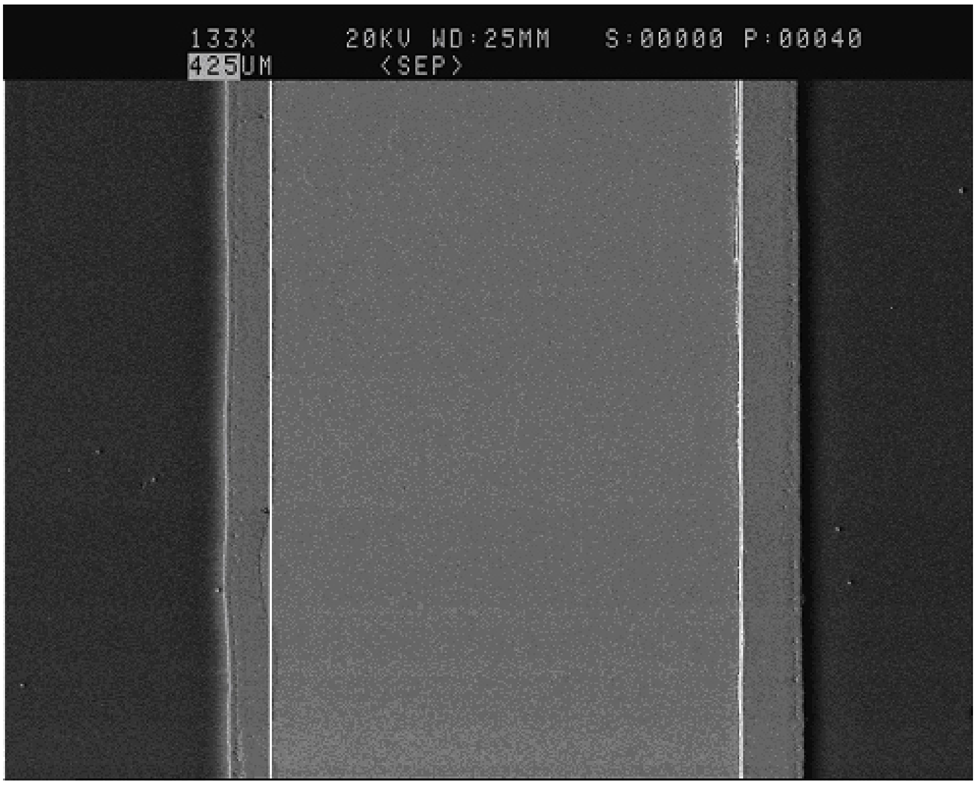


Elemental analysis of a typical particle of *Acacia saligna*.

Acacia saligna B154

Mild steel plate @ 800°C
(Please note measuring cursors)





Agonis flexuosa

Ash B144

Principle

Biomass / coal is slowly burnt at temperatures up to 800°C with convective air passing over the sample. A mild steel plate is positioned close to the burning fuel so that corrosion can occur on both surfaces at 800°C. A polished stainless steel stub, suitable for scanning electron microscopy (SEM), is positioned up side down in the outlet air, where the temperature is 400°C. Volatile components from the fuel and vapours formed during combustion are able to foul / corrode the mild steel and the stainless steel at 800°C and 400°C respectively. In a simple way, this test simulates the initiation of fouling or corrosion on variable surfaces at different temperatures in a conventional boiler.

The thinning of the mild steel plate and the thickness of corrosion deposits can be related to the fuel being burnt (see Figure). Fouling deposits on the stainless steel stub are examined by SEM. Energy dispersive X-ray (EDX) spectroscopy enables elements from the fuel contributing to the deposits to be identified (see Figure).

Analytical Results

Sample combusted (as received basis)	**200g**
Ash (dry basis)	**3.20%**
Estimate of fouling Deposit (at 400°C)	**minor**
Estimate of corrosion of steel (at 800°C)	**minor**

Summary

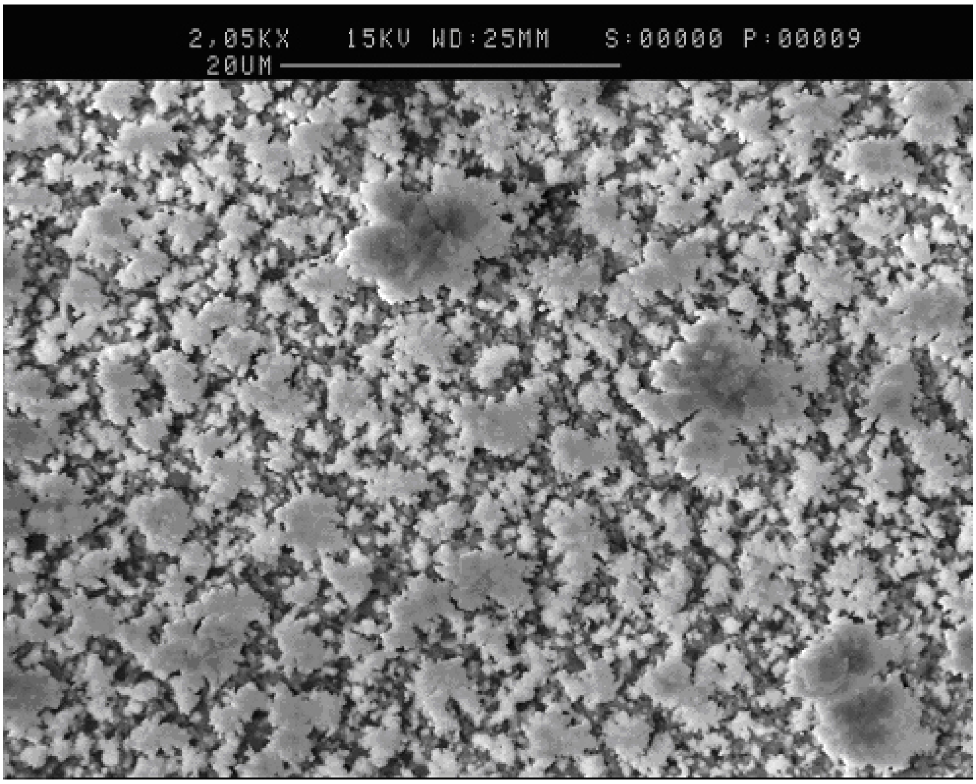
Combustion of *Agonis flexuosa* causes a **minor** increase in corrosion of mild steel at 800°C above that caused by air alone.

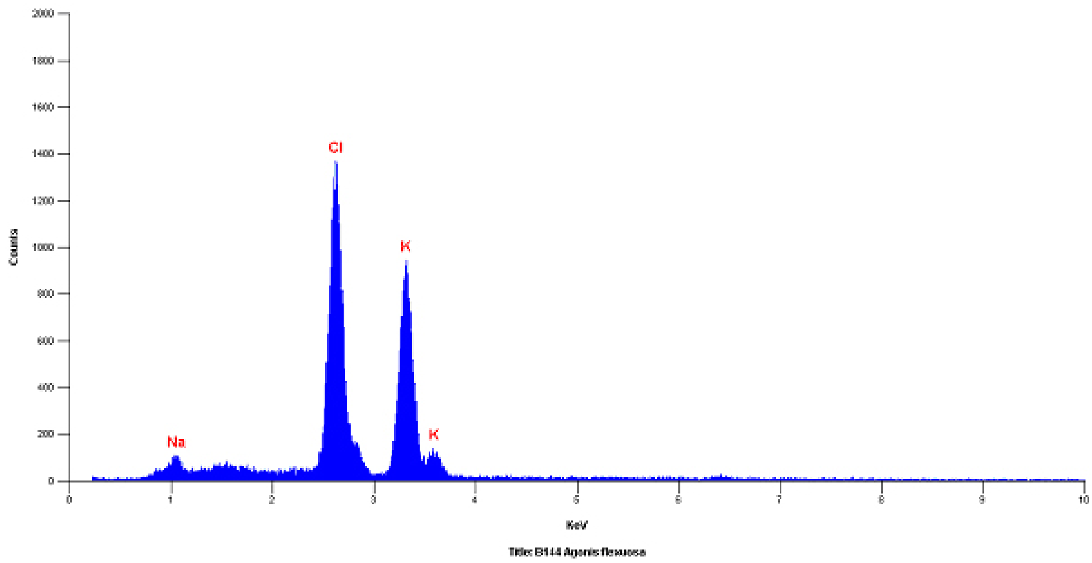
Agonis flexuosa ash produces a **minor** amount of fouling deposit by condensation at 400°C on a steel surface.

The dominant elements in the deposit are **potassium and chlorine**.

Negligible corrosion of the stainless steel at 400°C could be detected.

Agonis flexuosa B144– Stub deposit

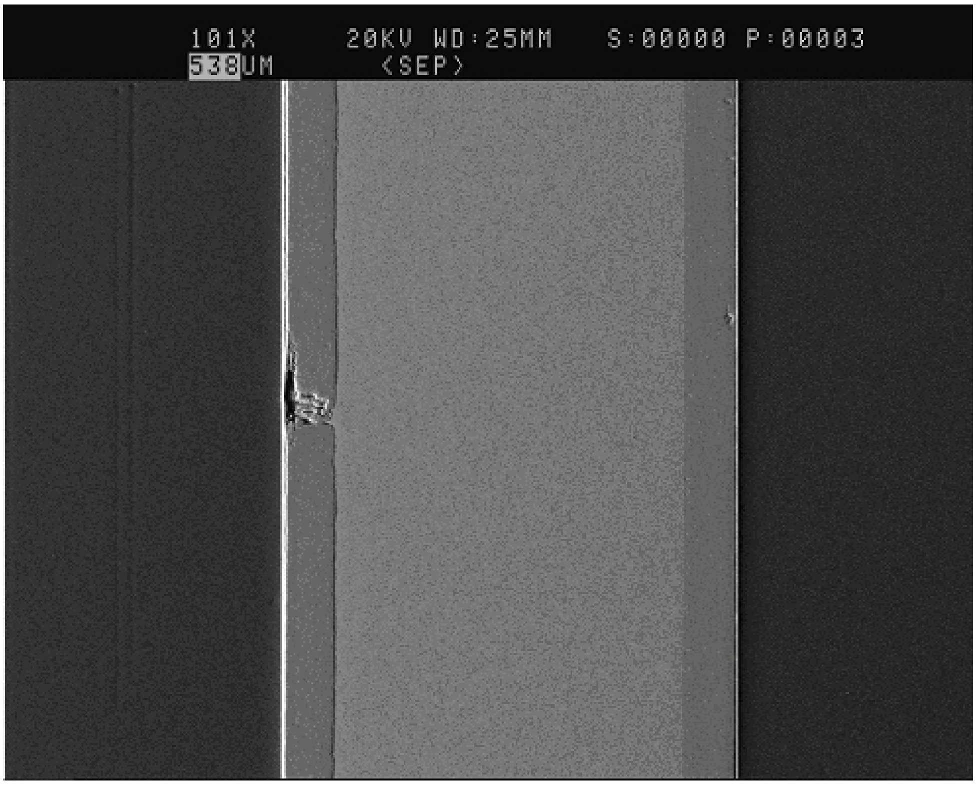


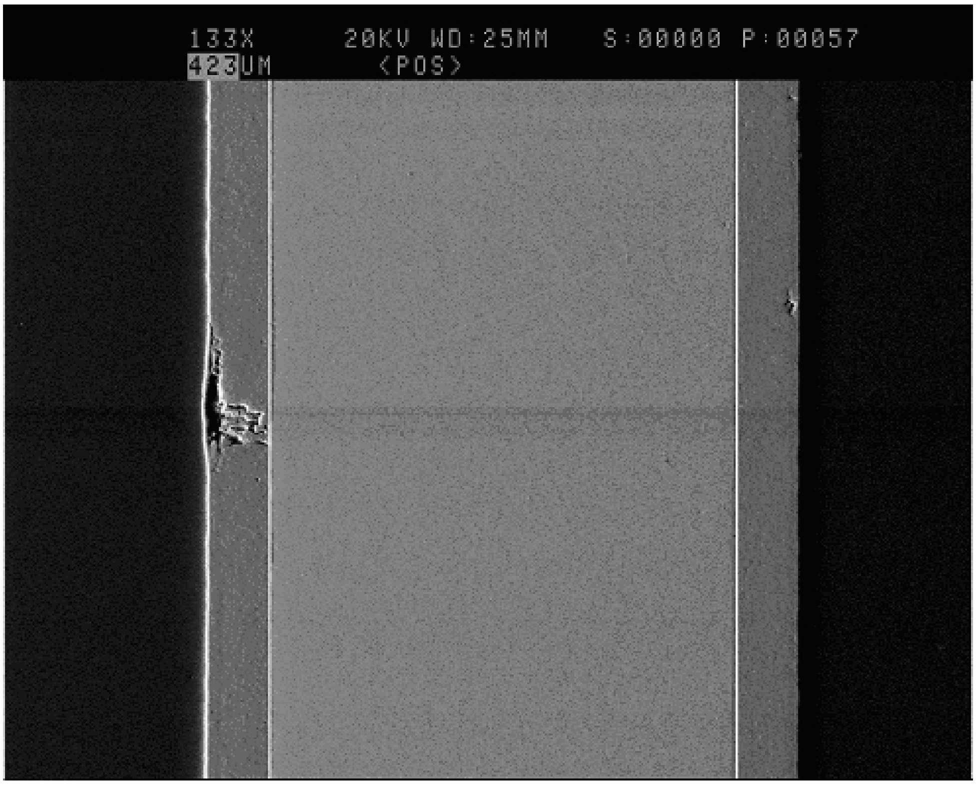


Elemental analysis of a typical particle of *Agonis flexuosa*.

Agonis flexuosa B144

Mild steel plate @ 800°C
(Please note measuring cursors)





Alyogyne huegelii

Ash B129

Principle

Biomass / coal is slowly burnt at temperatures up to 800°C with convective air passing over the sample. A mild steel plate is positioned close to the burning fuel so that corrosion can occur on both surfaces at 800°C. A polished stainless steel stub, suitable for scanning electron microscopy (SEM), is positioned up side down in the outlet air, where the temperature is 400°C. Volatile components from the fuel and vapours formed during combustion are able to foul / corrode the mild steel and the stainless steel at 800°C and 400°C respectively. In a simple way, this test simulates the initiation of fouling or corrosion on variable surfaces at different temperatures in a conventional boiler.

The thinning of the mild steel plate and the thickness of corrosion deposits can be related to the fuel being burnt (see Figure). Fouling deposits on the stainless steel stub are examined by SEM. Energy dispersive X-ray (EDX) spectroscopy enables elements from the fuel contributing to the deposits to be identified (see Figure).

Analytical Results

Sample combusted (as received basis)	**200g**
Ash (dry basis)	**3.95%**
Estimate of fouling Deposit (at 400°C)	**minor**
Estimate of corrosion of steel (at 800°C)	**moderate**

Summary

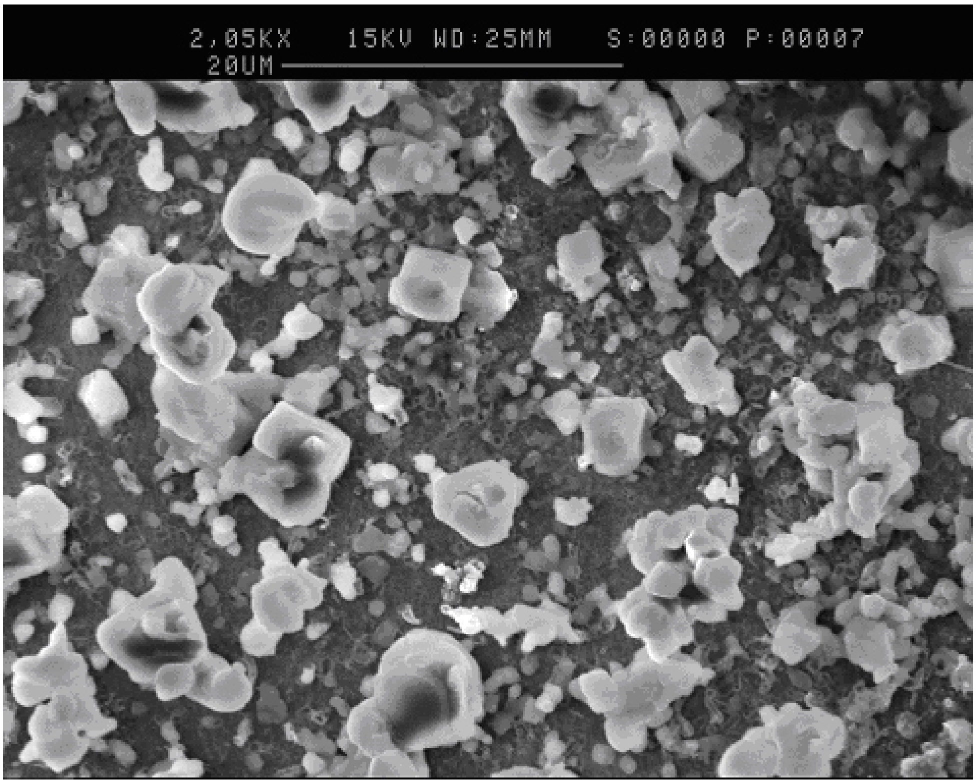
Combustion of ***Alyogyne huegelii*** causes a **moderate** increase in corrosion of mild steel at 800°C above that caused by air alone.

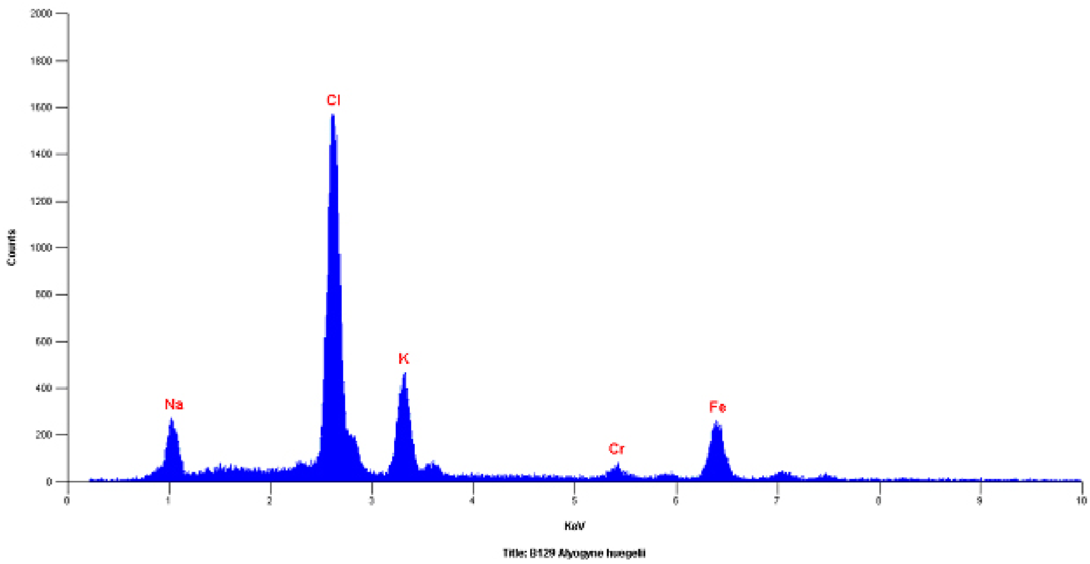
Alyogyne huegelii ash produces a **minor** amount of fouling deposit by condensation at 400°C on a steel surface.

The dominant elements in the deposit are **potassium, sodium and chlorine**.

Negligible corrosion of the stainless steel at 400°C could be detected.

Alyogyne huegelii B129– Stub deposit

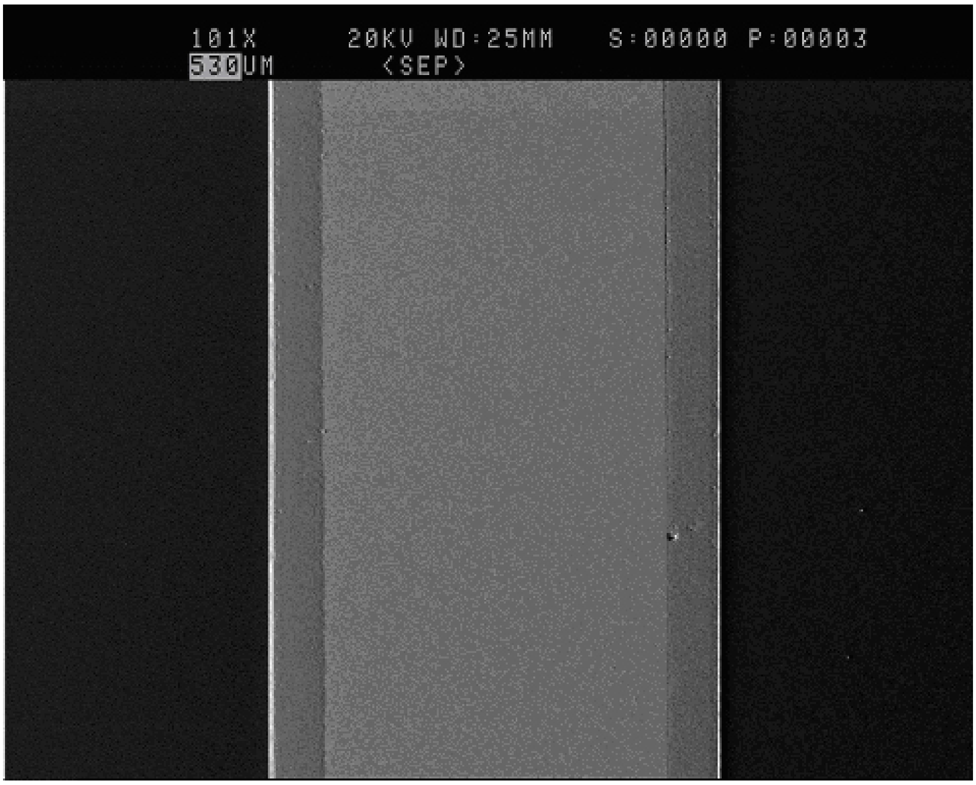


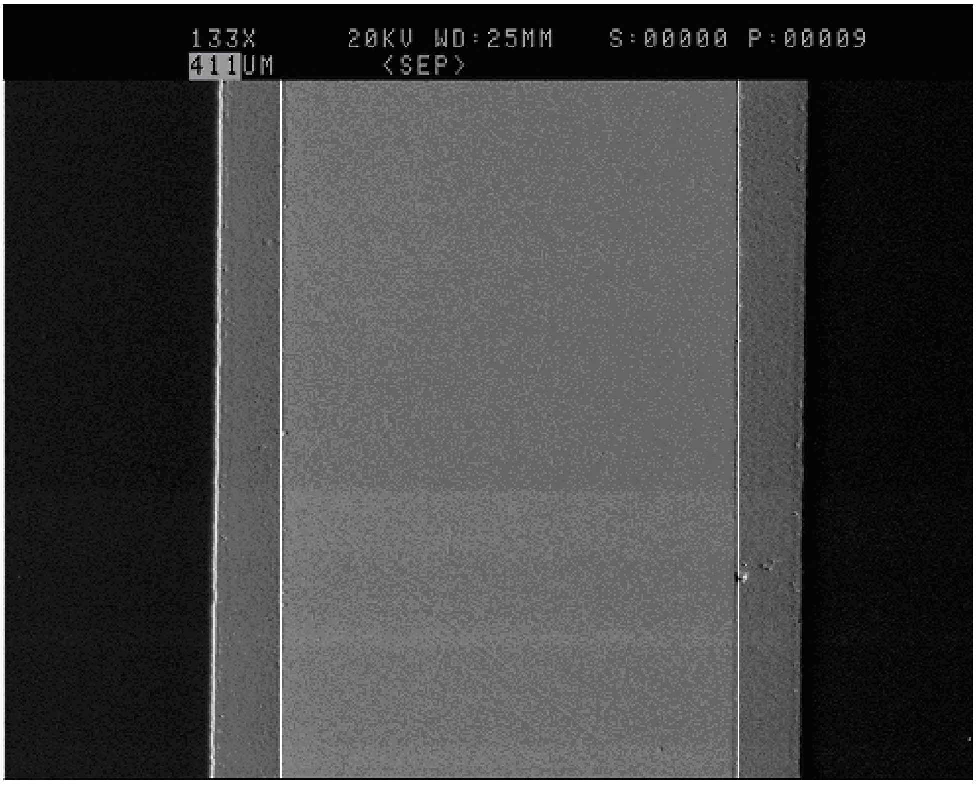


Elemental analysis of a typical particle of *Alyogyne huegelii*.

Alyogyne huegelii B129

Mild steel plate @ 800°C
(Please note measuring cursors)





Anthocercis littorea

Ash B139

Principle

Biomass / coal is slowly burnt at temperatures up to 800°C with convective air passing over the sample. A mild steel plate is positioned close to the burning fuel so that corrosion can occur on both surfaces at 800°C. A polished stainless steel stub, suitable for scanning electron microscopy (SEM), is positioned up side down in the outlet air, where the temperature is 400°C. Volatile components from the fuel and vapours formed during combustion are able to foul / corrode the mild steel and the stainless steel at 800°C and 400°C respectively. In a simple way, this test simulates the initiation of fouling or corrosion on variable surfaces at different temperatures in a conventional boiler.

The thinning of the mild steel plate and the thickness of corrosion deposits can be related to the fuel being burnt (see Figure). Fouling deposits on the stainless steel stub are examined by SEM. Energy dispersive X-ray (EDX) spectroscopy enables elements from the fuel contributing to the deposits to be identified (see Figure).

Analytical Results

Sample combusted (as received basis)	**200g**
Ash (dry basis)	**4.15%**
Estimate of fouling Deposit (at 400°C)	**moderate**
Estimate of corrosion of steel (at 800°C)	**minor**

Summary

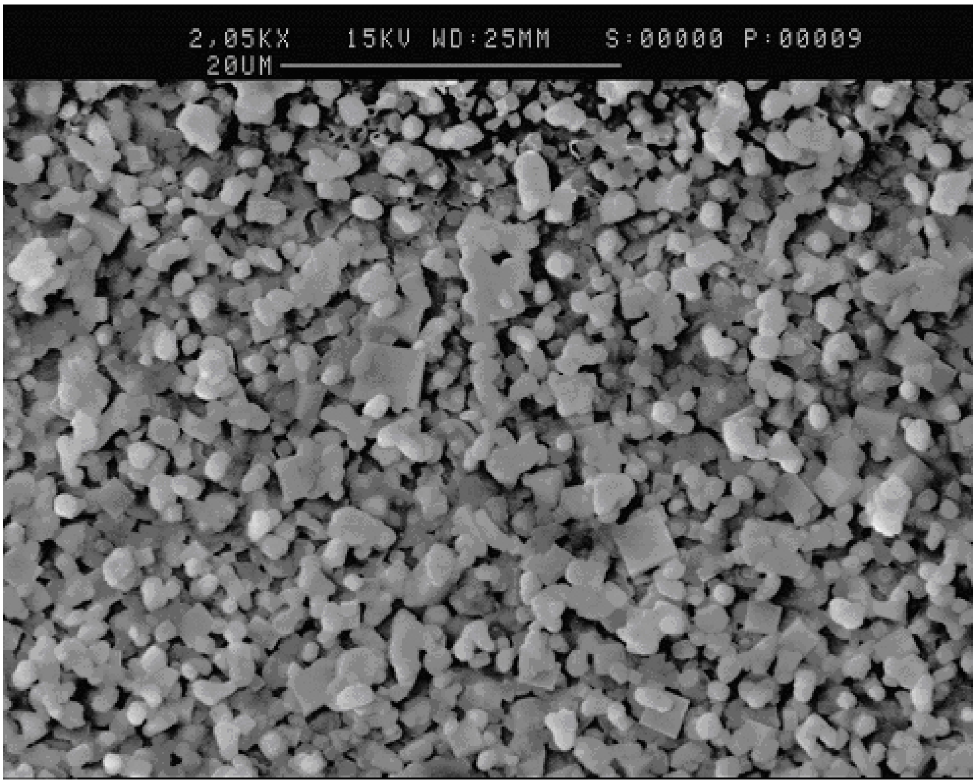
Combustion of ***Anthocercis littorea*** causes a **minor** increase in corrosion of mild steel at 800°C above that caused by air alone.

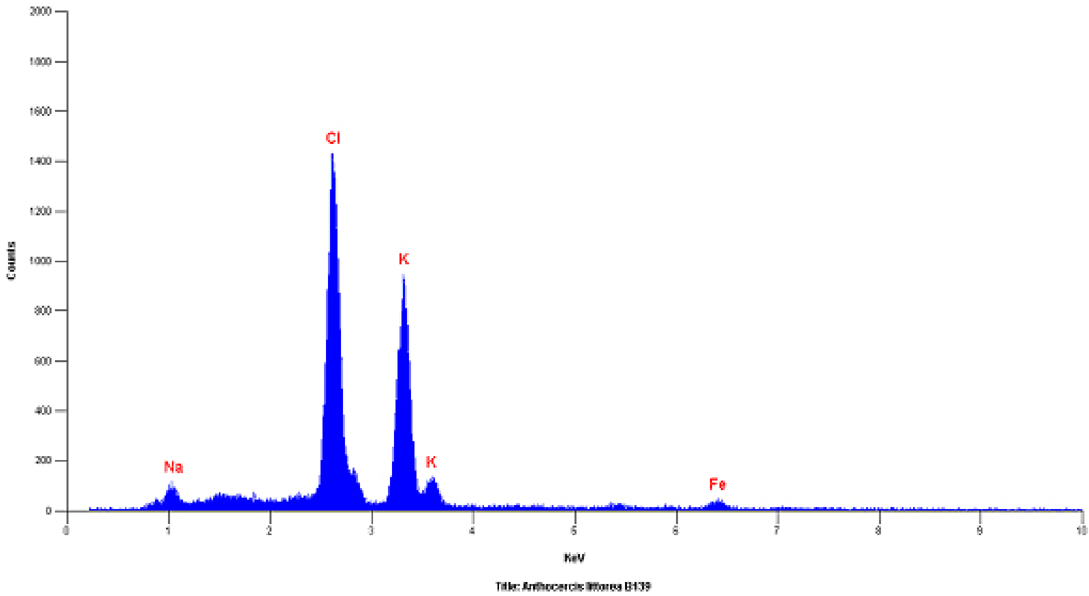
Anthocercis littorea ash produces a **moderate** amount of fouling deposit by condensation at 400°C on a steel surface.

The dominant elements in the deposit are **potassium, chlorine and sodium**.

Minor corrosion of the stainless steel at 400°C could be detected.

Anthocercis littorea B139– Stub deposit

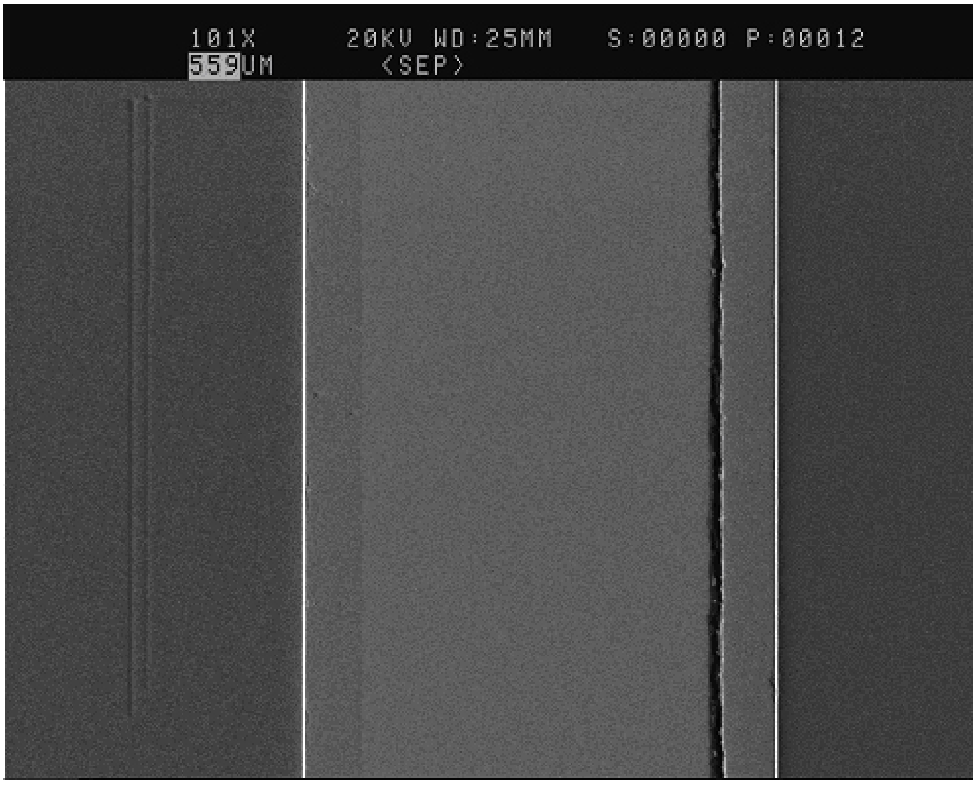


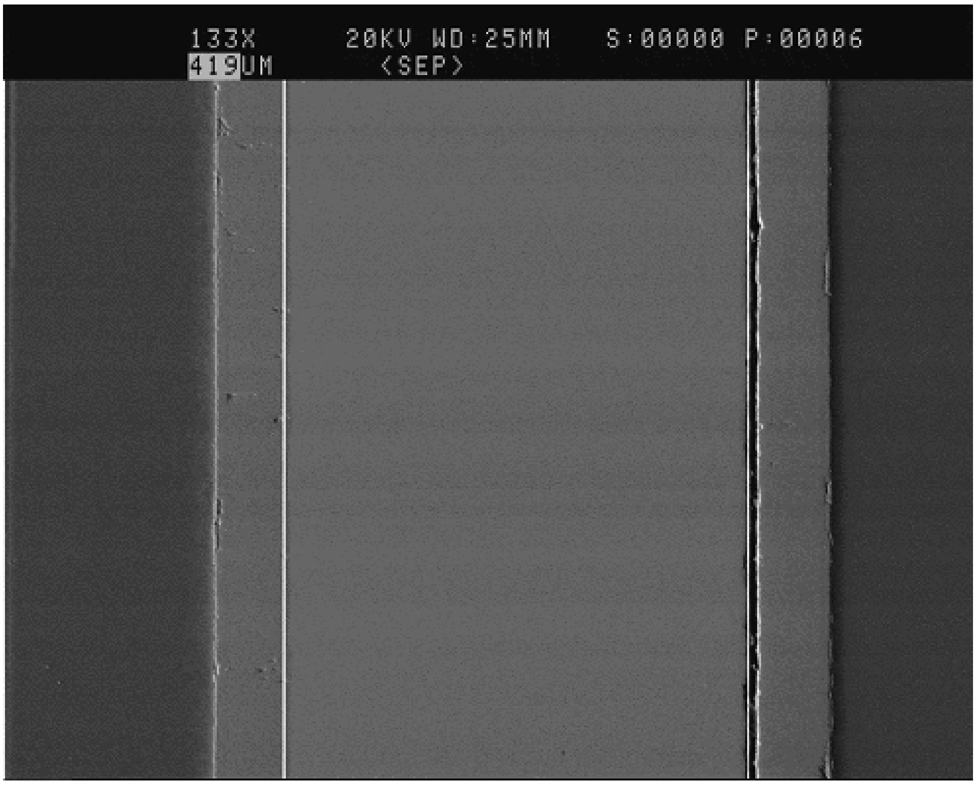


Elemental analysis of a typical particle of Anthocercis littorea.

Anthocercis littorea B139

Mild steel plate @ 800°C
(Please note measuring cursors)





Bursaria occidentalis

Ash B145

Principle

Biomass / coal is slowly burnt at temperatures up to 800°C with convective air passing over the sample. A mild steel plate is positioned close to the burning fuel so that corrosion can occur on both surfaces at 800°C. A polished stainless steel stub, suitable for scanning electron microscopy (SEM), is positioned up side down in the outlet air, where the temperature is 400°C. Volatile components from the fuel and vapours formed during combustion are able to foul / corrode the mild steel and the stainless steel at 800°C and 400°C respectively. In a simple way, this test simulates the initiation of fouling or corrosion on variable surfaces at different temperatures in a conventional boiler.

The thinning of the mild steel plate and the thickness of corrosion deposits can be related to the fuel being burnt (see Figure). Fouling deposits on the stainless steel stub are examined by SEM. Energy dispersive X-ray (EDX) spectroscopy enables elements from the fuel contributing to the deposits to be identified (see Figure).

Analytical Results

Sample combusted (as received basis)	**200g**
Ash (dry basis)	**2.70%**
Estimate of fouling Deposit (at 400°C)	**moderate**
Estimate of corrosion of steel (at 800°C)	**minor**

Summary

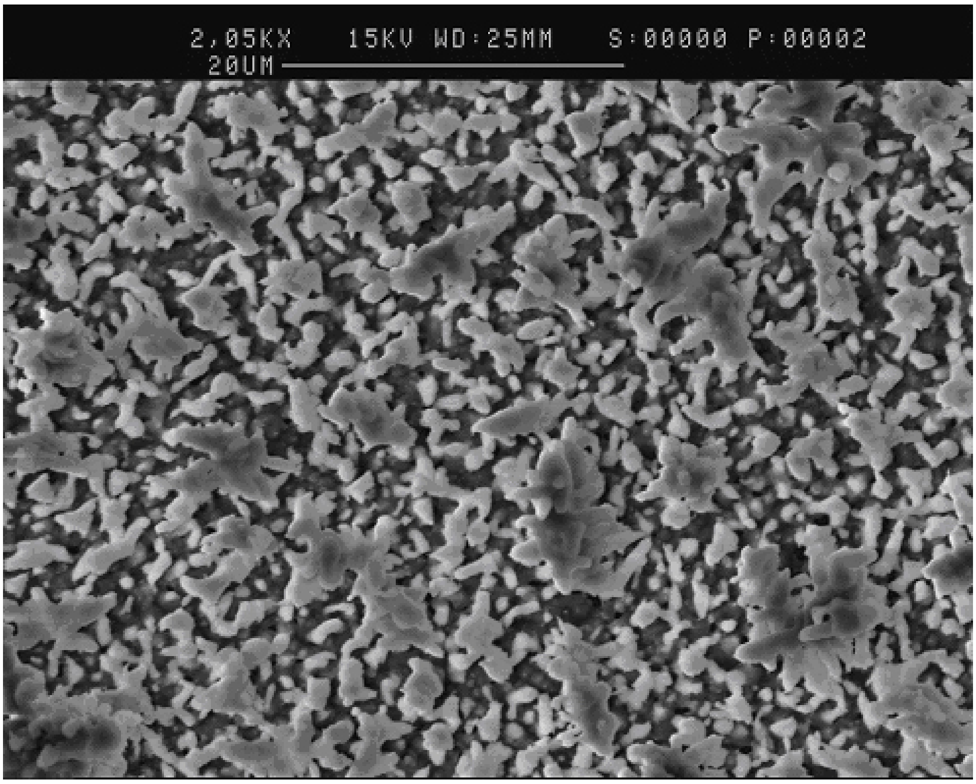
Combustion of ***Bursaria occidentalis*** causes a **minor** increase in corrosion of mild steel at 800°C above that caused by air alone.

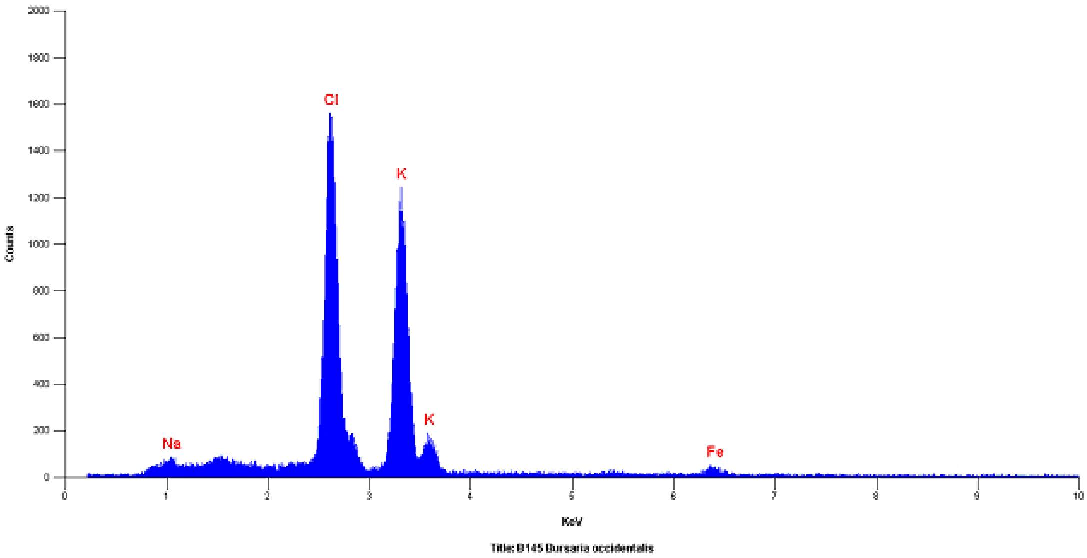
Bursaria occidentalis ash produces a **moderate** amount of fouling deposit by condensation at 400°C on a steel surface.

The dominant elements in the deposit are **potassium and chlorine**.

Negligible corrosion of the stainless steel at 400°C could be detected.

Bursaria occidentalis B145– Stub deposit

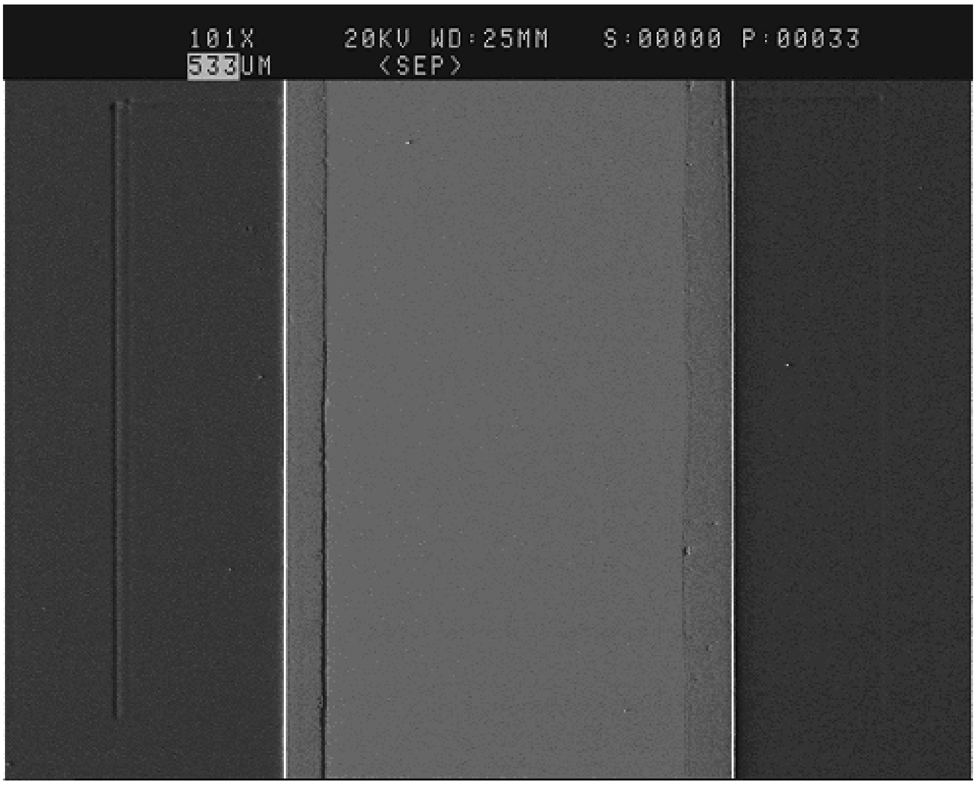


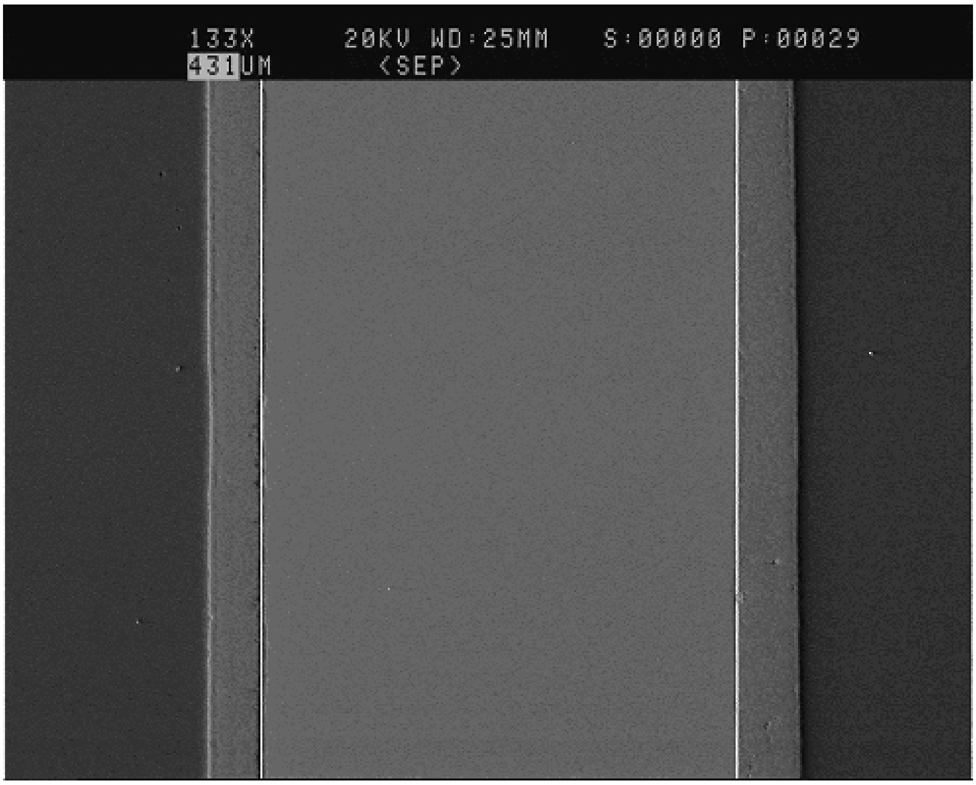


Elemental analysis of a typical particle of *Bursaria occidentalis*.

Bursaria occidentalis B145

Mild steel plate @ 800°C
(Please note measuring cursors)





Codonocarpus cotinifolius

Ash B134

Principle

Biomass / coal is slowly burnt at temperatures up to 800°C with convective air passing over the sample. A mild steel plate is positioned close to the burning fuel so that corrosion can occur on both surfaces at 800°C. A polished stainless steel stub, suitable for scanning electron microscopy (SEM), is positioned up side down in the outlet air, where the temperature is 400°C. Volatile components from the fuel and vapours formed during combustion are able to foul / corrode the mild steel and the stainless steel at 800°C and 400°C respectively. In a simple way, this test simulates the initiation of fouling or corrosion on variable surfaces at different temperatures in a conventional boiler.

The thinning of the mild steel plate and the thickness of corrosion deposits can be related to the fuel being burnt (see Figure). Fouling deposits on the stainless steel stub are examined by SEM. Energy dispersive X-ray (EDX) spectroscopy enables elements from the fuel contributing to the deposits to be identified (see Figure).

Analytical Results

Sample combusted (as received basis)	**200g**
Ash (dry basis)	**3.70%**
Estimate of fouling Deposit (at 400°C)	**negligible**
Estimate of corrosion of steel (at 800°C)	**minor**

Summary

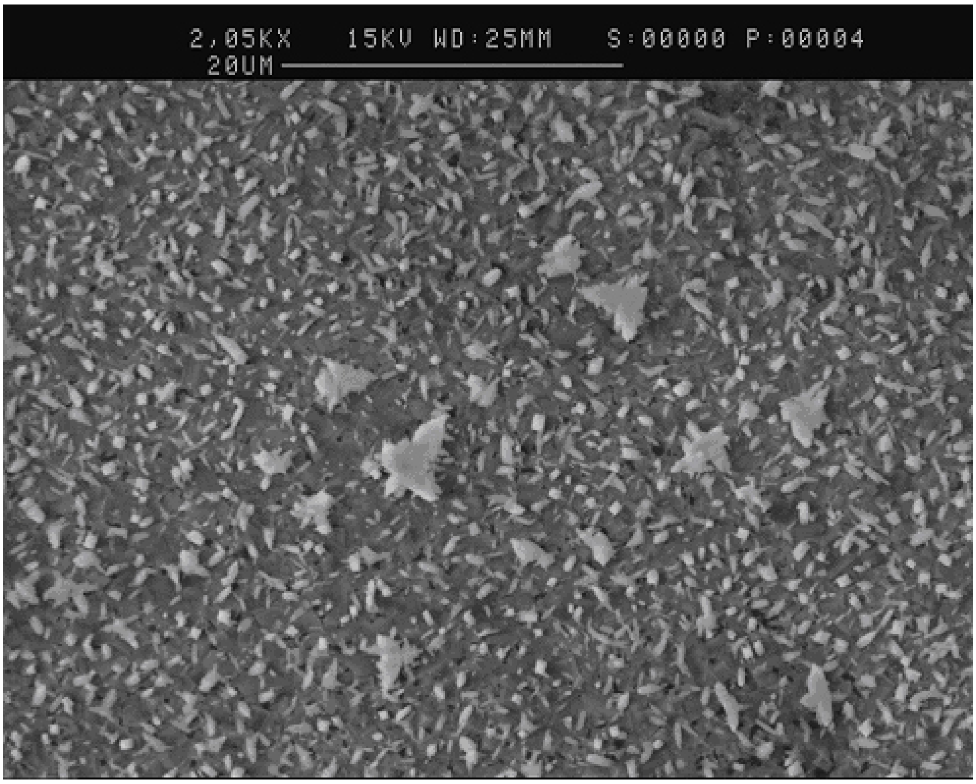
Combustion of ***Codonocarpus cotinifolius*** causes a **minor** increase in corrosion of mild steel at 800°C above that caused by air alone.

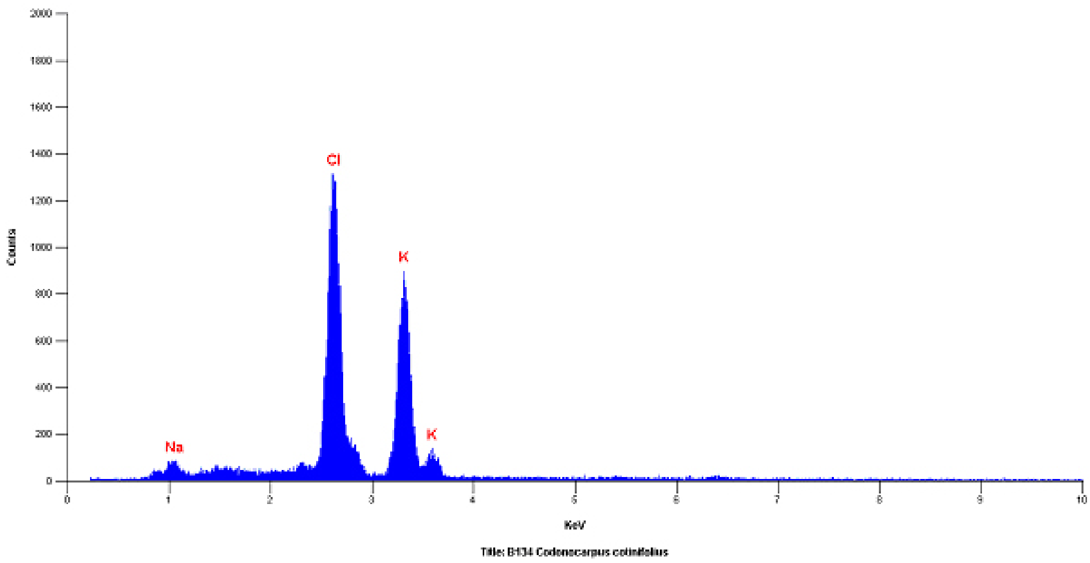
Codonocarpus cotinifolius ash produces a **negligible** amount of fouling deposit by condensation at 400°C on a steel surface.

The dominant elements in the deposit are **potassium and chlorine**.

Negligible corrosion of the stainless steel at 400°C could be detected.

Codonocarpus cotinifolius B134– Stub deposit

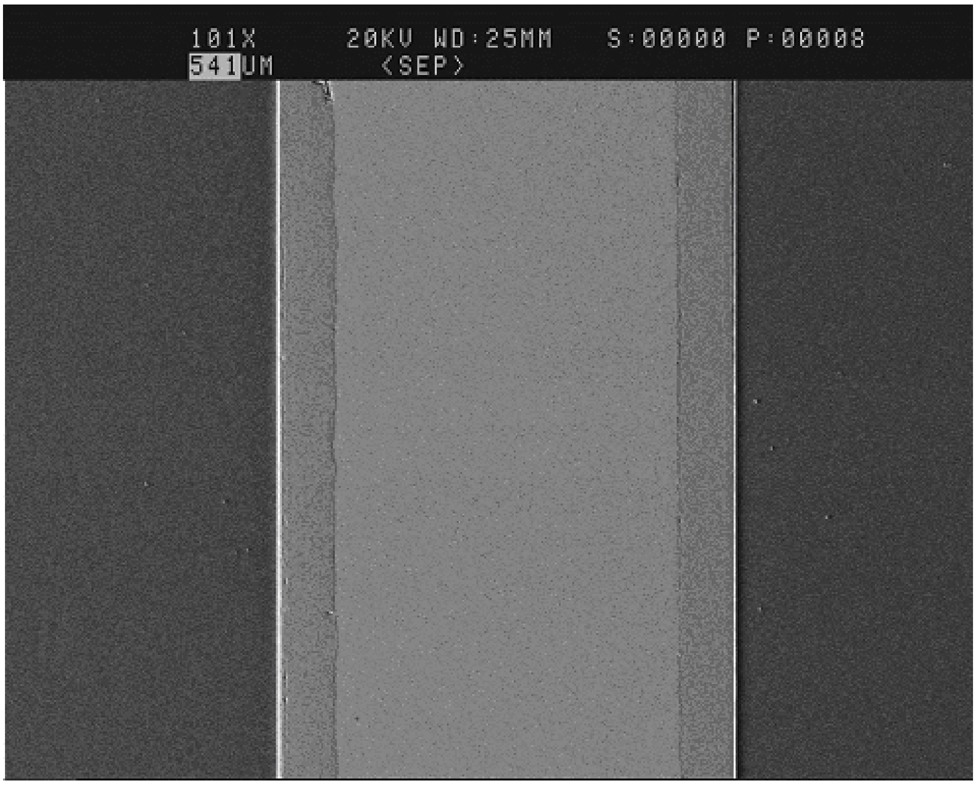


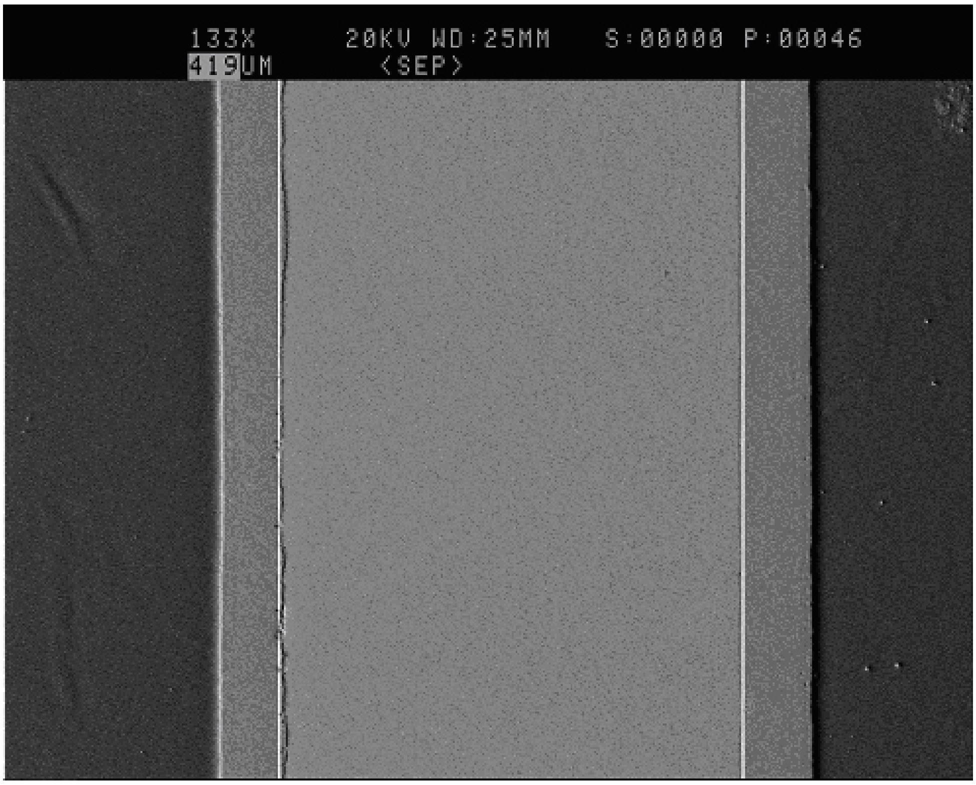


Elemental analysis of a typical particle of *Codonocarpus cotinifolius*.

Codonocarpus cotinifolius B134

Mild steel plate @ 800°C
(Please note measuring cursors)





Eucalyptus loxophleba ssp lissophloia

Ash B136

Principle

Biomass / coal is slowly burnt at temperatures up to 800°C with convective air passing over the sample. A mild steel plate is positioned close to the burning fuel so that corrosion can occur on both surfaces at 800°C. A polished stainless steel stub, suitable for scanning electron microscopy (SEM), is positioned up side down in the outlet air, where the temperature is 400°C. Volatile components from the fuel and vapours formed during combustion are able to foul / corrode the mild steel and the stainless steel at 800°C and 400°C respectively. In a simple way, this test simulates the initiation of fouling or corrosion on variable surfaces at different temperatures in a conventional boiler.

The thinning of the mild steel plate and the thickness of corrosion deposits can be related to the fuel being burnt (see Figure). Fouling deposits on the stainless steel stub are examined by SEM. Energy dispersive X-ray (EDX) spectroscopy enables elements from the fuel contributing to the deposits to be identified (see Figure).

Analytical Results

Sample combusted (as received basis)	**200g**
Ash (dry basis)	**3.30%**
Estimate of fouling Deposit (at 400°C)	**minor**
Estimate of corrosion of steel (at 800°C)	**minor**

Summary

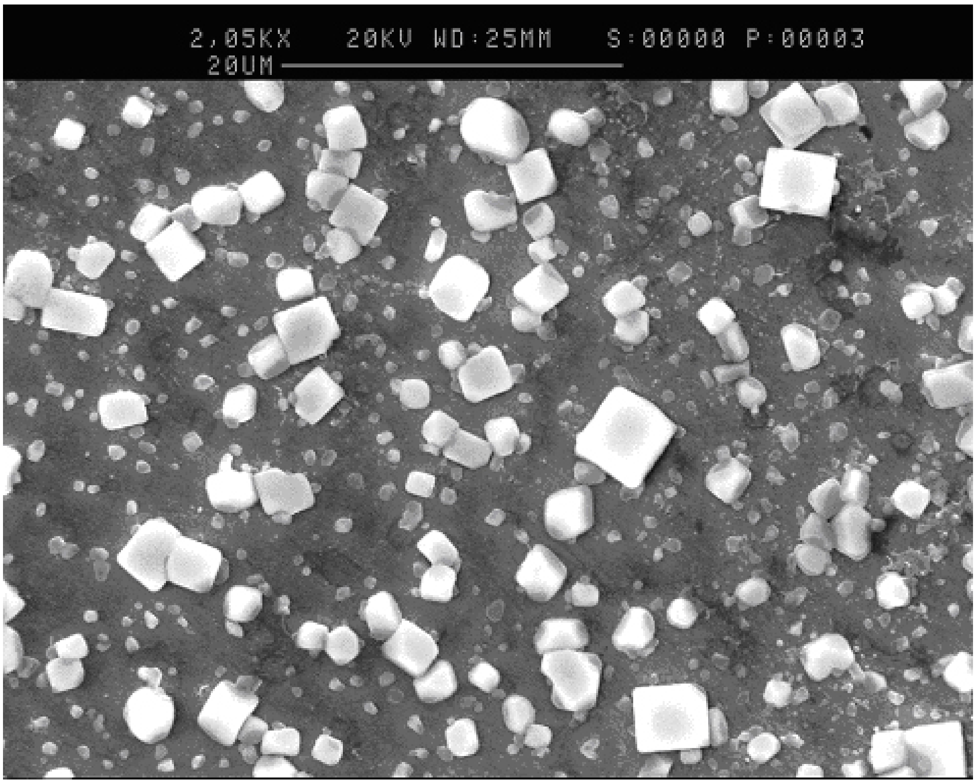
Combustion of ***Eucalyptus loxophleba ssp lissophloia*** causes a **minor** increase in corrosion of mild steel at 800°C above that caused by air alone.

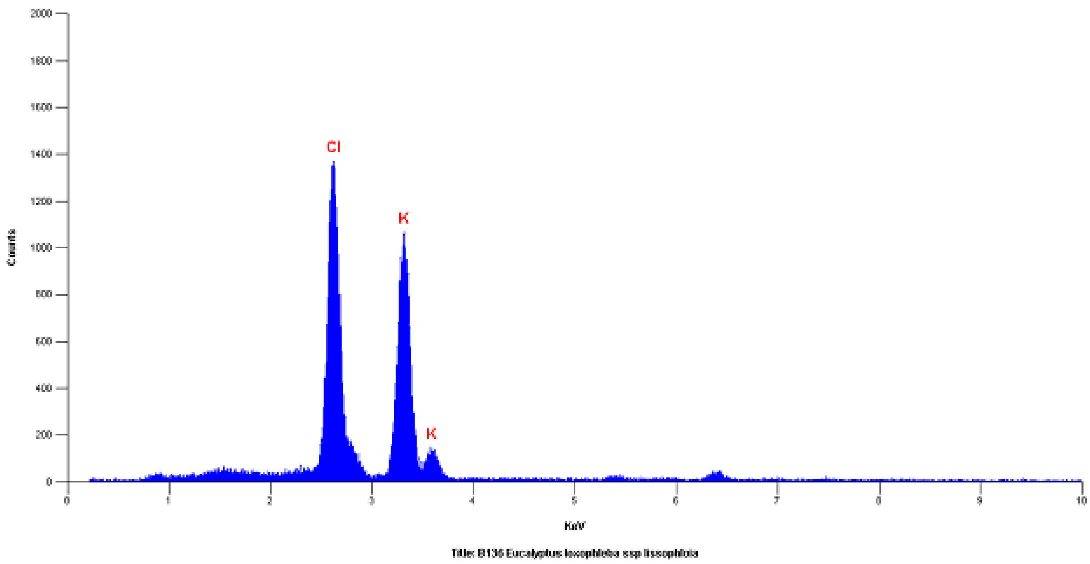
Eucalyptus loxophleba ssp lissophloia ash produces a **minor** amount of fouling deposit by condensation at 400°C on a steel surface.

The dominant elements in the deposit are **potassium and chlorine**.

Negligible corrosion of the stainless steel at 400°C could be detected.

Eucalyptus loxophleba ssp lissophloia B136– Stub deposit

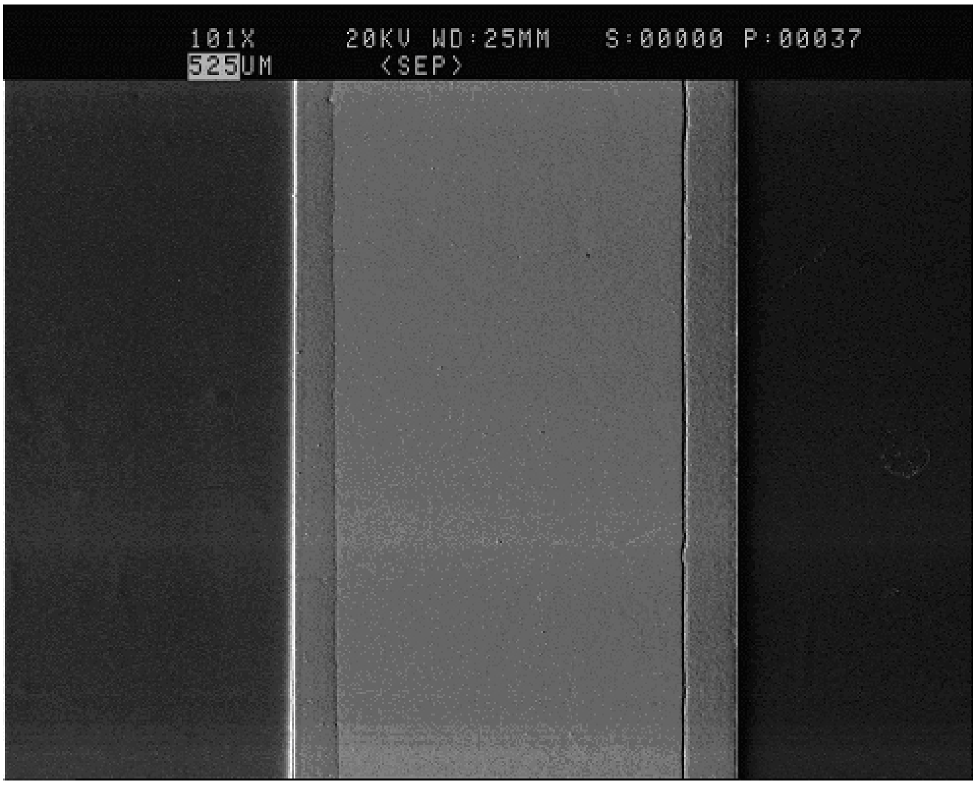


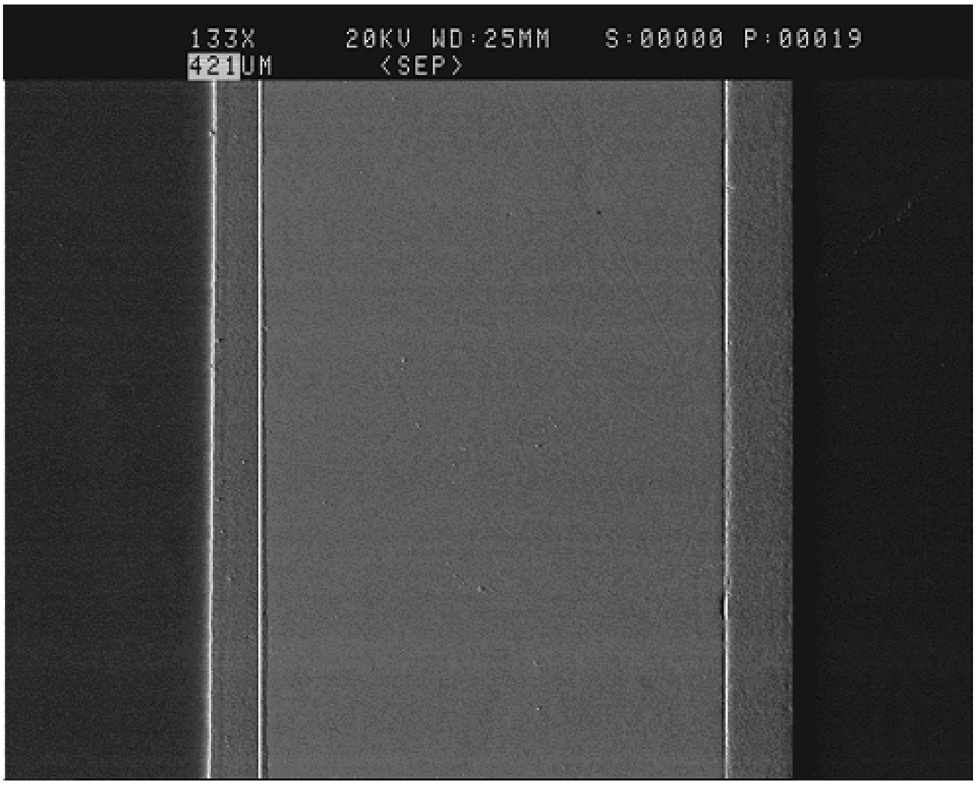


Elemental analysis of a typical particle of *Eucalyptus loxophleba ssp lissophloia*.

Eucalyptus loxophleba ssp lissophloia B136

Mild steel plate @ 800°C
(Please note measuring cursors)





Eucalyptus occidentalis

Ash B147

Principle

Biomass / coal is slowly burnt at temperatures up to 800°C with convective air passing over the sample. A mild steel plate is positioned close to the burning fuel so that corrosion can occur on both surfaces at 800°C. A polished stainless steel stub, suitable for scanning electron microscopy (SEM), is positioned up side down in the outlet air, where the temperature is 400°C. Volatile components from the fuel and vapours formed during combustion are able to foul / corrode the mild steel and the stainless steel at 800°C and 400°C respectively. In a simple way, this test simulates the initiation of fouling or corrosion on variable surfaces at different temperatures in a conventional boiler.

The thinning of the mild steel plate and the thickness of corrosion deposits can be related to the fuel being burnt (see Figure). Fouling deposits on the stainless steel stub are examined by SEM. Energy dispersive X-ray (EDX) spectroscopy enables elements from the fuel contributing to the deposits to be identified (see Figure).

Analytical Results

Sample combusted (as received basis)	**200g**
Ash (dry basis)	**1.70%**
Estimate of fouling Deposit (at 400°C)	**moderate**
Estimate of corrosion of steel (at 800°C)	**minor**

Summary

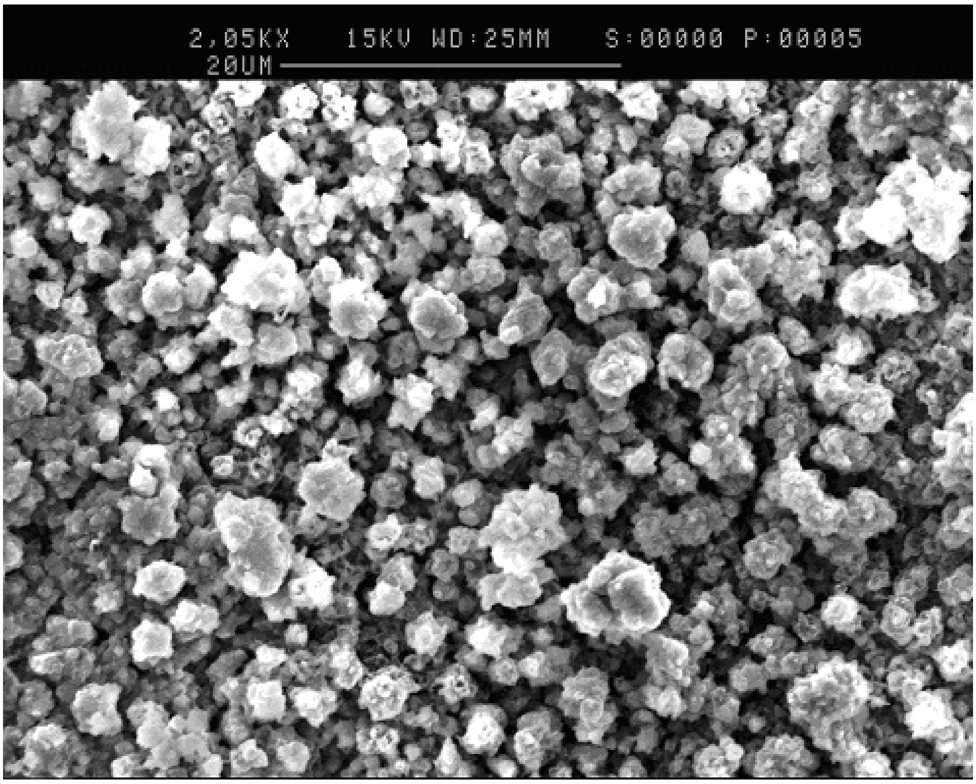
Combustion of ***Eucalyptus occidentalis*** causes a **minor** increase in corrosion of mild steel at 800°C above that caused by air alone.

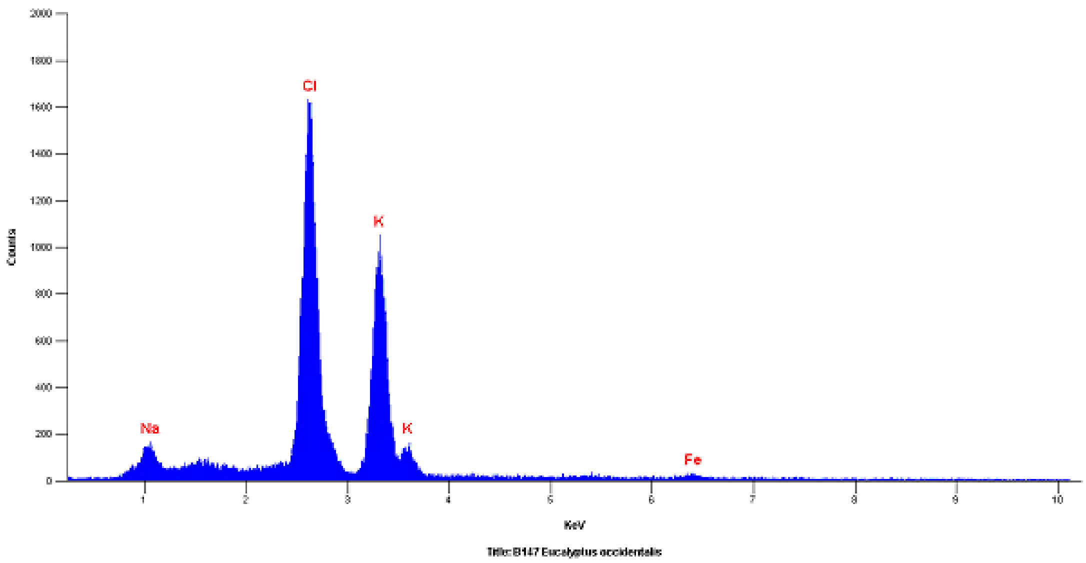
Eucalyptus occidentalis ash produces a **moderate** amount of fouling deposit by condensation at 400°C on a steel surface.

The dominant elements in the deposit are **potassium, chlorine and sodium**.

Minor corrosion of the stainless steel at 400°C could be detected.

Eucalyptus occidentalis B147– Stub deposit

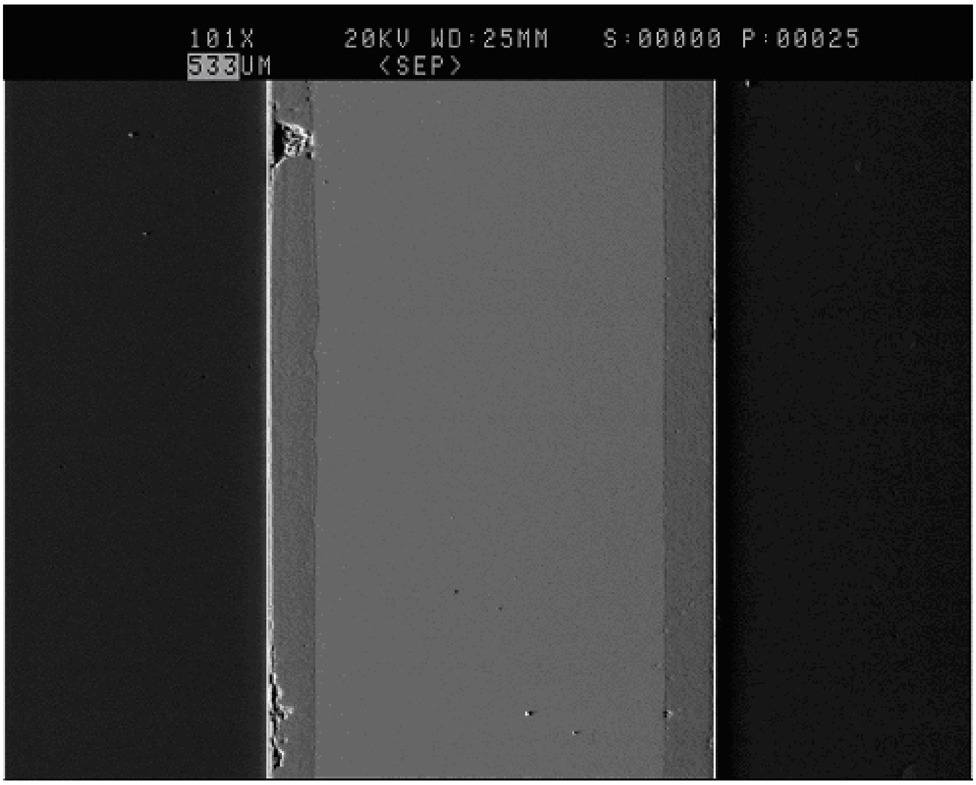


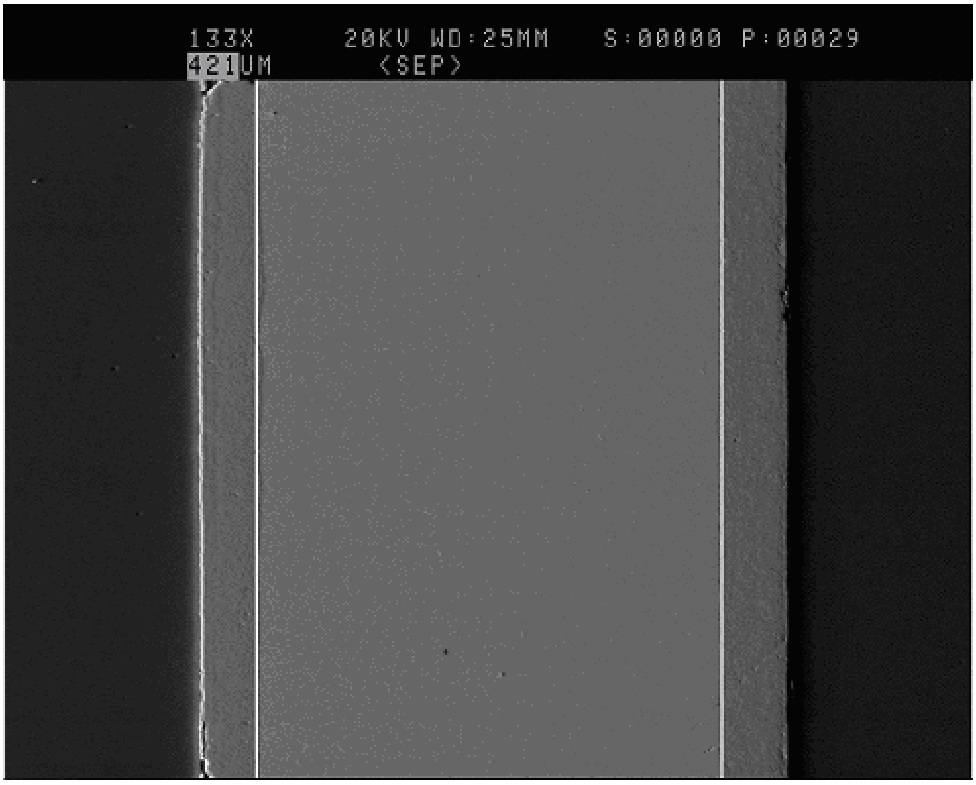


Elemental analysis of a typical particle of *Eucalyptus occidentalis*.

Eucalyptus occidentalis B147

Mild steel plate @ 800°C
(Please note measuring cursors)





Eucalyptus rudis

Ash B135

Principle

Biomass / coal is slowly burnt at temperatures up to 800°C with convective air passing over the sample. A mild steel plate is positioned close to the burning fuel so that corrosion can occur on both surfaces at 800°C. A polished stainless steel stub, suitable for scanning electron microscopy (SEM), is positioned up side down in the outlet air, where the temperature is 400°C. Volatile components from the fuel and vapours formed during combustion are able to foul / corrode the mild steel and the stainless steel at 800°C and 400°C respectively. In a simple way, this test simulates the initiation of fouling or corrosion on variable surfaces at different temperatures in a conventional boiler.

The thinning of the mild steel plate and the thickness of corrosion deposits can be related to the fuel being burnt (see Figure). Fouling deposits on the stainless steel stub are examined by SEM. Energy dispersive X-ray (EDX) spectroscopy enables elements from the fuel contributing to the deposits to be identified (see Figure).

Analytical Results

Sample combusted (as received basis)	**200g**
Ash (dry basis)	**3.40%**
Estimate of fouling Deposit (at 400°C)	**minor**
Estimate of corrosion of steel (at 800°C)	**minor**

Summary

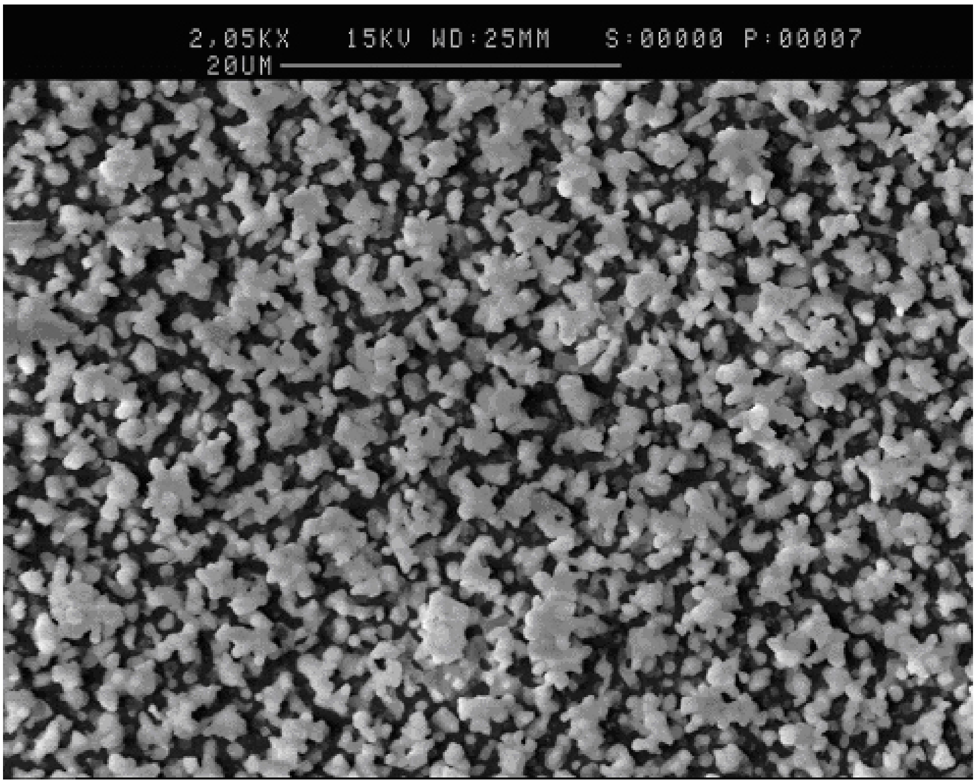
Combustion of ***Eucalyptus rudis*** causes a **minor** increase in corrosion of mild steel at 800°C above that caused by air alone.

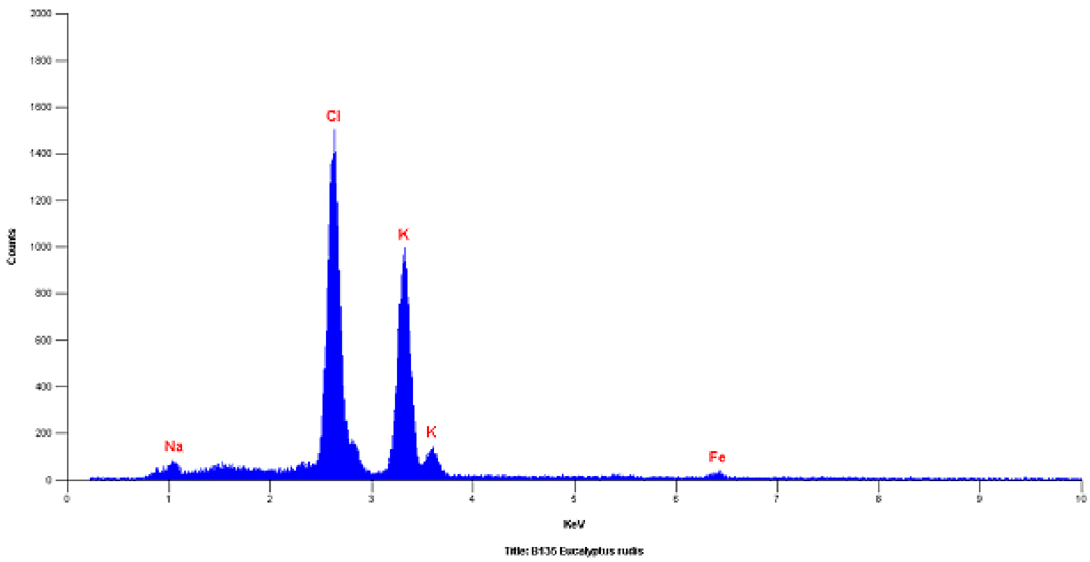
Eucalyptus rudis ash produces a **minor** amount of fouling deposit by condensation at 400°C on a steel surface.

The dominant elements in the deposit are **potassium and chlorine**.

Negligible corrosion of the stainless steel at 400°C could be detected.

Eucalyptus rudis B135– Stub deposit

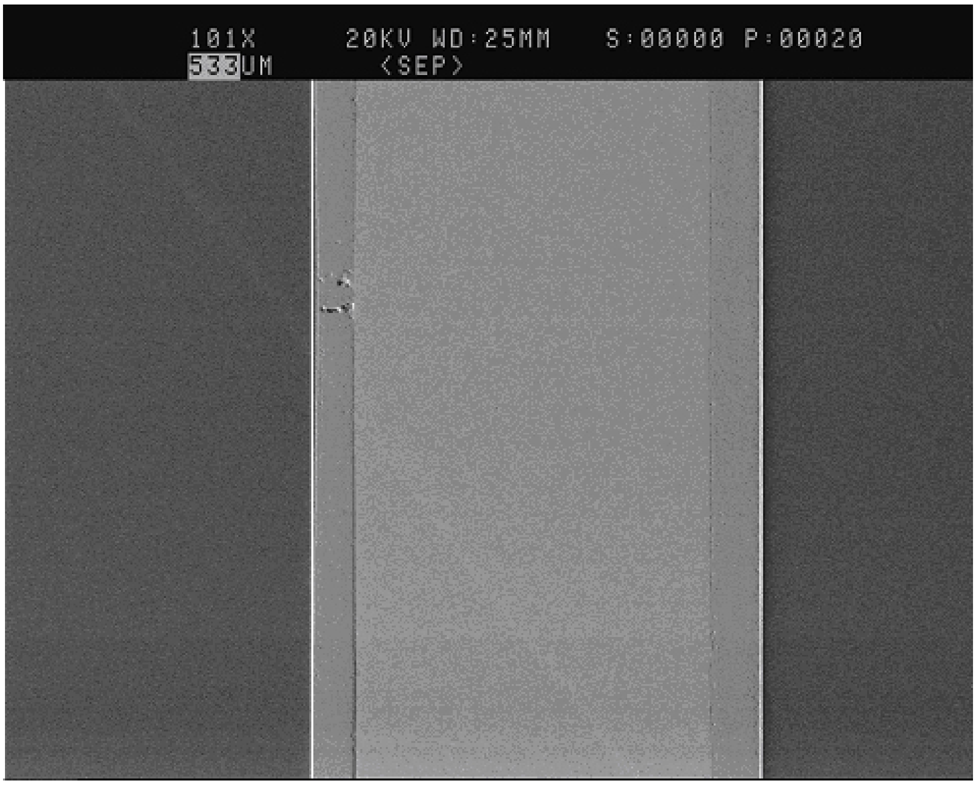


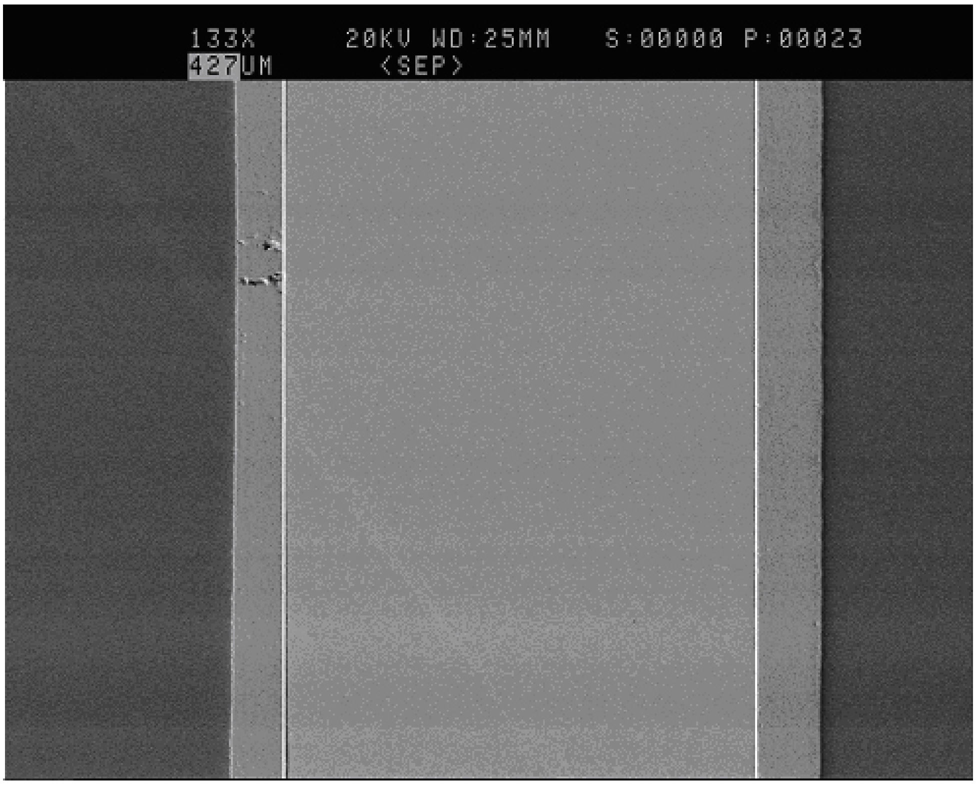


Elemental analysis of a typical particle of *Eucalyptus rudis*.

Eucalyptus rudis B135

Mild steel plate @ 800°C
(Please note measuring cursors)





Grevillea candelabroides

Ash B137

Principle

Biomass / coal is slowly burnt at temperatures up to 800°C with convective air passing over the sample. A mild steel plate is positioned close to the burning fuel so that corrosion can occur on both surfaces at 800°C. A polished stainless steel stub, suitable for scanning electron microscopy (SEM), is positioned up side down in the outlet air, where the temperature is 400°C. Volatile components from the fuel and vapours formed during combustion are able to foul / corrode the mild steel and the stainless steel at 800°C and 400°C respectively. In a simple way, this test simulates the initiation of fouling or corrosion on variable surfaces at different temperatures in a conventional boiler.

The thinning of the mild steel plate and the thickness of corrosion deposits can be related to the fuel being burnt (see Figure). Fouling deposits on the stainless steel stub are examined by SEM. Energy dispersive X-ray (EDX) spectroscopy enables elements from the fuel contributing to the deposits to be identified (see Figure).

Analytical Results

Sample combusted (as received basis)	**200g**
Ash (dry basis)	**3.20%**
Estimate of fouling Deposit (at 400°C)	**minor**
Estimate of corrosion of steel (at 800°C)	**minor**

Summary

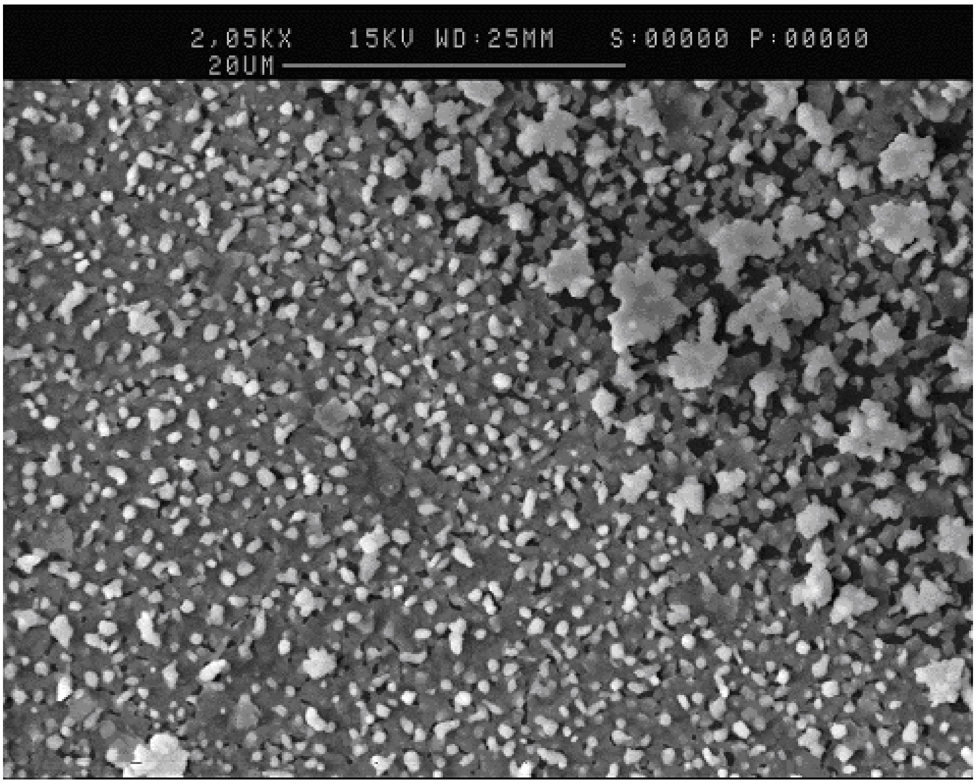
Combustion of ***Grevillea candelabroides*** causes a **minor** increase in corrosion of mild steel at 800°C above that caused by air alone.

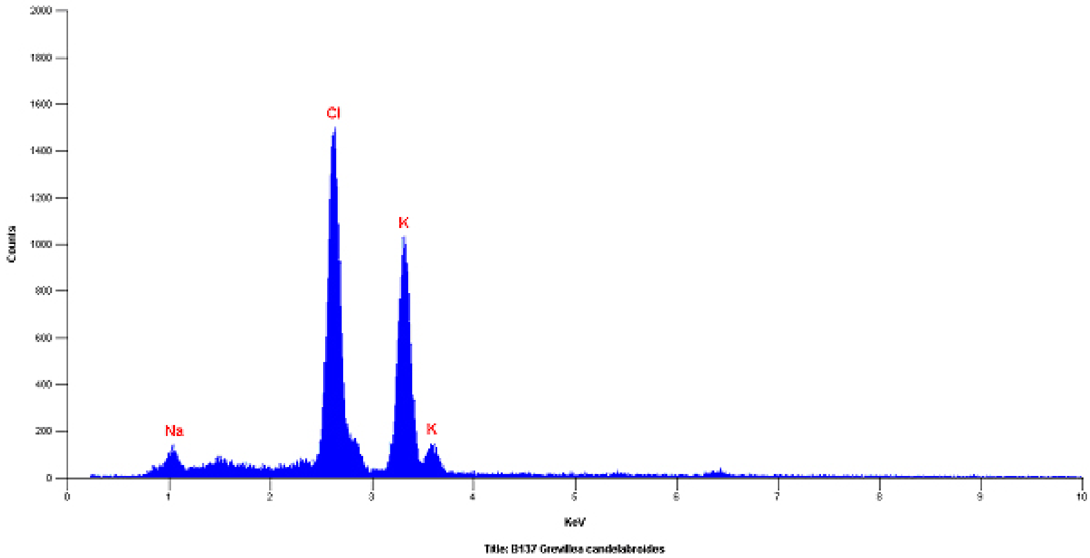
Grevillea candelabroides ash produces a **minor** amount of fouling deposit by condensation at 400°C on a steel surface.

The dominant elements in the deposit are **potassium and chlorine**.

Negligible corrosion of the stainless steel at 400°C could be detected.

Grevillea candelabroides B137– Stub deposit

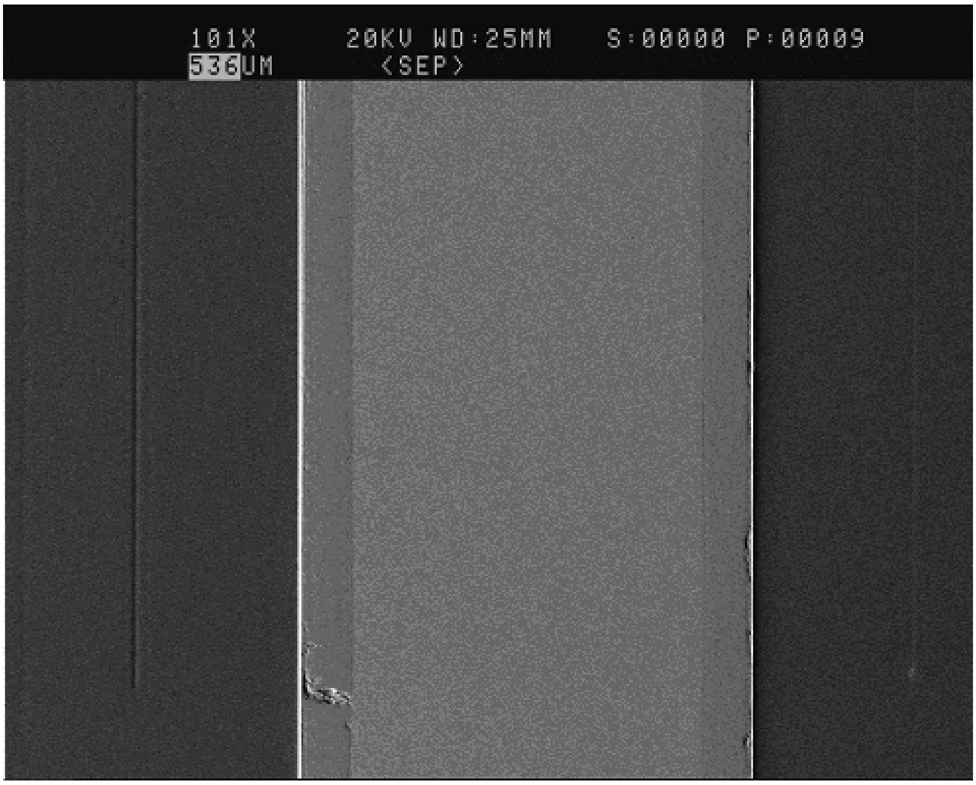


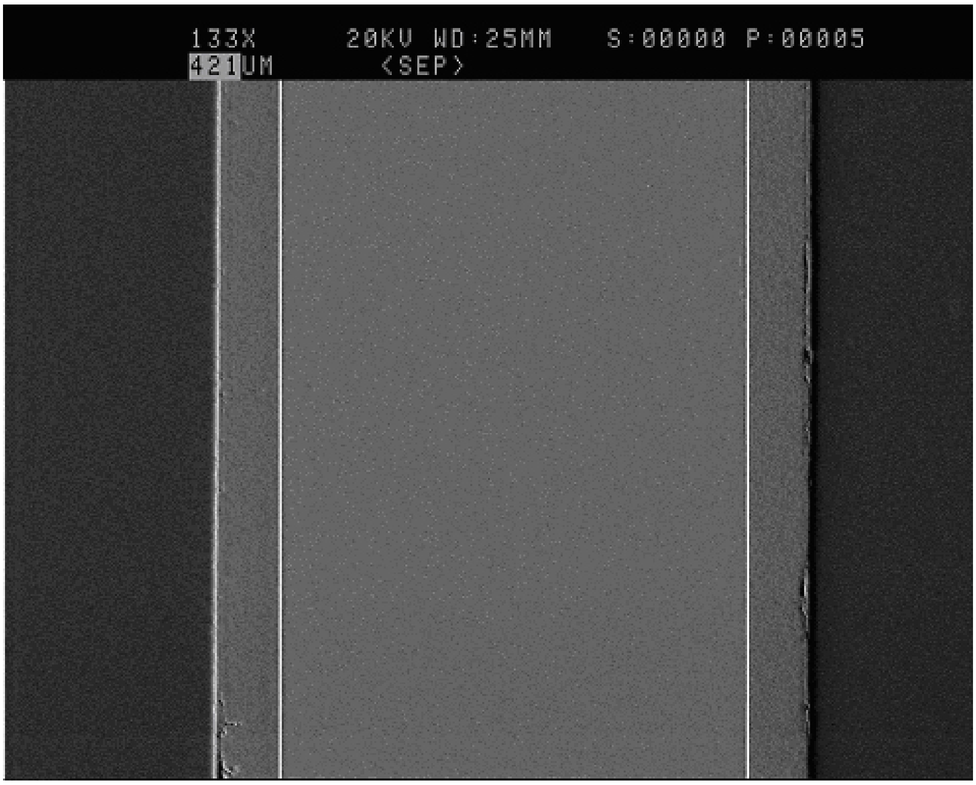


Elemental analysis of a typical particle of *Grevillea candelabroides*.

Grevillea candelabroides B137

Mild steel plate @ 800°C
(Please note measuring cursors)





Grevillea leucopteris

Ash B130

Principle

Biomass / coal is slowly burnt at temperatures up to 800°C with convective air passing over the sample. A mild steel plate is positioned close to the burning fuel so that corrosion can occur on both surfaces at 800°C. A polished stainless steel stub, suitable for scanning electron microscopy (SEM), is positioned up side down in the outlet air, where the temperature is 400°C. Volatile components from the fuel and vapours formed during combustion are able to foul / corrode the mild steel and the stainless steel at 800°C and 400°C respectively. In a simple way, this test simulates the initiation of fouling or corrosion on variable surfaces at different temperatures in a conventional boiler.

The thinning of the mild steel plate and the thickness of corrosion deposits can be related to the fuel being burnt (see Figure). Fouling deposits on the stainless steel stub are examined by SEM. Energy dispersive X-ray (EDX) spectroscopy enables elements from the fuel contributing to the deposits to be identified (see Figure).

Analytical Results

Sample combusted (as received basis)	**200g**
Ash (dry basis)	**3.70%**
Estimate of fouling Deposit (at 400°C)	**minor**
Estimate of corrosion of steel (at 800°C)	**minor**

Summary

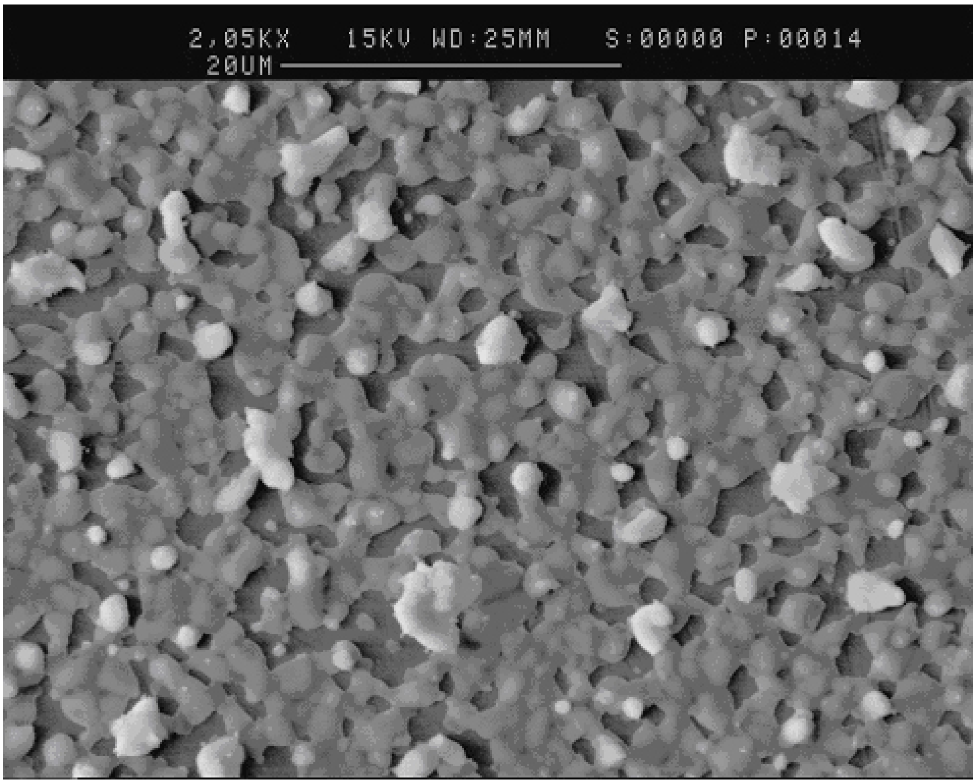
Combustion of ***Grevillea leucopteris*** causes a **minor** increase in corrosion of mild steel at 800°C above that caused by air alone.

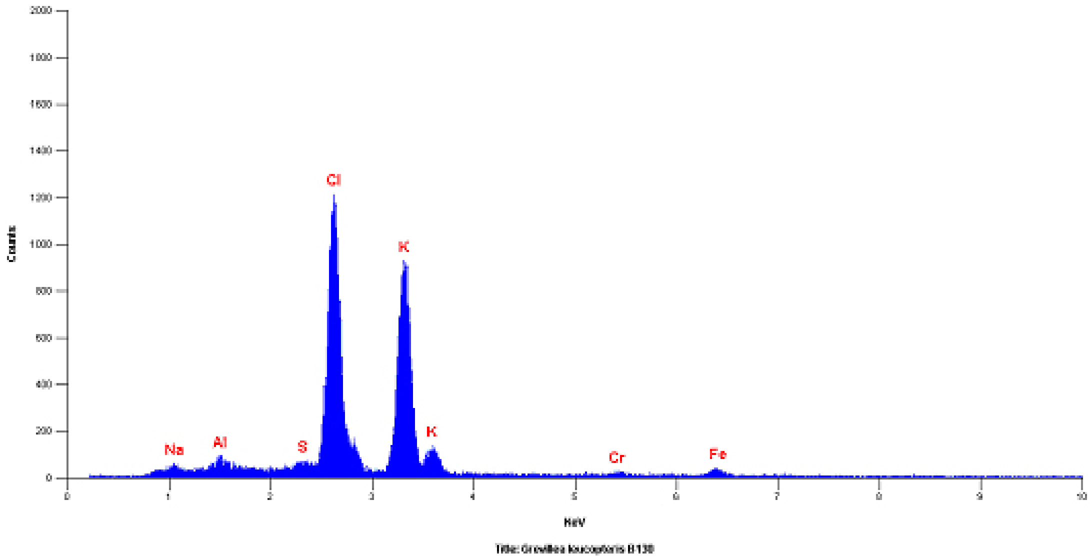
Grevillea leucopteris ash produces a **minor** amount of fouling deposit by condensation at 400°C on a steel surface.

The dominant elements in the deposit are **potassium and chlorine**.

Negligible corrosion of the stainless steel at 400°C could be detected.

Grevillea leucopteris B130– Stub deposit

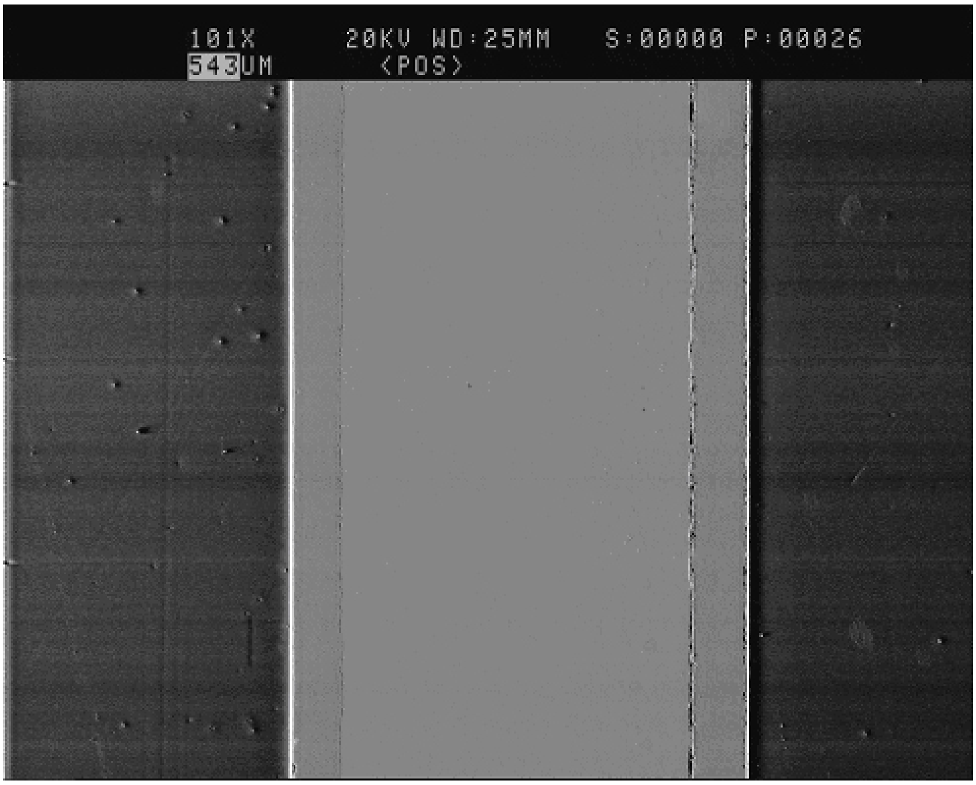


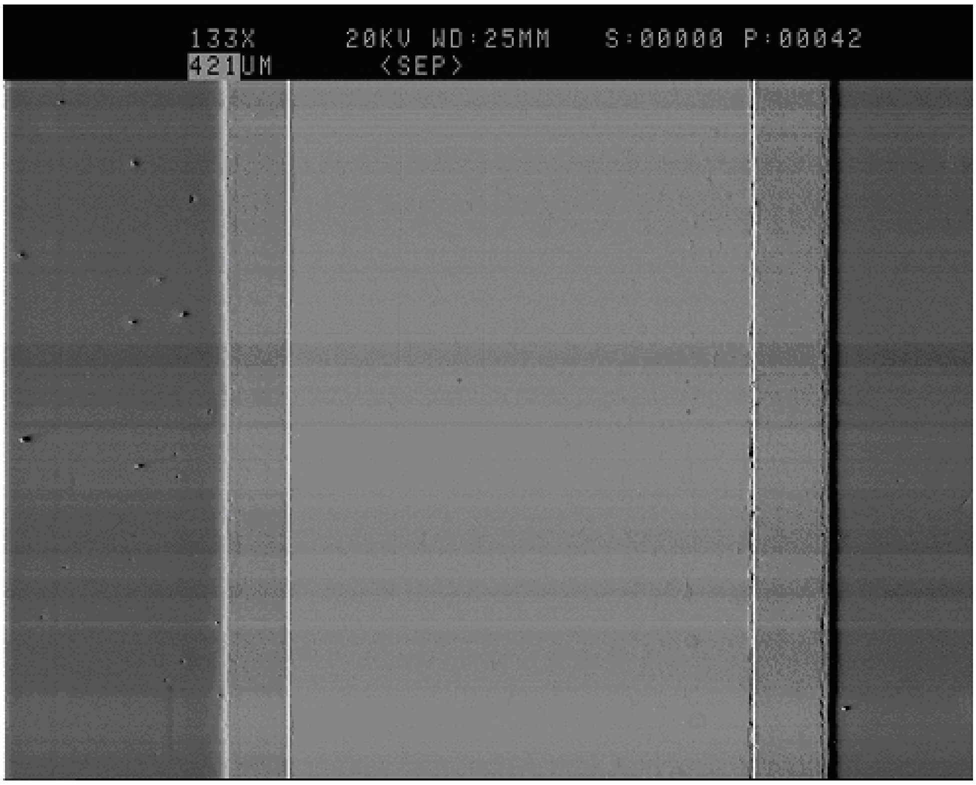


Elemental analysis of a typical particle of *Grevillea leucopteris*.

Grevillea leucopteris B130

Mild steel plate @ 800°C
(Please note measuring cursors)





Gyrostemon ramulosus

Ash B131

Principle

Biomass / coal is slowly burnt at temperatures up to 800°C with convective air passing over the sample. A mild steel plate is positioned close to the burning fuel so that corrosion can occur on both surfaces at 800°C. A polished stainless steel stub, suitable for scanning electron microscopy (SEM), is positioned up side down in the outlet air, where the temperature is 400°C. Volatile components from the fuel and vapours formed during combustion are able to foul / corrode the mild steel and the stainless steel at 800°C and 400°C respectively. In a simple way, this test simulates the initiation of fouling or corrosion on variable surfaces at different temperatures in a conventional boiler.

The thinning of the mild steel plate and the thickness of corrosion deposits can be related to the fuel being burnt (see Figure). Fouling deposits on the stainless steel stub are examined by SEM. Energy dispersive X-ray (EDX) spectroscopy enables elements from the fuel contributing to the deposits to be identified (see Figure).

Analytical Results

Sample combusted (as received basis)	**200g**
Ash (dry basis)	**4.65%**
Estimate of fouling Deposit (at 400°C)	**moderate**
Estimate of corrosion of steel (at 800°C)	**moderate**

Summary

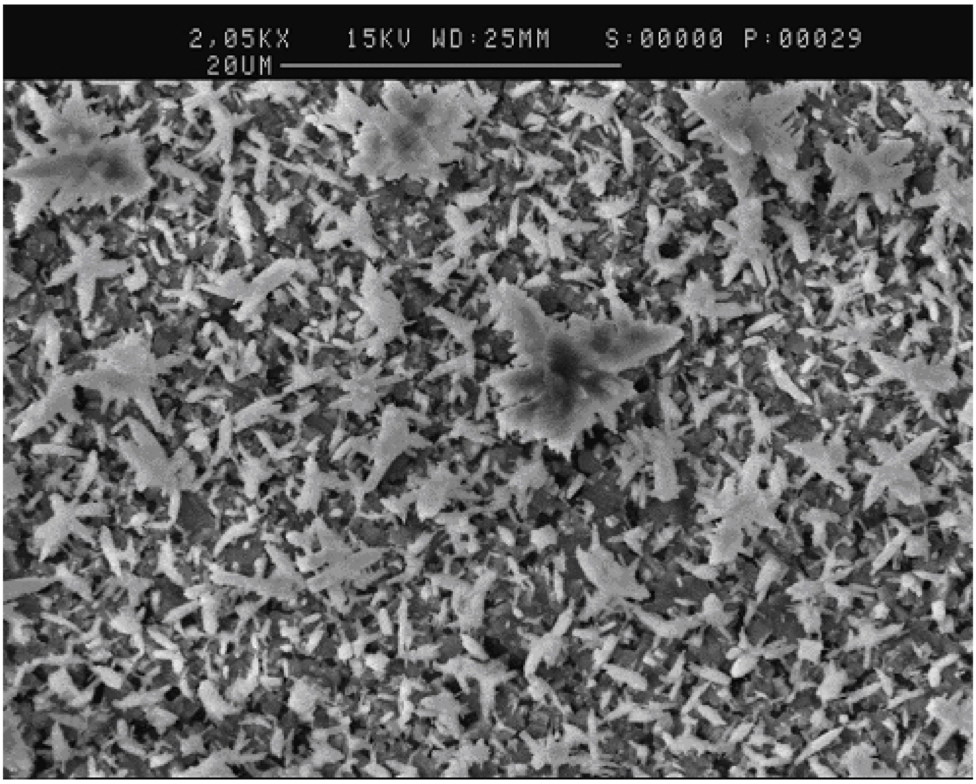
Combustion of ***Gyrostemon ramulosus*** causes a **moderate** increase in corrosion of mild steel at 800°C above that caused by air alone.

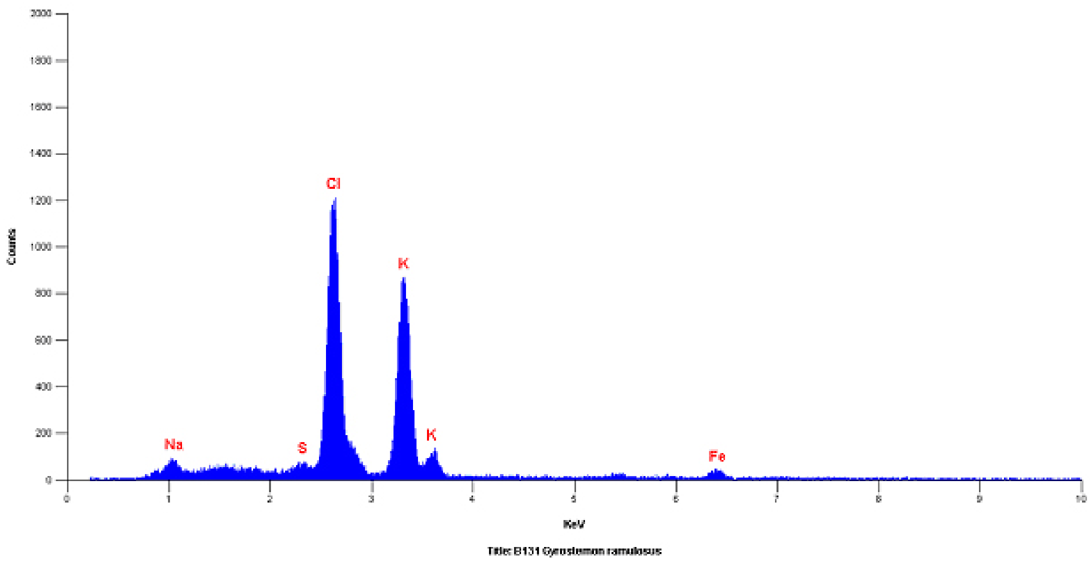
Gyrostemon ramulosus ash produces a **moderate** amount of fouling deposit by condensation at 400°C on a steel surface.

The dominant elements in the deposit are **potassium and chlorine**.

Negligible corrosion of the stainless steel at 400°C could be detected.

Gyrostemon ramulosus B131– Stub deposit

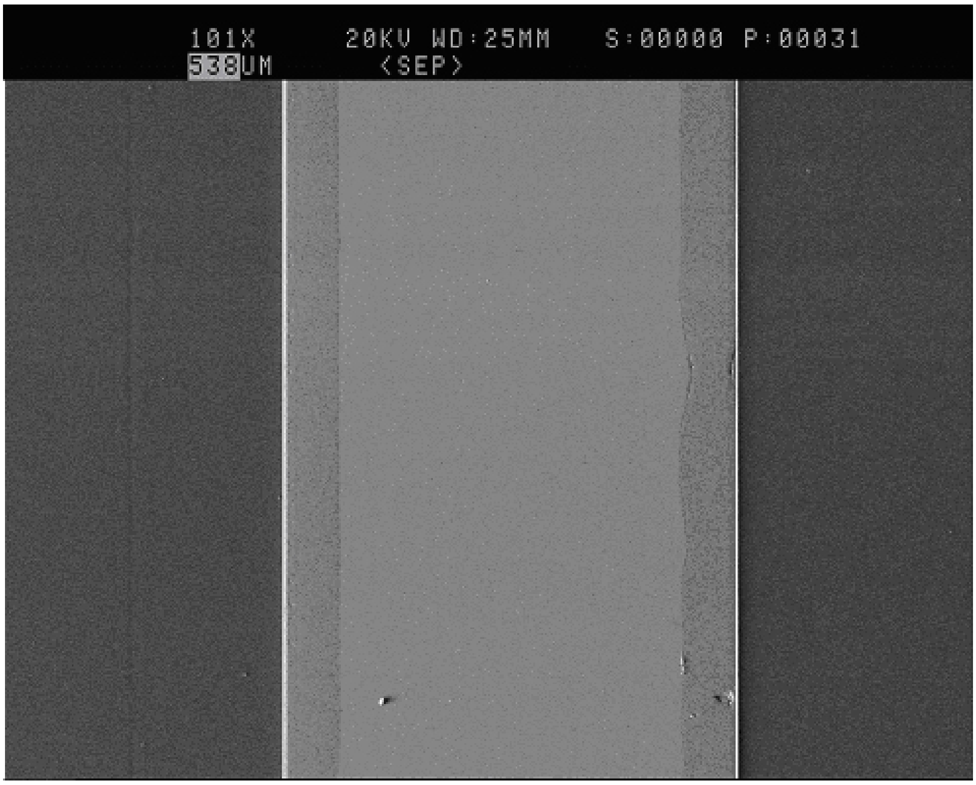


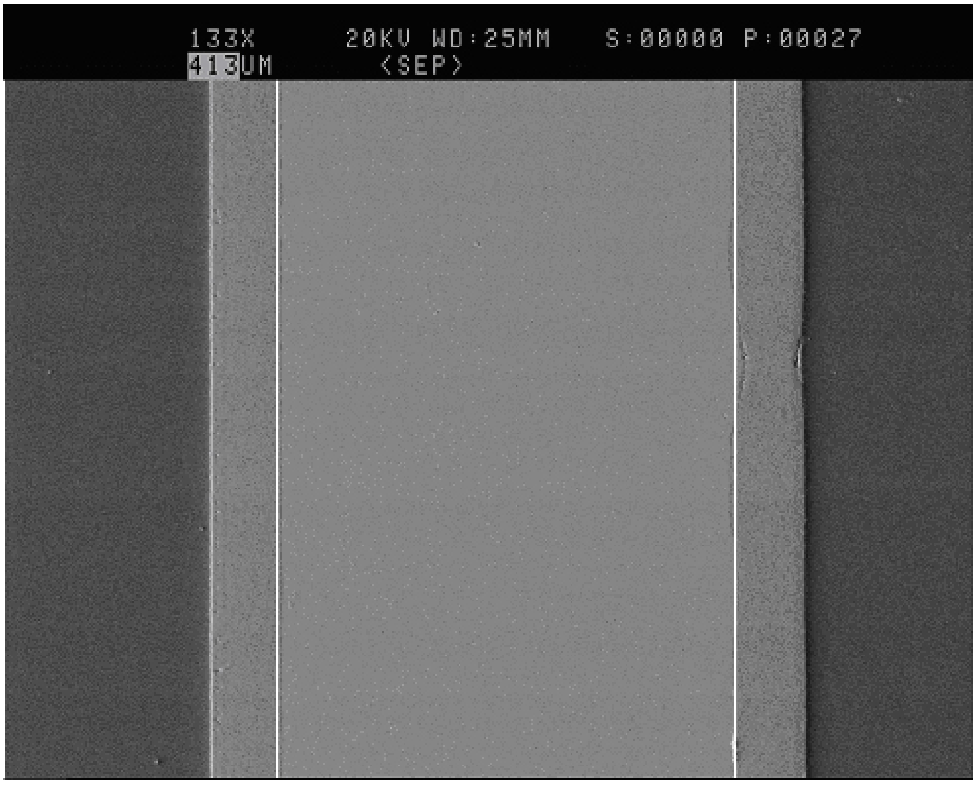


Elemental analysis of a typical particle of *Gyrostemon ramulosus*.

Gyrostemon ramulosus B131

Mild steel plate @ 800°C
(Please note measuring cursors)





Hakea oleifolia

Ash B141

Principle

Biomass / coal is slowly burnt at temperatures up to 800°C with convective air passing over the sample. A mild steel plate is positioned close to the burning fuel so that corrosion can occur on both surfaces at 800°C. A polished stainless steel stub, suitable for scanning electron microscopy (SEM), is positioned up side down in the outlet air, where the temperature is 400°C. Volatile components from the fuel and vapours formed during combustion are able to foul / corrode the mild steel and the stainless steel at 800°C and 400°C respectively. In a simple way, this test simulates the initiation of fouling or corrosion on variable surfaces at different temperatures in a conventional boiler.

The thinning of the mild steel plate and the thickness of corrosion deposits can be related to the fuel being burnt (see Figure). Fouling deposits on the stainless steel stub are examined by SEM. Energy dispersive X-ray (EDX) spectroscopy enables elements from the fuel contributing to the deposits to be identified (see Figure).

Analytical Results

Sample combusted (as received basis)	**200g**
Ash (dry basis)	**2.60%**
Estimate of fouling Deposit (at 400°C)	**minor**
Estimate of corrosion of steel (at 800°C)	**minor**

Summary

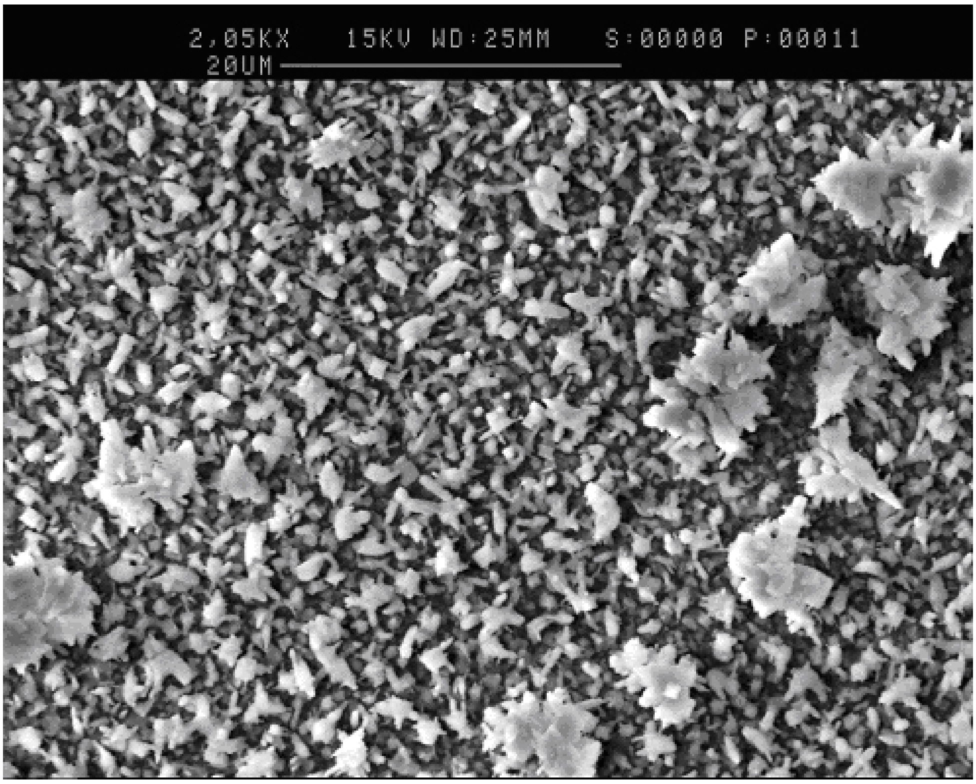
Combustion of ***Hakea oleifolia*** causes a **minor** increase in corrosion of mild steel at 800°C above that caused by air alone.

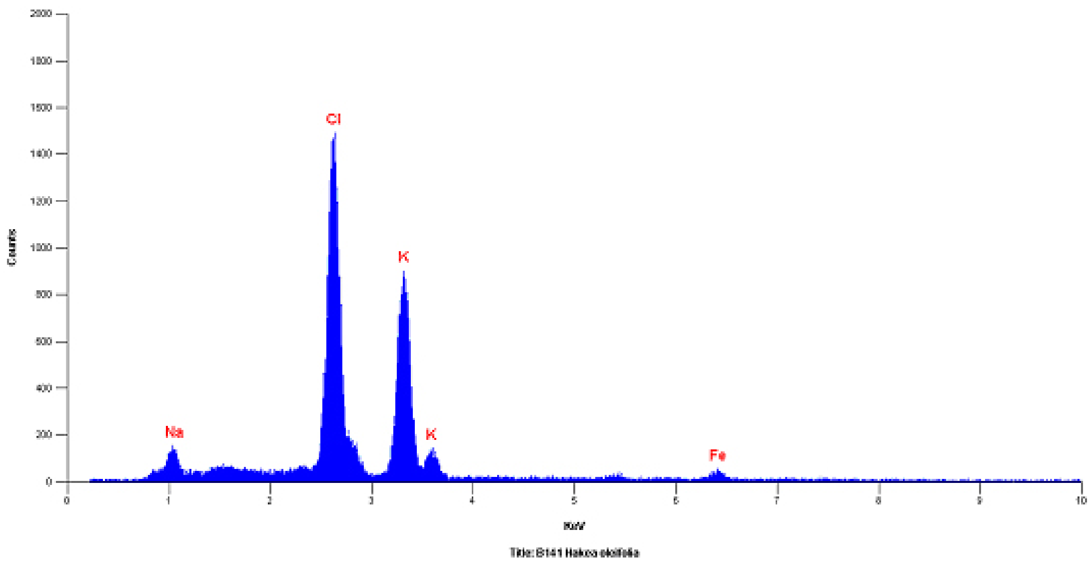
Hakea oleifolia ash produces a **minor** amount of fouling deposit by condensation at 400°C on a steel surface.

The dominant elements in the deposit are **potassium and chlorine**.

Minor corrosion of the stainless steel at 400°C could be detected.

Hakea oleifolia B141– Stub deposit

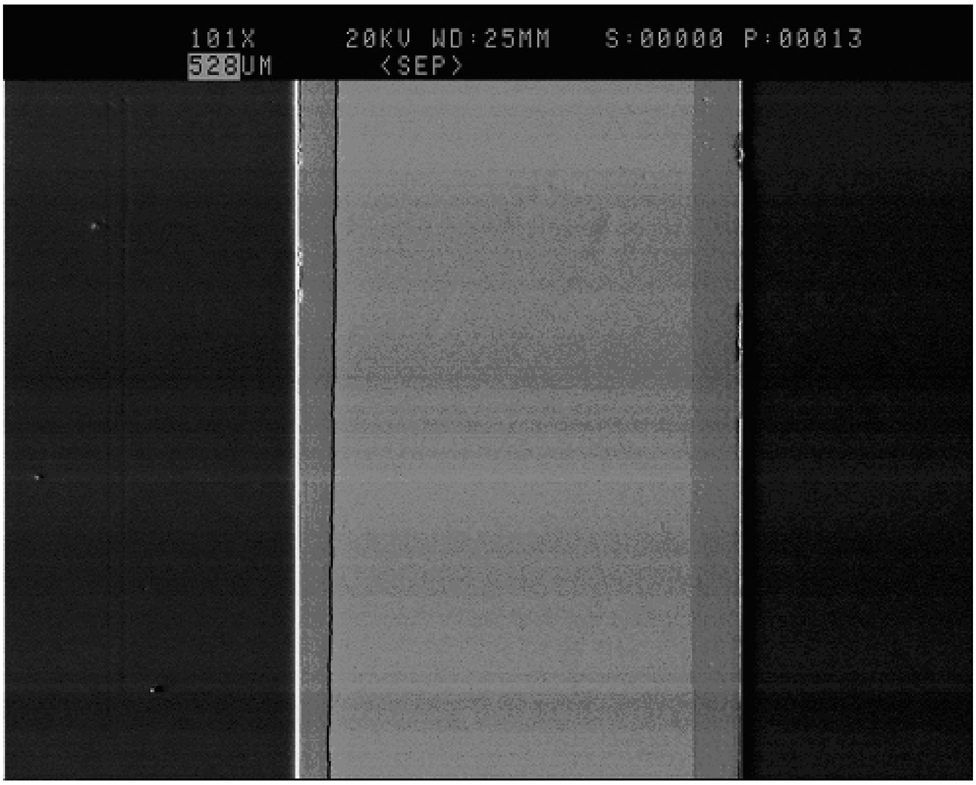


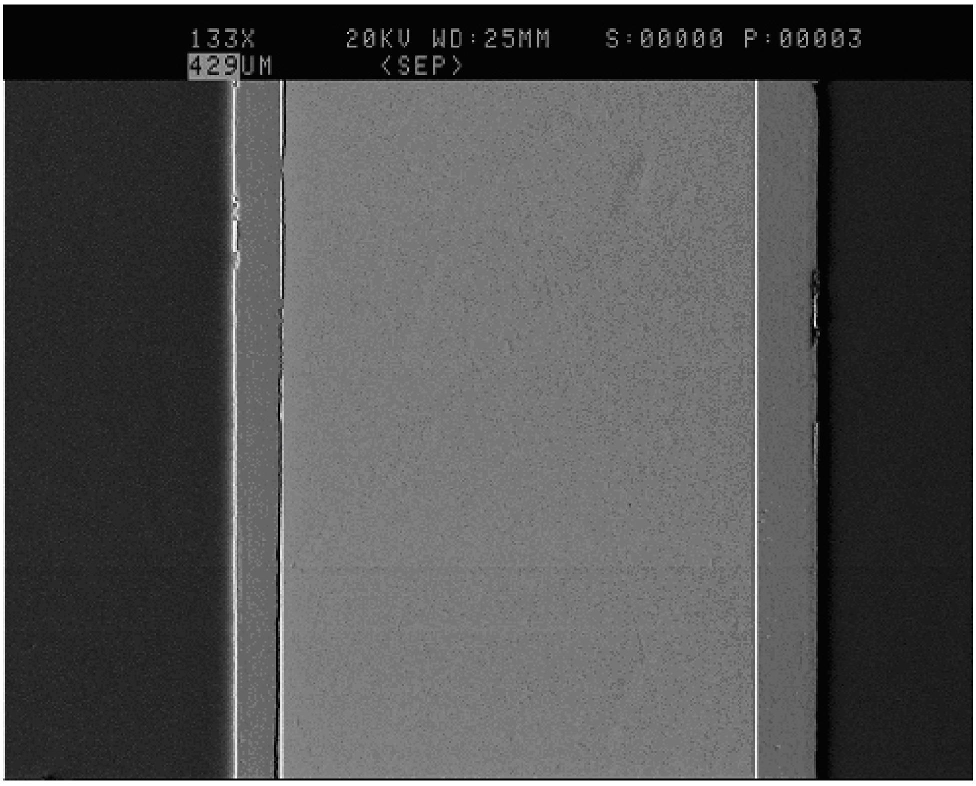


Elemental analysis of a typical particle of *Hakea oleifolia*.

Hakea oleifolia B141

Mild steel plate @ 800°C
(Please note measuring cursors)





Jacksonia sternbergiana

Ash B142

Principle

Biomass / coal is slowly burnt at temperatures up to 800°C with convective air passing over the sample. A mild steel plate is positioned close to the burning fuel so that corrosion can occur on both surfaces at 800°C. A polished stainless steel stub, suitable for scanning electron microscopy (SEM), is positioned up side down in the outlet air, where the temperature is 400°C. Volatile components from the fuel and vapours formed during combustion are able to foul / corrode the mild steel and the stainless steel at 800°C and 400°C respectively. In a simple way, this test simulates the initiation of fouling or corrosion on variable surfaces at different temperatures in a conventional boiler.

The thinning of the mild steel plate and the thickness of corrosion deposits can be related to the fuel being burnt (see Figure). Fouling deposits on the stainless steel stub are examined by SEM. Energy dispersive X-ray (EDX) spectroscopy enables elements from the fuel contributing to the deposits to be identified (see Figure).

Analytical Results

Sample combusted (as received basis)	**200g**
Ash (dry basis)	**1.75%**
Estimate of fouling Deposit (at 400°C)	**moderate**
Estimate of corrosion of steel (at 800°C)	**minor**

Summary

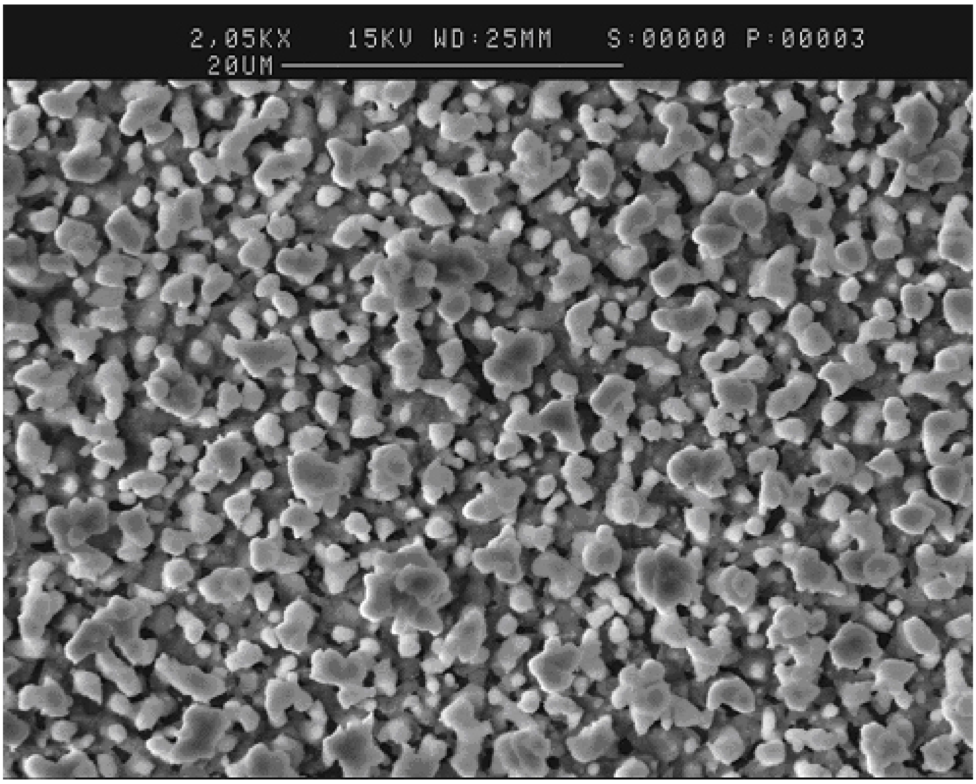
Combustion of ***Jacksonia sternbergiana*** causes a **minor** increase in corrosion of mild steel at 800°C above that caused by air alone.

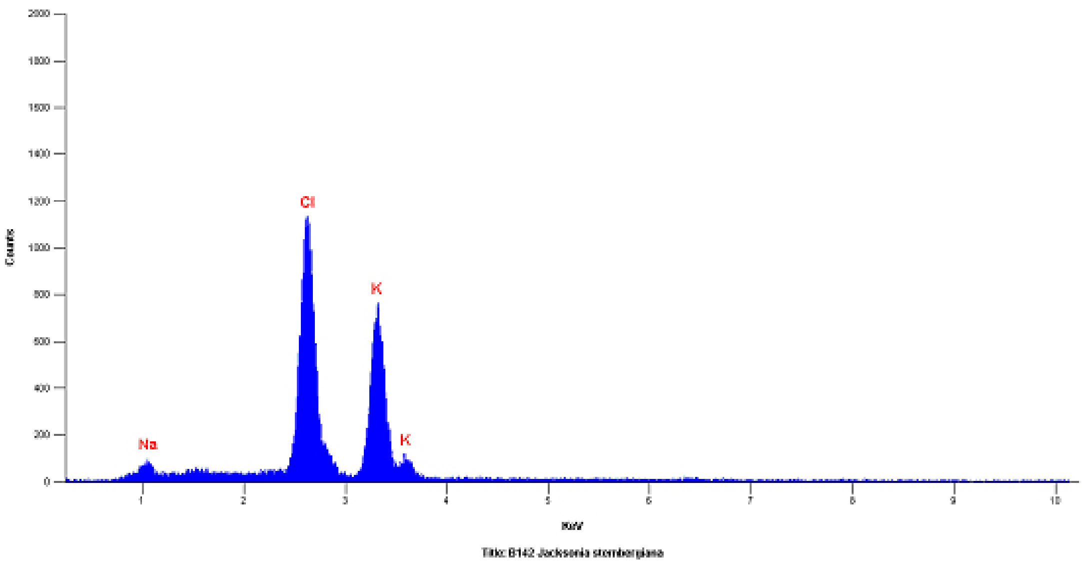
Jacksonia sternbergiana ash produces a **moderate** amount of fouling deposit by condensation at 400°C on a steel surface.

The dominant elements in the deposit are **potassium and chlorine**.

Negligible corrosion of the stainless steel at 400°C could be detected.

Jacksonia sternbergiana B142– Stub deposit

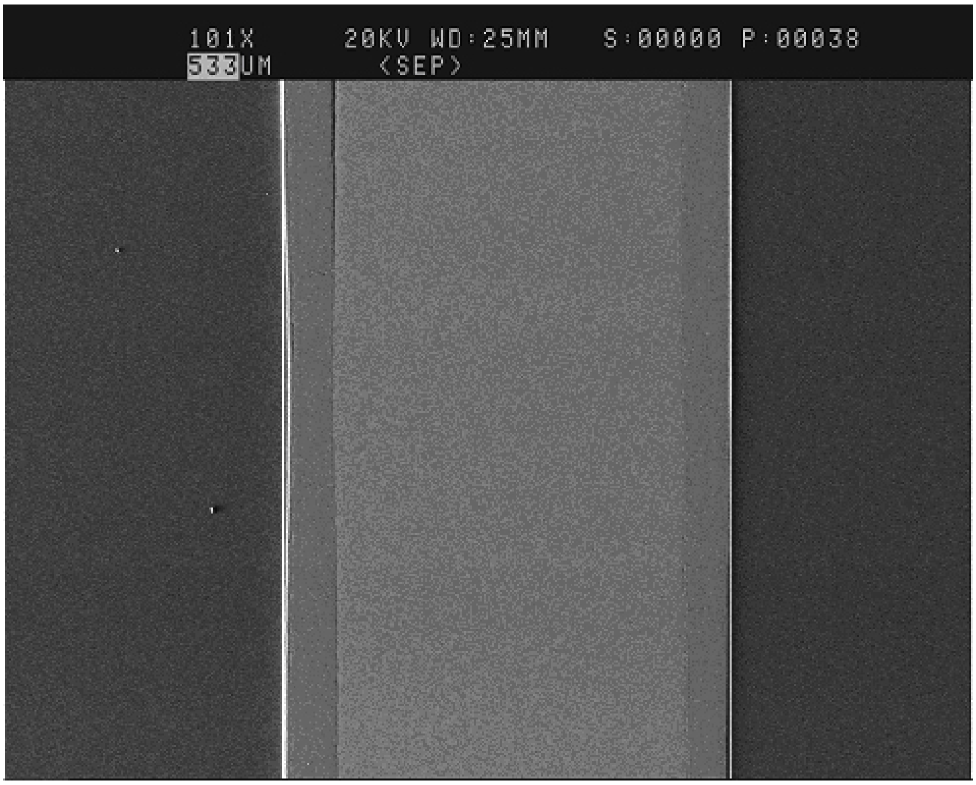


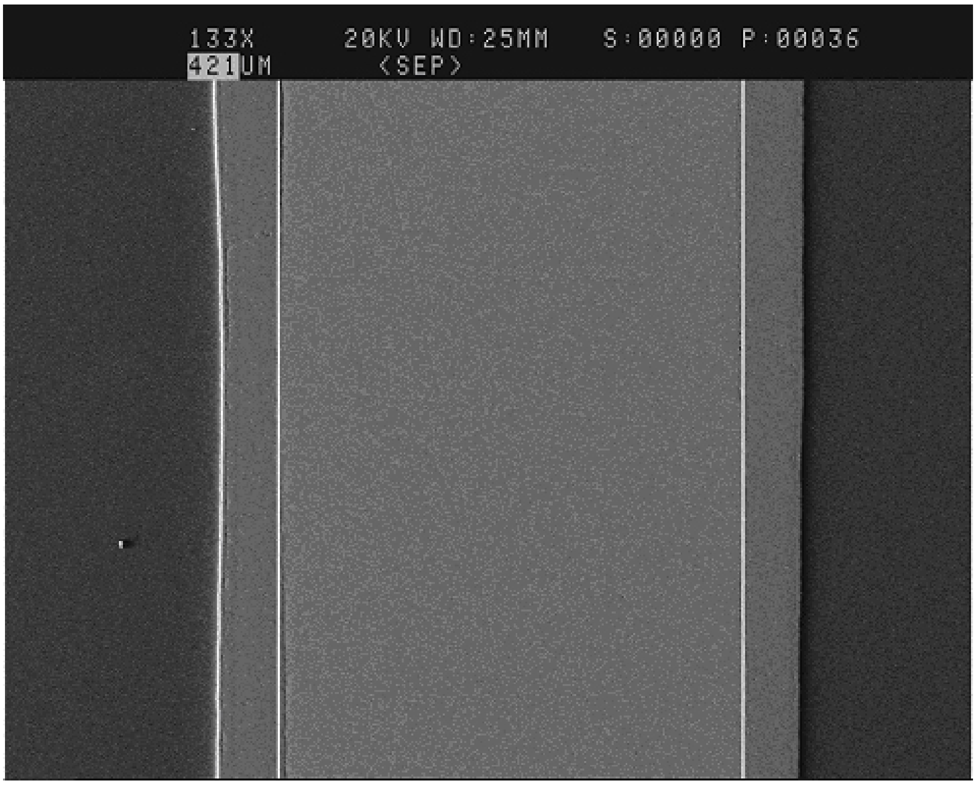


Elemental analysis of a typical particle of *Jacksonia sternbergiana*.

Jacksonia sternbergiana B142

Mild steel plate @ 800°C
(Please note measuring cursors)





Melaleuca preissiana

Ash B149

Principle

Biomass / coal is slowly burnt at temperatures up to 800°C with convective air passing over the sample. A mild steel plate is positioned close to the burning fuel so that corrosion can occur on both surfaces at 800°C. A polished stainless steel stub, suitable for scanning electron microscopy (SEM), is positioned up side down in the outlet air, where the temperature is 400°C. Volatile components from the fuel and vapours formed during combustion are able to foul / corrode the mild steel and the stainless steel at 800°C and 400°C respectively. In a simple way, this test simulates the initiation of fouling or corrosion on variable surfaces at different temperatures in a conventional boiler.

The thinning of the mild steel plate and the thickness of corrosion deposits can be related to the fuel being burnt (see Figure). Fouling deposits on the stainless steel stub are examined by SEM. Energy dispersive X-ray (EDX) spectroscopy enables elements from the fuel contributing to the deposits to be identified (see Figure).

Analytical Results

Sample combusted (as received basis)	**200g**
Ash (dry basis)	**2.15%**
Estimate of fouling Deposit (at 400°C)	**moderate**
Estimate of corrosion of steel (at 800°C)	**negligible**

Summary

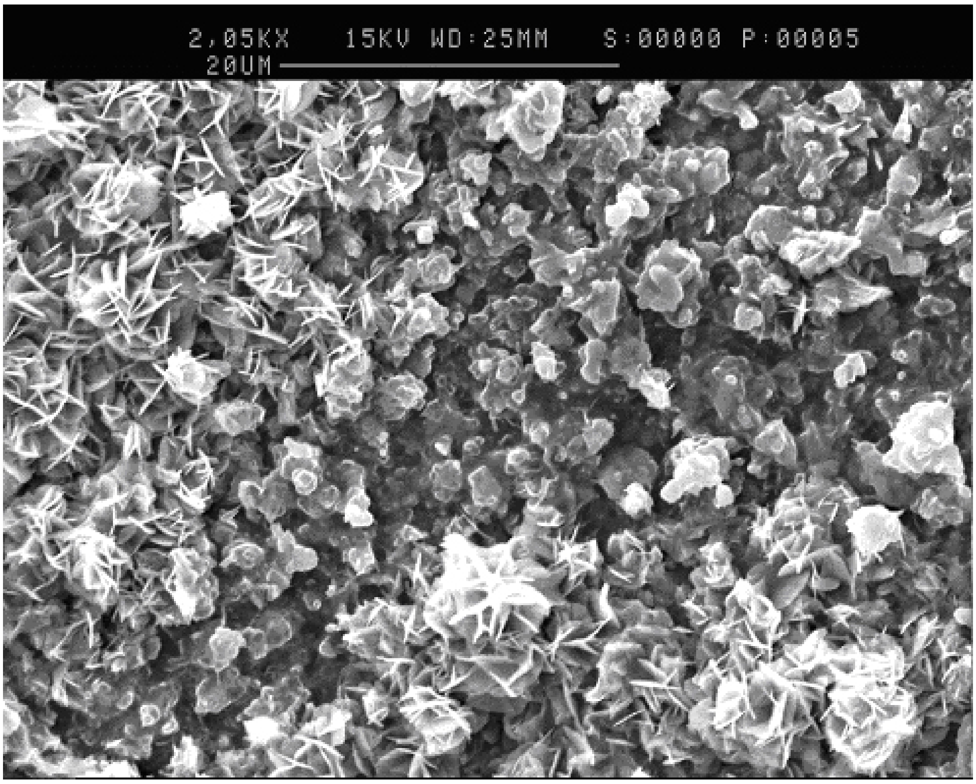
Combustion of ***Melaleuca preissiana*** causes a **negligible** increase in corrosion of mild steel at 800°C above that caused by air alone.

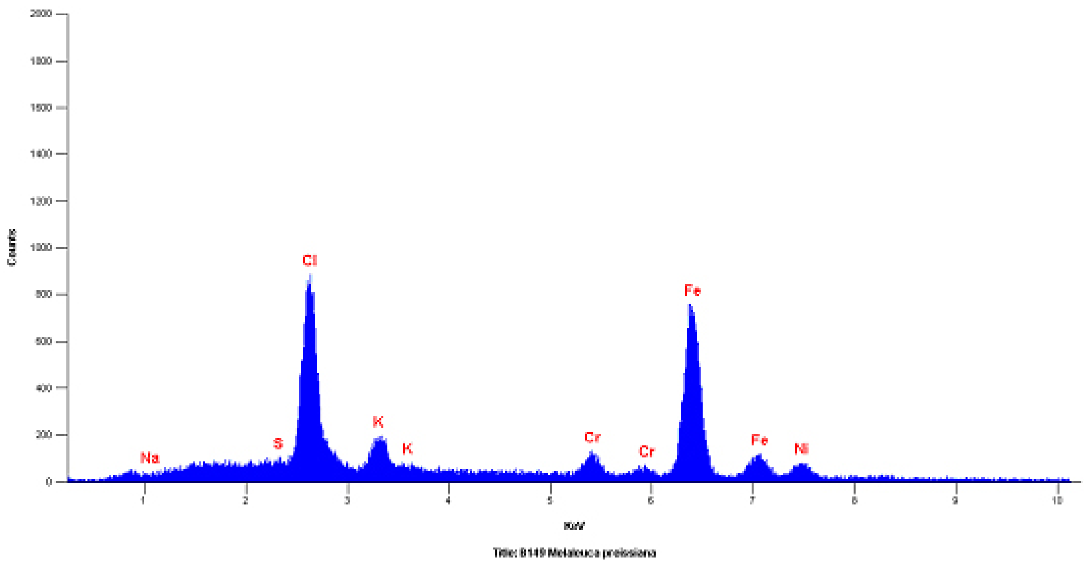
Melaleuca preissiana ash produces a **moderate** amount of fouling deposit by condensation at 400°C on a steel surface.

The dominant elements in the deposit are **potassium, chlorine and sodium**.

Minor corrosion of the stainless steel at 400°C could be detected.

Melaleuca preissiana B149– Stub deposit

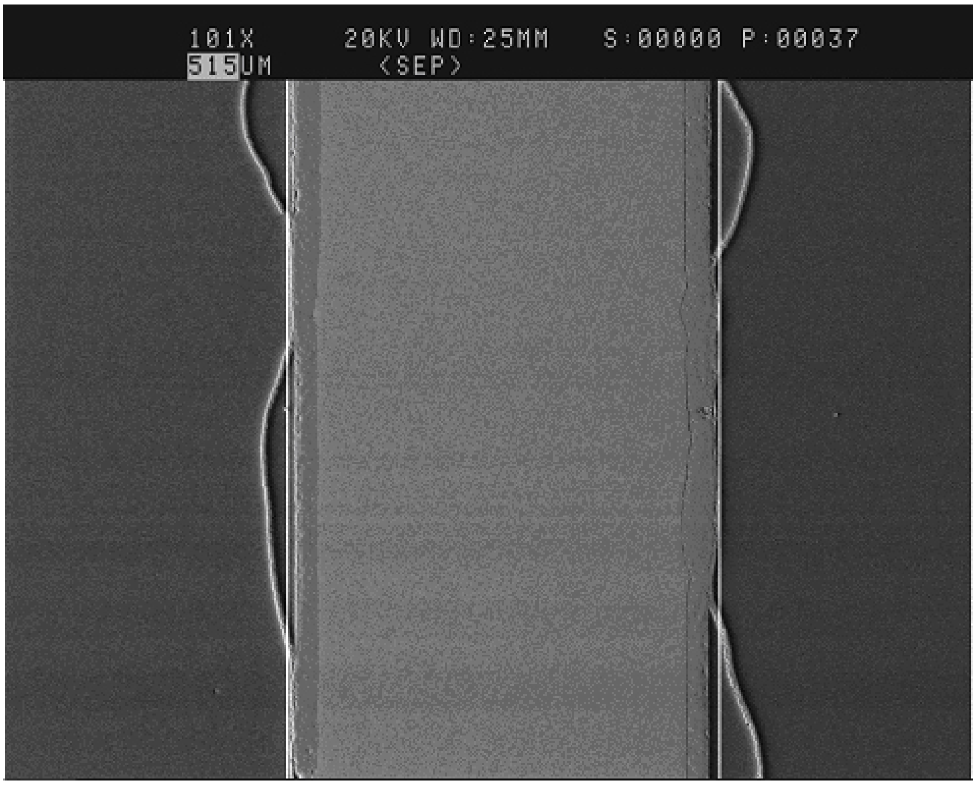


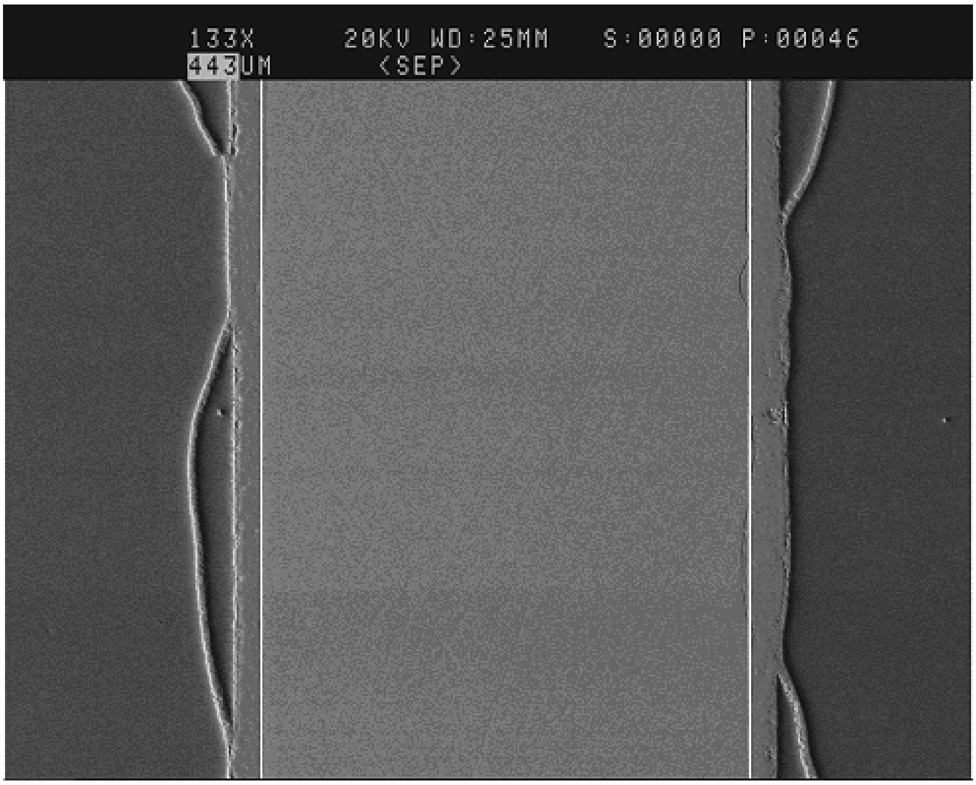


Elemental analysis of a typical particle of *Melaleuca preissiana*.

Melaleuca preissiana B149

Mild steel plate @ 800°C
(Please note measuring cursors)





Senna pleurocarpa

Ash B132

Principle

Biomass / coal is slowly burnt at temperatures up to 800°C with convective air passing over the sample. A mild steel plate is positioned close to the burning fuel so that corrosion can occur on both surfaces at 800°C. A polished stainless steel stub, suitable for scanning electron microscopy (SEM), is positioned up side down in the outlet air, where the temperature is 400°C. Volatile components from the fuel and vapours formed during combustion are able to foul / corrode the mild steel and the stainless steel at 800°C and 400°C respectively. In a simple way, this test simulates the initiation of fouling or corrosion on variable surfaces at different temperatures in a conventional boiler.

The thinning of the mild steel plate and the thickness of corrosion deposits can be related to the fuel being burnt (see Figure). Fouling deposits on the stainless steel stub are examined by SEM. Energy dispersive X-ray (EDX) spectroscopy enables elements from the fuel contributing to the deposits to be identified (see Figure).

Analytical Results

Sample combusted (as received basis)	**200g**
Ash (dry basis)	**3.75%**
Estimate of fouling Deposit (at 400°C)	**minor**
Estimate of corrosion of steel (at 800°C)	**minor**

Summary

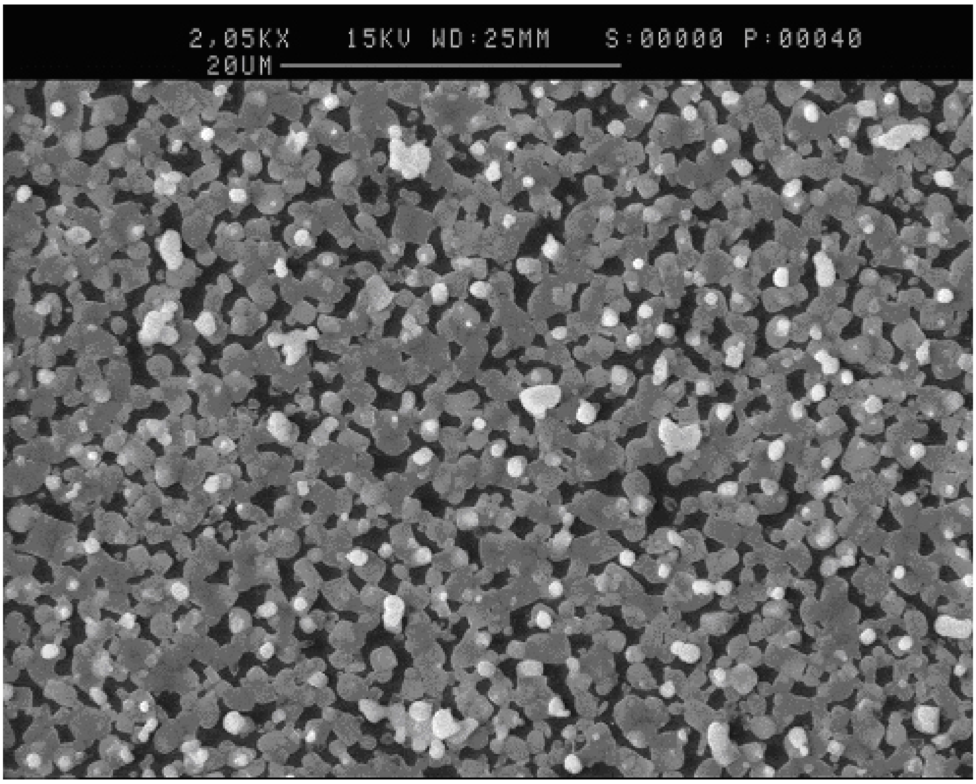
Combustion of ***Senna pleurocarpa*** causes a **minor** increase in corrosion of mild steel at 800°C above that caused by air alone.

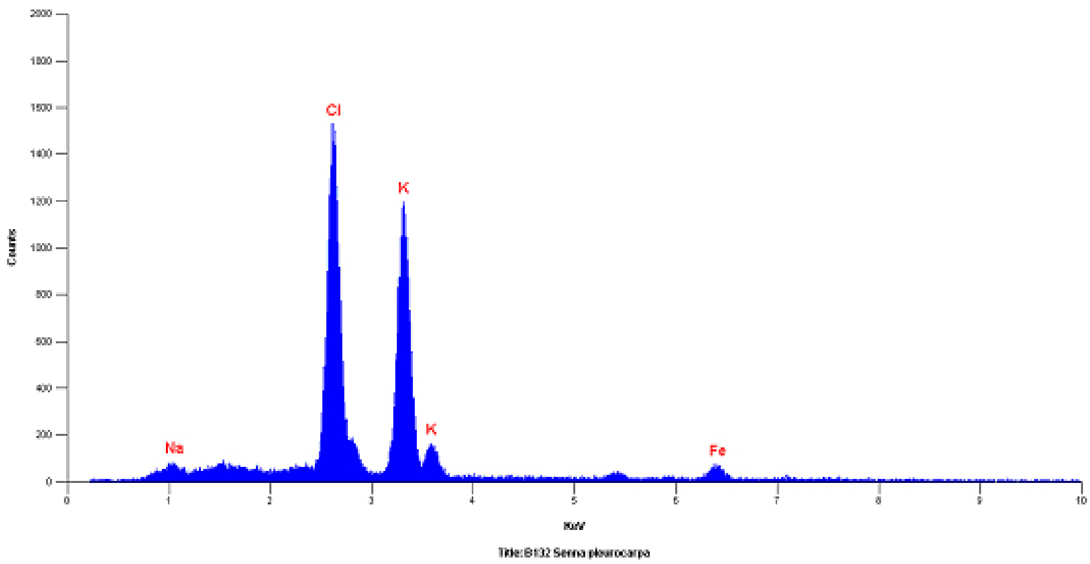
Senna pleurocarpa ash produces a **minor** amount of fouling deposit by condensation at 400°C on a steel surface.

The dominant elements in the deposit are **potassium and chlorine**.

Negligible corrosion of the stainless steel at 400°C could be detected.

Senna pleurocarpa B132– Stub deposit

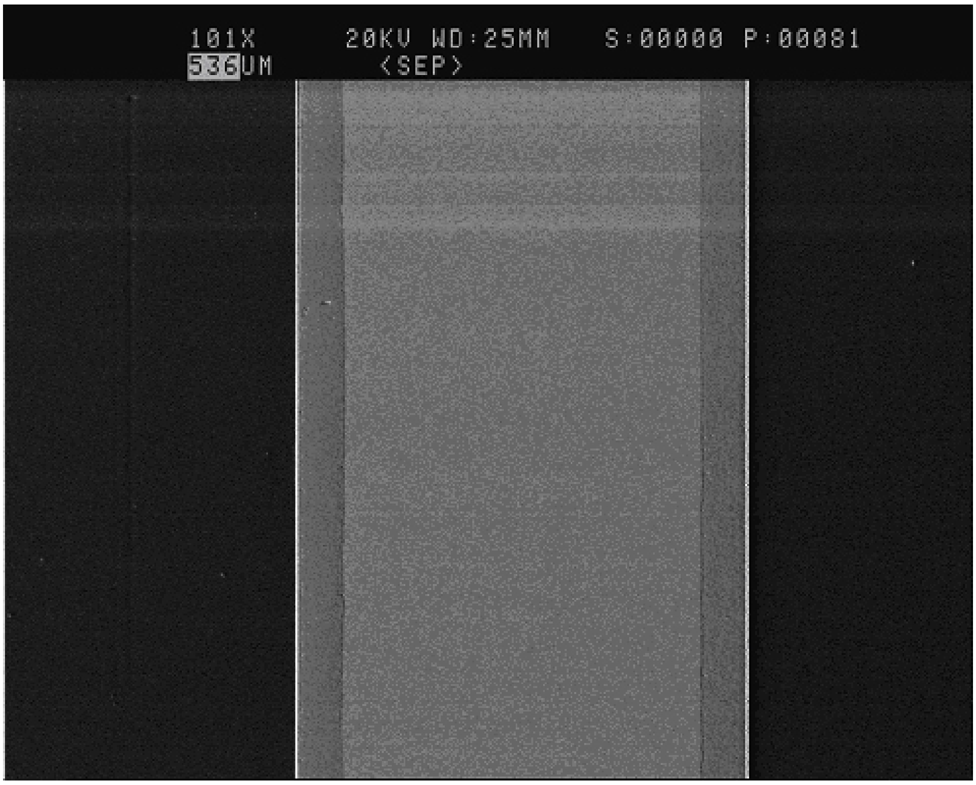


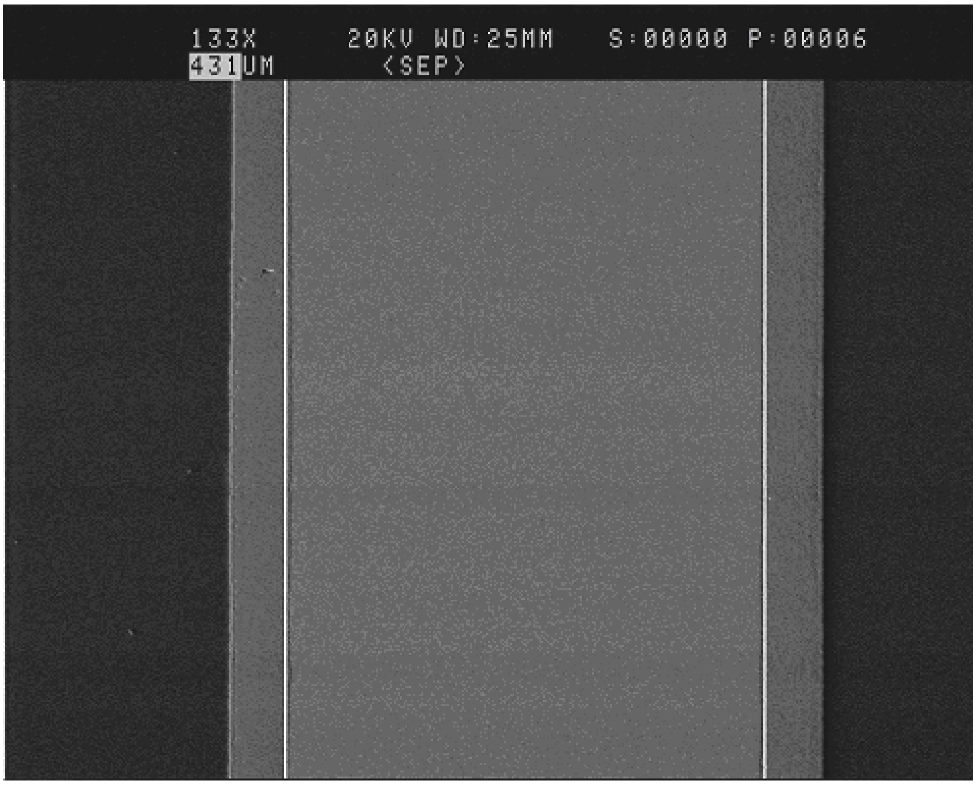


Elemental analysis of a typical particle of *Senna pleurocarpa*.

Senna pleurocarpa B132

Mild steel plate @ 800°C
(Please note measuring cursors)





Taxandria juniperina

Ash B133

Principle

Biomass / coal is slowly burnt at temperatures up to 800°C with convective air passing over the sample. A mild steel plate is positioned close to the burning fuel so that corrosion can occur on both surfaces at 800°C. A polished stainless steel stub, suitable for scanning electron microscopy (SEM), is positioned up side down in the outlet air, where the temperature is 400°C. Volatile components from the fuel and vapours formed during combustion are able to foul / corrode the mild steel and the stainless steel at 800°C and 400°C respectively. In a simple way, this test simulates the initiation of fouling or corrosion on variable surfaces at different temperatures in a conventional boiler.

The thinning of the mild steel plate and the thickness of corrosion deposits can be related to the fuel being burnt (see Figure). Fouling deposits on the stainless steel stub are examined by SEM. Energy dispersive X-ray (EDX) spectroscopy enables elements from the fuel contributing to the deposits to be identified (see Figure).

Analytical Results

Sample combusted (as received basis)	**200g**
Ash (dry basis)	**1.55%**
Estimate of fouling Deposit (at 400°C)	**minor**
Estimate of corrosion of steel (at 800°C)	**minor**

Summary

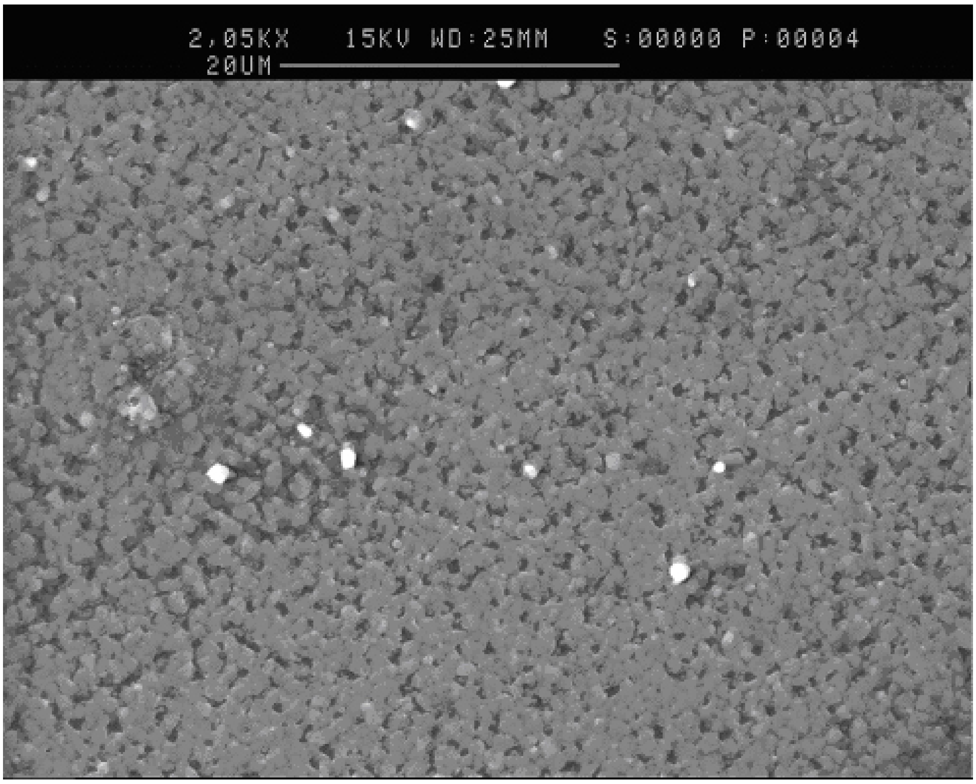
Combustion of ***Taxandria juniperina*** causes a **minor** increase in corrosion of mild steel at 800°C above that caused by air alone.

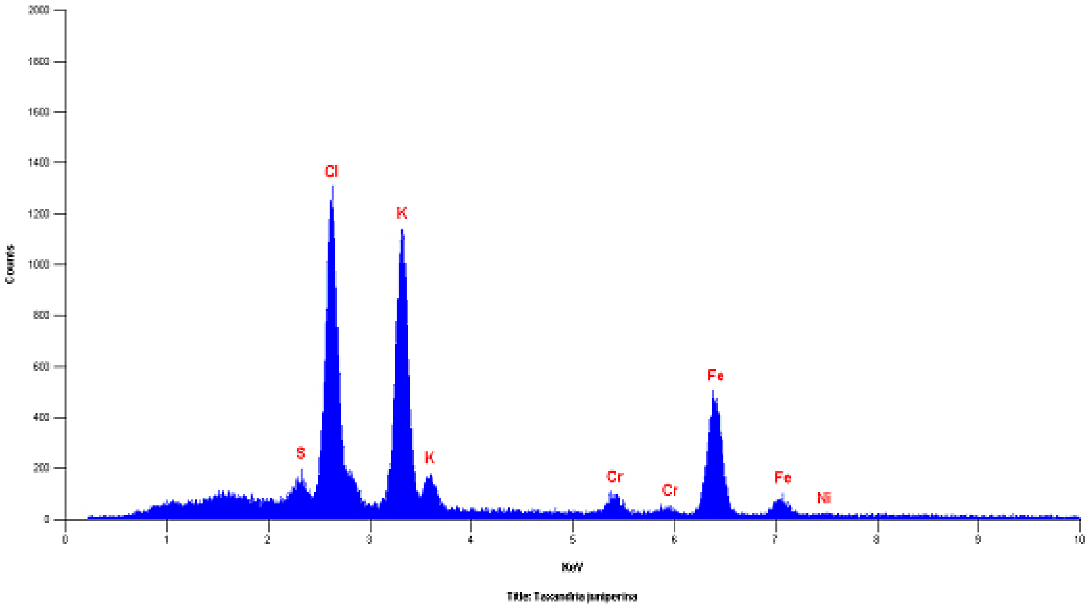
Taxandria juniperina ash produces a **minor** amount of fouling deposit by condensation at 400°C on a steel surface.

The dominant elements in the deposit are **potassium and chlorine**.

Negligible corrosion of the stainless steel at 400°C could be detected.

Taxandria juniperina B133– Stub deposit

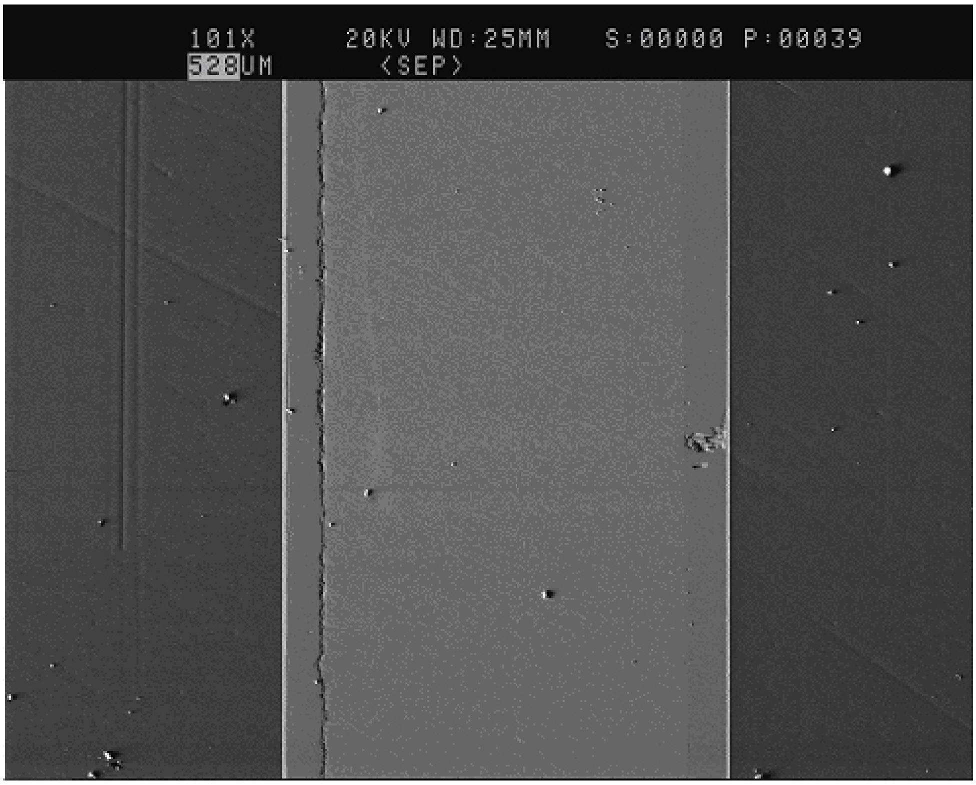


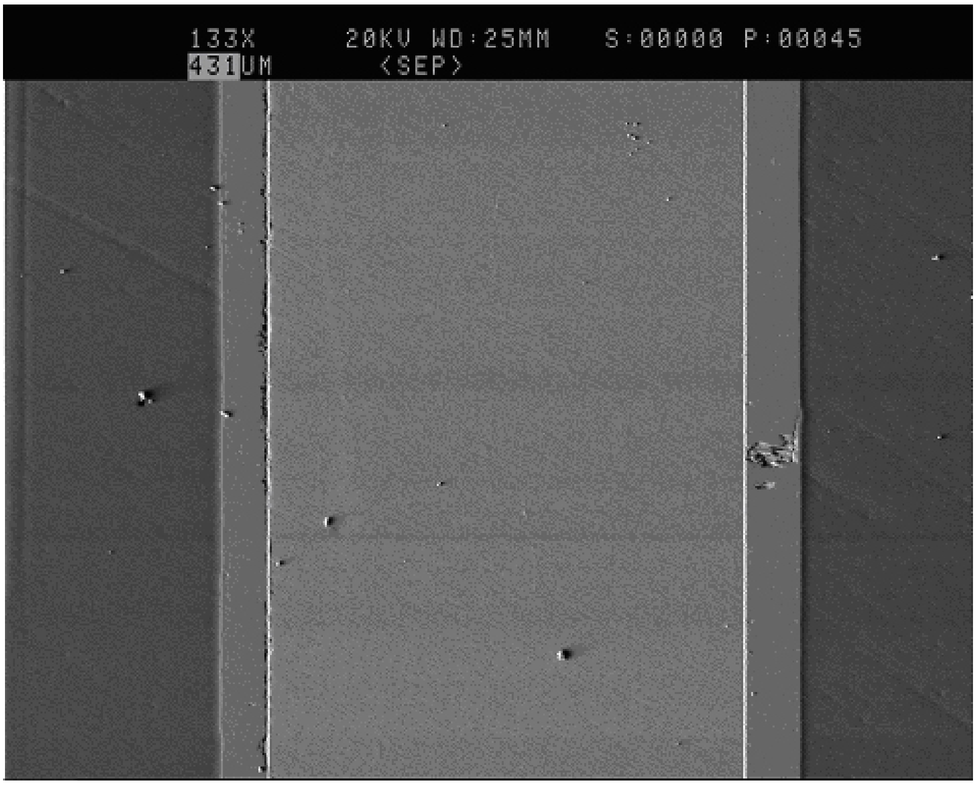


Elemental analysis of a typical particle of *Taxandria juniperina*.

Taxandria juniperina B133

Mild steel plate @ 800°C
(Please note measuring cursors)





Trymalium floribundum

Ash B146

Principle

Biomass / coal is slowly burnt at temperatures up to 800°C with convective air passing over the sample. A mild steel plate is positioned close to the burning fuel so that corrosion can occur on both surfaces at 800°C. A polished stainless steel stub, suitable for scanning electron microscopy (SEM), is positioned up side down in the outlet air, where the temperature is 400°C. Volatile components from the fuel and vapours formed during combustion are able to foul / corrode the mild steel and the stainless steel at 800°C and 400°C respectively. In a simple way, this test simulates the initiation of fouling or corrosion on variable surfaces at different temperatures in a conventional boiler.

The thinning of the mild steel plate and the thickness of corrosion deposits can be related to the fuel being burnt (see Figure). Fouling deposits on the stainless steel stub are examined by SEM. Energy dispersive X-ray (EDX) spectroscopy enables elements from the fuel contributing to the deposits to be identified (see Figure).

Analytical Results

Sample combusted (as received basis)	**200g**
Ash (dry basis)	**2.80%**
Estimate of fouling Deposit (at 400°C)	**minor**
Estimate of corrosion of steel (at 800°C)	**negligible**

Summary

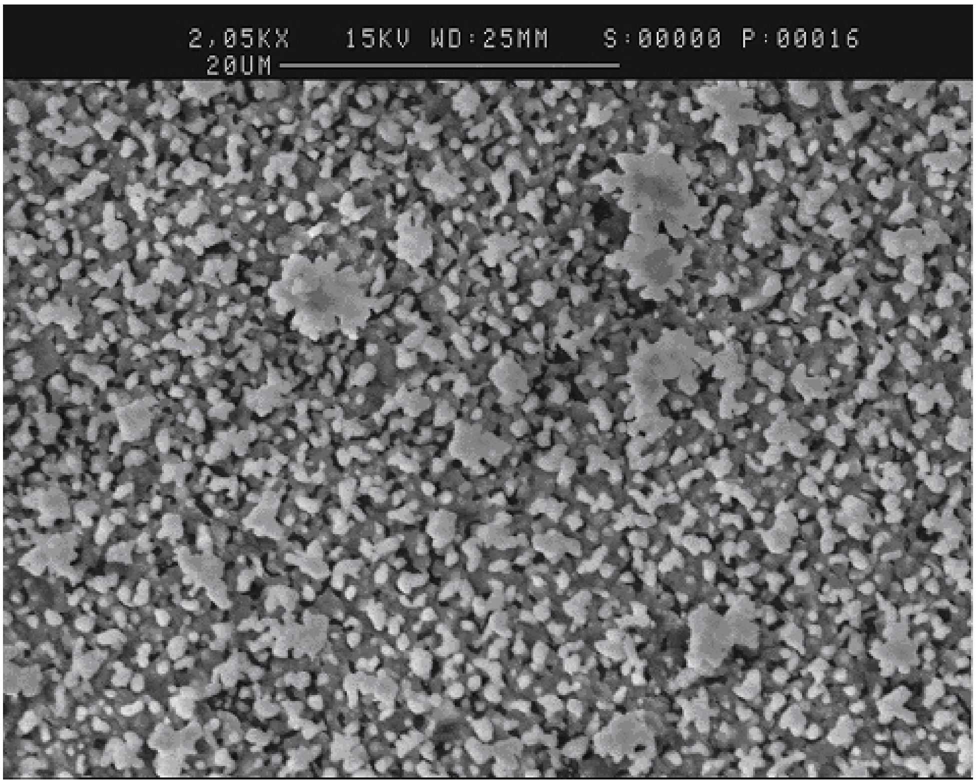
Combustion of ***Trymalium floribundum*** causes a **negligible** increase in corrosion of mild steel at 800°C above that caused by air alone.

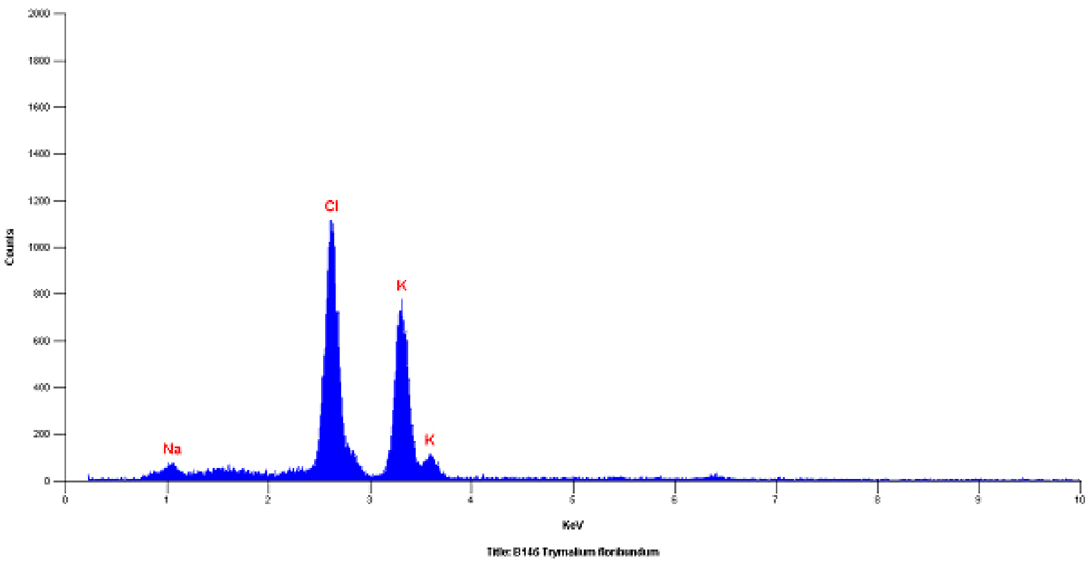
Trymalium floribundum ash produces a **minor** amount of fouling deposit by condensation at 400°C on a steel surface.

The dominant elements in the deposit are **potassium and chlorine**.

Negligible corrosion of the stainless steel at 400°C could be detected.

Trymalium floribundum B146– Stub deposit

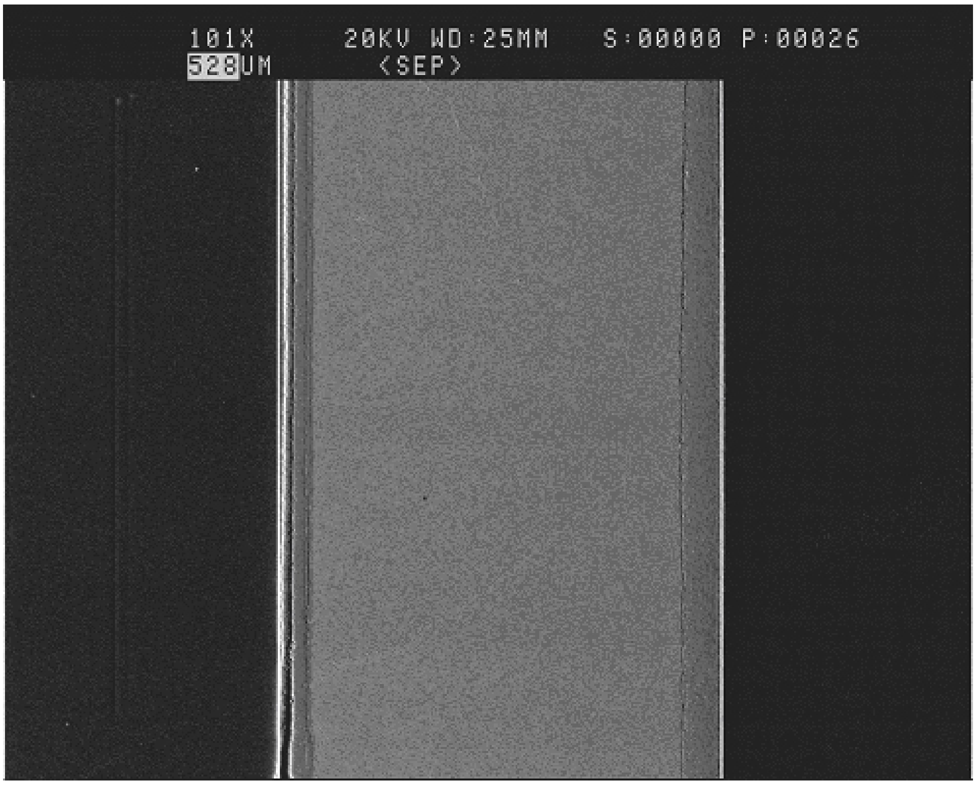


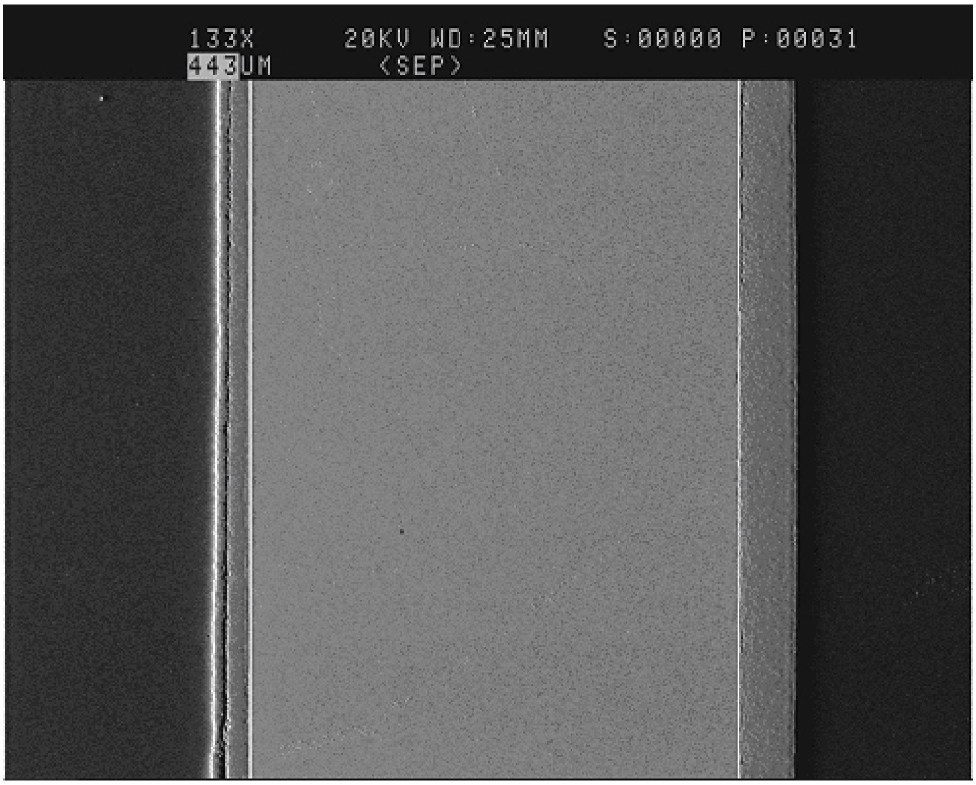


Elemental analysis of a typical particle of Trymalium floribundum.

Trymalium floribundum B146

Mild steel plate @ 800°C
(Please note measuring cursors)





Viminaria juncea

Ash B140

Principle

Biomass / coal is slowly burnt at temperatures up to 800°C with convective air passing over the sample. A mild steel plate is positioned close to the burning fuel so that corrosion can occur on both surfaces at 800°C. A polished stainless steel stub, suitable for scanning electron microscopy (SEM), is positioned up side down in the outlet air, where the temperature is 400°C. Volatile components from the fuel and vapours formed during combustion are able to foul / corrode the mild steel and the stainless steel at 800°C and 400°C respectively. In a simple way, this test simulates the initiation of fouling or corrosion on variable surfaces at different temperatures in a conventional boiler.

The thinning of the mild steel plate and the thickness of corrosion deposits can be related to the fuel being burnt (see Figure). Fouling deposits on the stainless steel stub are examined by SEM. Energy dispersive X-ray (EDX) spectroscopy enables elements from the fuel contributing to the deposits to be identified (see Figure).

Analytical Results

Sample combusted (as received basis)	**200g**
Ash (dry basis)	**1.60%**
Estimate of fouling Deposit (at 400°C)	**moderate**
Estimate of corrosion of steel (at 800°C)	**minor**

Summary

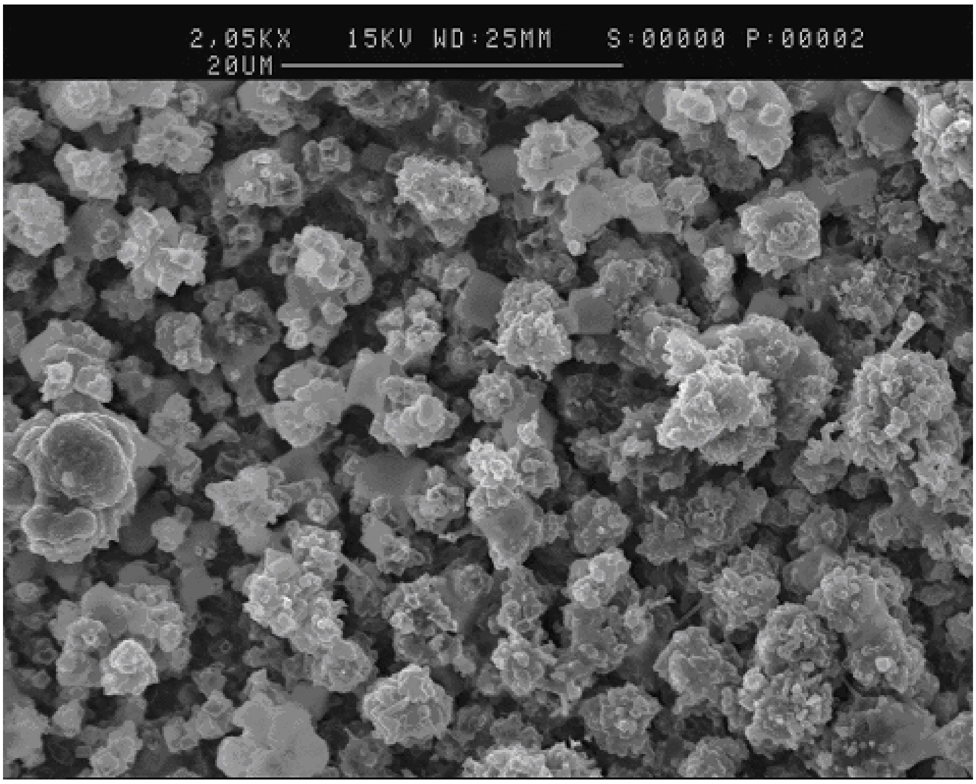
Combustion of ***Viminaria juncea*** causes a **minor** increase in corrosion of mild steel at 800°C above that caused by air alone.

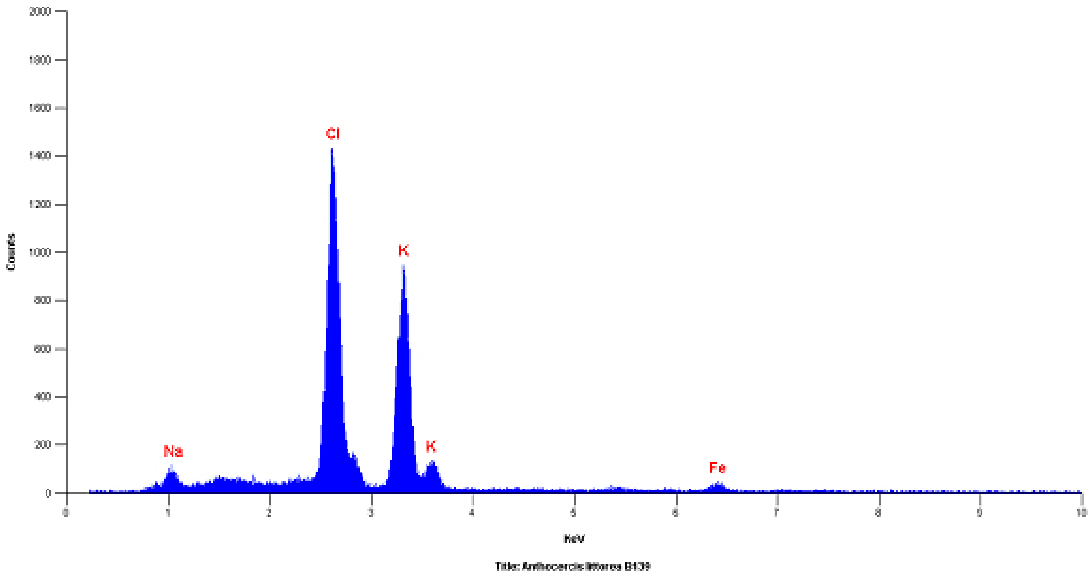
Viminaria juncea ash produces a **moderate** amount of fouling deposit by condensation at 400°C on a steel surface.

The dominant elements in the deposit are **potassium, chlorine and sodium**.

Minor corrosion of the stainless steel at 400°C could be detected.

Viminaria juncea B140– Stub deposit

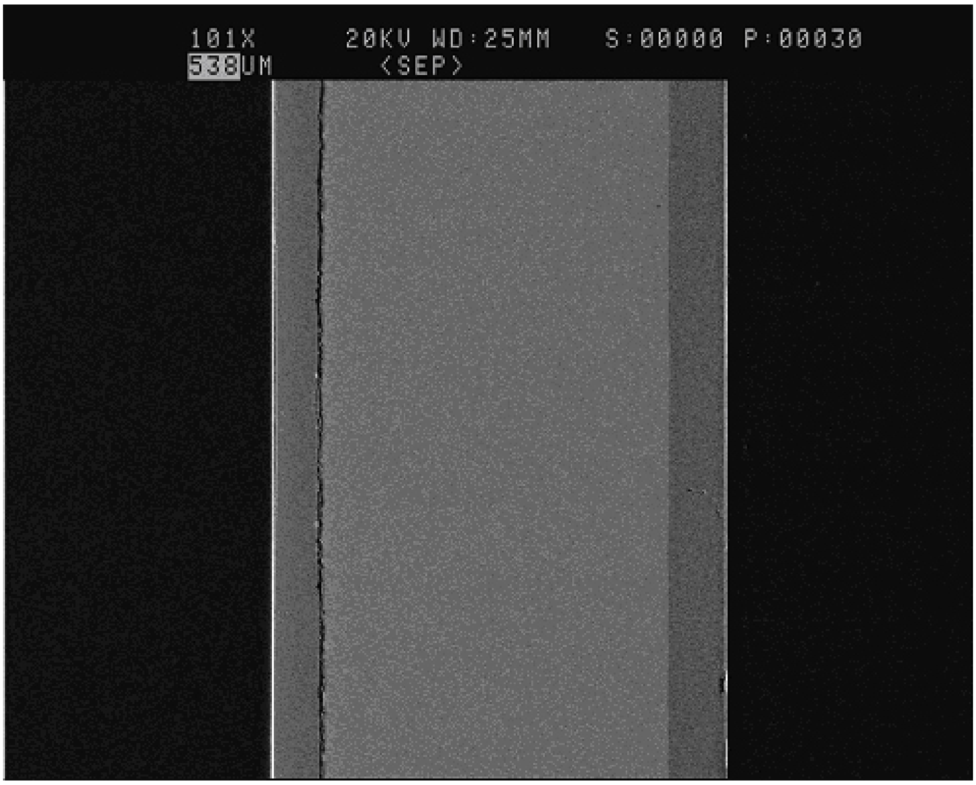


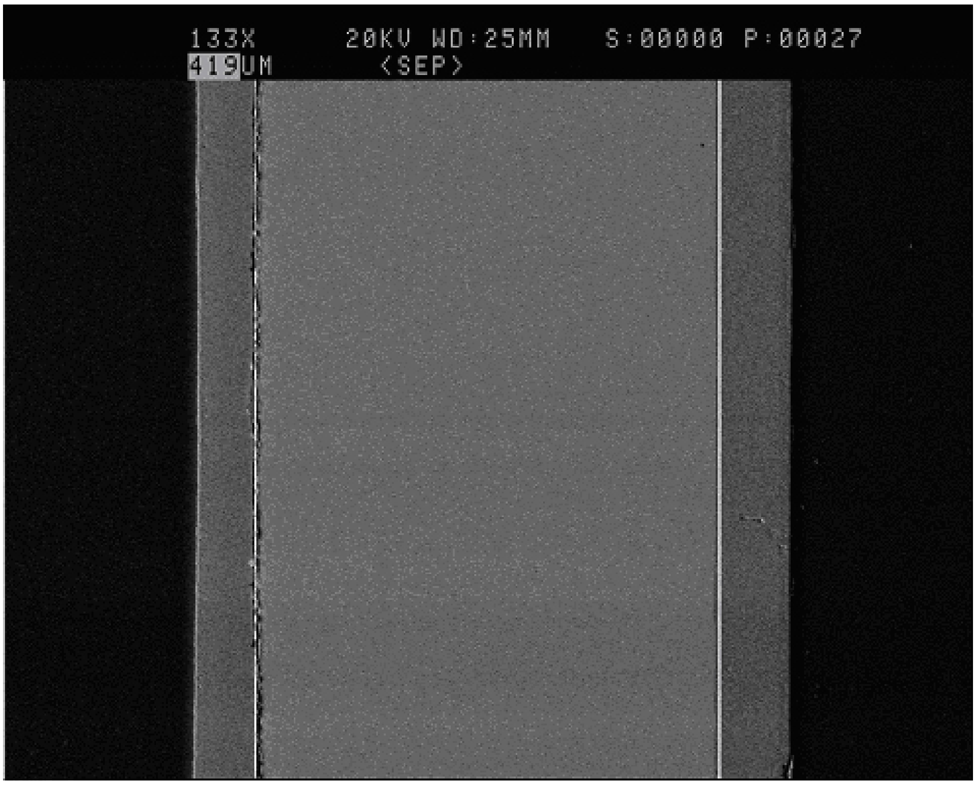


Elemental analysis of a typical particle of *Viminaria juncea*.

Viminaria juncea B140

Mild steel plate @ 800°C
(Please note measuring cursors)





Search Report

Appendix 4

Assessment of timber potential of low-rainfall species

Graeme Siemon, Forest Products Commission

WOODY BIOMASS PROJECT
ASSESSMENT OF SPECIES FOR SOLID WOOD USE

The following information relating to the potential of a wide range of species, suitable for use in semi-arid and arid areas of the State for solid wood production, has been extracted from FPC Timber Technology reports and records.

Wood properties

Wood density and shrinkage of a large number of Goldfields species has been reported (1), as well as properties of Wheatbelt species (2, 3, 4). Several commercial species are referred to in Bootle's '*Wood in Australia. Types, properties and uses*' (5). Basic density, air-dry density and tangential and radial shrinkage data are given in Table 1.

Sawmilling

Backsawing is recommended for most species, except for example where rays are a feature and quartersawing gives better results, e.g. the *Grevillea* spp. The former method produces the attractive cathedral pattern, but tangential shrinkage or swelling of the board's face may be a problem at times. The latter method has advantages in producing flooring timber because radial shrinkage and swelling is less than tangential.

Fine kerf sawing is required for small diameter logs, but high wood density slows production rates. Stellite tipped saws have given good results, and there is general discussion on sawing in the Goldfields report (p18) (1).

Drying

As a general rule, the higher the air-dry or basic densities, the more conservative the drying schedule required. A recommended drying schedule is given for high density Goldfields timbers (p33 of 1; 8).

Utilisation

General basic information on utilisation of semi-arid species is based on FPC records, with some information from Chippendale (9) and Boland *et al*. (10). A general summary of marri utilisation is given (12).

<u>Sawn timber</u>
Trees grown for commercial purposes in semi-arid areas will be more economic if specialty timber is produced, because there will be other objectives involved, including prevention or amelioration of salinity, erosion control, and stock protection. All factors must be considered because it is unlikely that timber production alone can be commercially justified. Commodity timbers would not be economic.

Suitable products would include flooring, and hardness as measured by the Janka hardness test is directly related to air-dry density of the species. Some hardness data are given on p51 of the Goldfields report (1).

Gluing

Research has indicated that gluing high density eucalypts is difficult because of problems with glue penetration, and cold pressing is required (1, 6). A hot press sets the adhesive before sufficient penetration has been achieved.

Specialty timber and craftwood

There are a large number of species with potential for this use, including those suitable for turnery and marquetry. Table 2 lists the machining and working properties of a large number of these species.

Reconstituted wood

Alternative possible uses include reconstituted wood (e.g. MDF). For example, a CSIRO report (7) discussed the potential for MDF manufacture using *Acacia saligna, A. microbotrya*, and *Eucalyptus loxophleba subsp lissophloia, E. polybractea* and *E. horistes*. Bark removal is a problem with small trees, but is necessary to achieve good quality. The boards had higher density than current commercial boards, and internal bond strengths were lower than required. Although *A. saligna* is promising, more research would be needed. More of a problem is the overall market situation regarding the current excess production capacity around the world and product demand.

Bioenergy

Use of woody residues for bioenergy is becoming more important, as indicated by construction of a plant in Narrogin to use oil mallee wood for energy generation after the leaves have cineole extracted. The amount of heat available from hardwoods is about 19 MJ/kg oven dry, and is mainly affected by moisture content. There will heat losses of perhaps 25% in the system.

RECOMMENDED SPECIES

When making a decision regarding the most suitable species to plant, the existing resource should be taken into account because it can supply markets in the next fifteen to twenty years until plantation material is suitable for harvesting. However, preference should be given to faster growing species. As an example, the Goldfields species currently being assessed by the FPC are *E. lesouefii*, *E. salmonophloia, E. salubris and E. transcontinentalis*, but only the second species is considered fast-growing. *Acacia acuminata* is included in the list below because it can also be a host tree for sandalwood, while *Casuarina obesa* and *E. salicola* are salt tolerant as well as producing timber.

Based on existing Timber Technology knowledge, the recommended species with suitable wood properties for utilisation as well as fast growth include:
Acacia acuminata
Allocasuarina huegeliana
Casuarina obesa
Corymbia calophylla
Eucalyptus astringens
E. camaldulensis
E. gomphocephala
E. longicornis
E. occidentalis
E. salmonophloia
E. wandoo ssp wandoo
Myoporum platycarpum.

Although they have slower growth rates, the following species could be considered because of their craft potential:
Grevillea striata
Pittosporum phylliraeoides.

G.R. Siemon
Timber Scientist
Forest Products Commission WA

1 October 2002

REFERENCES

1. Siemon, G.R. and *Kealley, I.G. (1999). Goldfields Timber Research Report. Report by the Research Project Steering Committee. Department of Commerce and Trade, Goldfields Esperance Development Commission, Department of Conservation and Land Management, Curtin University Kalgoorlie Campus.

2. Hill, P. and Brennan, G.K. (2000). Wood properties of southern gidgee (*Acacia pruinocarpa*) from different sites in the Pilbara and Goldfields regions of Western Australia. CALMScience 3(3): 317-322.

3. Brennan, G.K., Siemon, G.R. and Pitcher, J. (1997). Timber properties and market potential of selected Wheatbelt species. 2. Raspberry jam, brown mallet and York gum. Department of Conservation and Land Management, CALM Timber Technology Internal Report.

4. Siemon, G.R. and Pitcher, J. (1996). Timber properties and market potential of selected Wheatbelt species. 2. Rock sheoak and swamp sheoak. Department of Conservation and Land Management, CALM Timber Technology Internal Report.

5. Bootle, K.R. (1983). *Wood in Australia. Types, properties and uses*. McGraw-Hill Book Co, Sydney.

6. Brennan, G.K. and Newby, P. (1992). Potential of Western Australian Eastern goldfields timbers for high quality wood products. Australian Forestry 55: 74-79.

7. Freischmidt, G., Langfors, N.G., Terrill, S., Williams, M.D and Collins, P.J. (1999). Evaluation of Western Australian hardwoods for wood based composites. CSIRO Forestry and Forest Products Client Report.

8. Piper, P. (2000). Drying gimlet and Goldfields blackbutt timber. Department of Conservation and Land Management, Forest Products Division. Unpublished report.

9. Chippendale, G.M. (1973). *Eucalypts of the Western Australian goldfields (and the adjacent wheatbelt*). Australian Government Publishing Service, Canberra.

10. Boland, D.J., Brooker, M.I.H., Chippendale, G.M., Hall, N., Hyland, B.P.M., Johnston, R.D., Kleinig, D.A. and Turner, J.D. (1984). *Forest trees of Australia*. Nelson-CSIRO.

11. Piper, P. (2001). Drying behaviour and utilisation potential of Preiss's paperbark (*Melaleuca preissiana*). Forest Products Commission WA. Unpublished report.

12. Siemon, G.R. (2001). Utilisation of sawn and round marri timber (*Corymbia calophylla*). Forest Products Commission WA. Unpublished report.

Table 1.
Wood properties and processing of potential species for solid wood production

Species	Basic density (kg/m3)	Air-dry density (kg/m3)	Shrinkage %		Heart Colour	Grain	Texture	Drying	Utilisation
			Tan	Rad					
Acacia acuminata ssp acuminata	940[3]	1040[3] 1170[1]	1.8[3]	1.2[3]	Dark reddish-brown	Interlocked. Fiddleback common	Fine and even	Slow drying schedule because of high wood density	Turnery, furniture, decorative woodware, fencing. Potential specialty timber.
A. aff redolens									
A. aneura	1020[1]	1195[1]	2.3[1]	2.0[1]	Dark brown, contrasting golden yellow	Interlocked	Fine	“	Previously fencing, Aboriginal use. Turns and polishes well. Fodder potential.
A. grasbyi	1050[1]	1230[1]	2.9[1]	1.9[1]	Dark brown, lighter golden streaks		Fine		Potential specialty timber.
A. lasiocalyx		795							
A. papyrocarpa	1080[1]	1235[1]	1.5[1]	1.0[1]	Chocolate to golden-brown	Rippled	Fine		Previously fencing and firewood. Potential specialty timber.
A. pruinocarpa	970[1] 925[2]	1150[1] 1085[2]	2.9[1] 2.5[2]	2.3[1] 1.7[2]	Dark brown	Tends to wavy	Fine	“	Potential specialty timber.
A. subfalcata									
Agonis juniperina					Brownish			Use jarrah drying schedule	Potential specialty timber.
Allocasuarina huegeliana	720[4]	895[4]	6.5[4]	3.5[4]	Deep red-brown		Coarse		Potential specialty timber
Brachychiton gregorii									
Callitris glaucophylla	580[5]	680[5]	2.8[5]	2.1[5]	Pale yellow	Straight	Fine and even	Easy to dry	Flooring, lining, posts and small poles.
Casuarina obesa	650[4]	820[4]	9.2[4]	3.2[4]	Straw colour to creamy-brown				Potential specialty timber.

Species	Basic density (kg/m3)	Air-dry density (kg/m3)	Shrinkage		Heart Colour	Grain	Texture	Drying	Utilisation
			Tan	Rad					
C. pauper	1095[1]	1290[1]	2.6[1]	2.1[1]	Chocolate to reddish-brown		Fine		Fencing, firewood and craftwood (turnery).
Corymbia calophylla	580(R) 650(M)	790(R) 835(M)	6.5	3.5	Pale brown	Slightly interlocked	Coarse but even		Furniture (‘Natural Feature Grade’), some flooring.
Eremophila oldfieldii ssp oldfieldii	710	850	3.4[1]	2.3[1]	Brownish	Distinctive patterns	Medium		Craftwork and woodturning.
Eucalyptus accedens					Dark red		Medium	Slow drying schedule because of high wood density	Potential flooring
E. argyphea								“	
E. astringens ssp astringens	865[3]	1095[3]	7.1[3]	5.5[3]	Light red-brown to dark grey-brown	Often interlocked	Fine and even	“	Tool handles, mining timbers, firewood. Potential flooring. Bark tannins not commercial now.
E. astringens ssp redacta								“	
E. brockwayi		1085[1]	5.0	4.0	Brownish-red	Straight	Fine	“	Potential woodturning and craftwork.
E. camaldulensis var obtusa			est 8.0[5]	est 4.0[5]				“	
E. capillosa ssp capillosa								“	
E. clelandii	975[1]	1130[1]	4.8[1]	3.3[1]	Light chocolate-brown	Patterned grain	Fine	“	Potential woodturning and craftwork.
E. cornuta		1130[10]			Pale yellow-brown	Interlocked		“	Wheelwright work.
E. dundasii	840[1]	1030[1]	6.0[1]	4.5[1]	Light brown to reddish	Medium	Fine	“	Mining timber, fencing. Potential craftwork.
E. flocktoniaea ssp flocktoniaea		1075[1]			Deep reddish brown		Fine	“	Potential wood turning and craftwork.

Species	Basic density (kg/m3)	Air-dry density (kg/m3)	Shrinkage		Heart Colour	Grain	Texture	Drying	Utilisation
			Tan	Rad					
E. gomphocephala	840[5]	1030[5]	7.0[5]	3.0[5]	Yellowish	Interlocked	Close	“	Flooring, general uses
E. kondininensis								“	
E. lesouefii	880[1]	1130[1]	5.5[1]	4.2[1]	Chocolate brown		Fine	“	Mining timber and fuelwood. Potential flooring and craftwork, furniture.
E. longicornis	955[1]	1145[1]	6.8[1]	5.6[1]	Reddish	Interlocked	Fine	“	Tool handles, mining timbers, fuelwood, fencing. Potential for furniture.
E. loxophleba ssp loxophleba	885[3]	1060[3]	5.0[3]	2.5[3]	Yellow-brown	Interlocked		“	Mallets, poles, posts. Potentail craftwork.
E. loxophleba ssp supralaevis									
E. melanoxylon	870[1]	1130[1]	7.2[1]	6.0[1]	Dark brown (obvious growth rings)			“	Potential woodturning and craftwork.
E. occidentalis					Pale brown	Straight		“	
E. ornata									
E. rudis ssp rudis	630[6]	815[6]	10.0[6]	5.0[6]	Pale brown to reddish	Cross-grained			Firewood.
E. salicola	940[1]	1165[1]	5.3[1]	3.8[1]	Brownish-red		Fine - medium		Recommended for woodturning and general craftwork.
E. salmonophloia	870[1]	1040[1]	5.8[1]	4.0[1]	Red to red-brown	Straight		“	Round and sawn mining timber, firewood, sleepers. Potential for flooring and furniture, flutes.
E. salubris	940[1]	1225[1]	4.9[1]	3.8[1]	Pale brown, orange tint		Fine	“	Fencing, posts, mining timber fuelwood. Potential for flooring and furniture.
E. todtiana									

Species	Basic density (kg/m3)	Air-dry density (kg/m3)	Shrinkage		Heart Colour	Grain	Texture	Drying	Utilisation
			Tan	Rad					
E. transcontinentalis	925[1]	1080[1]	5.7[1]	4.2[1]	Red-brown		Fine		Mining timber and fuelwood. Potential flooring, panelling and fine design furniture, musical instruments.
E. urna									
E. wandoo ssp wandoo	920[5]	1110[5]	4.0[5]	2.5[5]	Yellow-to reddish-brown		Medium	"	Construction, poles, sleepers, flooring.
Grevillea excelsior		770[1]							
G. striata	820[1]	965[1]	3.3[1]	2.0[1]	Rich red	Straight			Potential for furniture, marquetry inlays.
Hakea laurina									
Melaleuca lanceolata		560[10]			Pinkish-brown to brown				Firewood, round timber for fencing
M. preissiana					Mahogany		Highly figured		Potential for specialty timber (11).
M. rhaphiophylla					Yellow-brown				
Myoporum platycarpum ssp platycarpum		1025[1]							Potential for craftwork.
Pittosporum angustifolium									
P. phylliraeoides	640[1]	805[1]	7.4[1]	3.3[1]	Blonde	Patterned	Fine		Potential for craftwork, inlays.
Santalum lanceolatum					Golden yellow	Interlocked	Fine		Excellent for woodturning and general craftwork.
S. spicatum	785[1]	905[1]	1.6[1]	1.4[1]	Yellow-brown		Fine		Incense, craftwork.

Table 2
Average ratings of machining and working properties of selected timbers
(1 = very poor, 2 = poor, 3 = average, 4 = good, 5 = excellent, U = untested)
Ratings are taken from Siemon and Kealley (1).

Species	Common name	Turning	Machin-ability	Boring/ drilling	Hardness	Screw-holding	Stability	Sanding	Gluing	Finishing
Acacia acuminata	Jam	4	4	4	5	4	4	5	4	5
A. aneura	Mulga	3.5	4	4	5	4	4	4.5	4	5
A. grasbyi	Miniritchie	5	3	4	5	4	2	4	U	4
A. lasiocalyx	Silver wattle	5	3	4	2	3	3	2	U	3.5
A. papyrocarpa	Western myall	5	4	5	5	4	5	5	4	5
A. pruinocarpa	Gidgee	4	3	4	4	4	3	4	U	4
Agonis juniperina	Warren River cedar									
Allocasuarina huegeliana	Rock sheoak	4	3	5	4	4	4	4	4	4
Brachychiton gregorii	Kurrajong	3	4	3	2	2	3	2	4	3
Callitris glaucophylla	White cypress pine	4.5	4	4	3	3	3	2	3	4
Casuarina obesa	Swamp sheoak									
C. pauper	Black oak/Belah	4	3	5	4.5	4	3	4	4	5
Corymbia calophylla	Marri									
Eremophila oldfieldii ssp oldfieldii	Pixie bush	4	2	3	3	3	2	3	U	3
Eucalyptus accedens										
E. astringens ssp astringens										
E. brockwayi	Dundas mahogany	5	5	4	4.5	4	4	5	4	5
E. camaldulensis	River red gum	3	4	4	3	3	3	4	U	4
E. capillosa	Inland mallee	3	3	4	5	4	3	4	3	4
E. clelandii	Cleland's blackbutt	4	4	4	4.5	4	4	4	U	4
E. cornuta										
E. dundasii	Dundas blackbutt	4	4	4	5	4	4	4	4	4
E. flocktoniae	Merrit	3	3	4	4	4	4	4	U	4
E. gomphocephala										

Species	Common name	Turning	Machin-ability	Boring/ drilling	Hardness	Screw-holding	Stability	Sanding	Gluing	Finishing
E. lesouefii	Goldfields blackbutt	4	4	4	5	4	4	5	4	5
E. longicornis	Red morrel	3	2	4	5	4	3	3.5	4	3
E. loxophleba var lissophloia	Mallee York gum	4.5	2	5	4	4	4	4.5	3	3
E. melanoxylon	Black morrel	5	4	5	5	4	4	5	4	5
E. occidentalis										
E. salicola	Salt gum	4.5	5	5	4	4	5	4.5	U	5
E. salmonophloia	Salmon gum	4	4	4	4.5	4	4	4	4	4
E. salubris	Gimlet	4.5	3.5	4	5	5	4	5	4	5
E. stricklandii	Strickland's gum	3	4	4	4	4	3	4	U	4
E. transcontinentalis	Redwood/Boongul	5	5	4	4	4	5	4.5	4	5
E. wandoo ssp wandoo	Wandoo									
Grevillea striata	Beefwood	5	4	3	3	3	3	1	4	3
Melaleuca lanceolata										
M. preissiana										
M. raphiophylla										
Myoporum platycarpum	Sugar tree	4.5	4	4	3.5	4	3	3	U	4
Pittosporum phylliraeoides var microcarpa	Native willow	5	5	5	3	4	5	5	4	5
Santalum lanceolatum	Plumbush	5	5	5	3	4	4	4	4	5
S. spicatum	Sandalwood	5	5	5	4	4	4	4	4	5

Search Report

Appendix 5

Investigation of timber properties of selected Western Australian species

Part One

Forest Products Commission

SEARCH PROJECT

WOOD PROPERTIES AND POSSIBLE SOLID WOOD PRODUCTS FROM SELECTED WESTERN AUSTRALIAN TIMBERS

PART 1: LOG DESCRIPTION, SAWMILLING AND WOOD PROPERTIES

SUMMARY

Twelve Western Australian native species were assessed for their sawn timber potential and wood properties, as part of the nationally funded Search Project. The species assessed were *Acacia aff. redolens, A. bartleana Maslin (ms), Eucalyptus accedens, E. argyphea, E. clivicola, E. kondininensis, E. occidentalis, E. ornata, E. moderata Nicolle (ms), Melaleuca preissiana, M. rhaphiophylla* and *Taxandria juniperina.* This report (PART 1) discusses log descriptions (including defects), green sawn recoveries, and wood density and shrinkage.

Defective heart was observed in logs of all species. Green sawn recoveries after backsawing timber ranged from 51.7 per cent for *M. rhaphiophylla* to 68.4 per cent for *E. accedens*, but significant defects will need to be docked before dried dressed graded recoveries are estimated.

Wood density assessments (green, air-dry and basic densities) showed some variation in green density (from 995 kg/m^3 for *Taxandria juniperina* to 1207 kg/m^3 for *Acacia bartleana Maslin (ms)*). Air-dry density of the eucalypts was 1100 to 1200 kg/m^3, while *Taxandria juniperina* was the lightest of the twelve species assessed at 636 kg/m^3.

Shrinkage assessments showed tangential and radial shrinkage in *M. preissiana* of 23.2 per cent and 11.2 per cent respectively. Tangential shrinkage in the eucalypt timbers ranged from 3.1 per cent in *E. accedens* to 9.1 per cent on *E. occidentalis*, while in those species radial shrinkage ranged from 1.5 per cent to 4.5 per cent.

The timber was sorted into lower density and higher density species for drying, with a conservative and a very conservative drying schedule respectively. The drying time required has significantly increased because of the poor drying behaviour of the *Melaleuca* boards, and the attempt to recover them.

INTRODUCTION

With increasing salinity problems in the Wheatbelt and other semi-arid and arid areas of Western Australia, combined with increasing conservation pressures in the South-West forests, there is an increasing need to grow plantations for salinity amelioration, stock shelter and timber production.

This NHT-funded project included making initial decisions on a range of suitable species for planting programs and to assess their growth potential and potential utilisation. The Timber Technology centre at the Forest Products Commission, Harvey, was requested to participate in harvesting of selected species, organise the sawmilling and drying, assess basic wood properties (e.g. density and shrinkage), and assess gluing and machining properties. Other research included in the project is medium density fibreboard (MDF) manufacture, which is being done by CSIRO Forestry and Forest Products.

This report discusses the following aspects of the research:

- Log dimensions
- Sawmilling
- Wood properties

The results of the following aspects will be discussed in a second report, although the methodology is given here:

- Drying
- Dressing
- Grading
- Hardness
- Panel manufacture
- Machining trials
- General descriptions.

METHODS

The different aspects of the research project are described in detail. The full methodology is discussed below, however, at this stage only the first few aspects are discussed in the Results and Discussion section because of delays in drying timber and therefore being able to proceed with dressing, grading, panel manufacture, etc. It was considered necessary to provide this progress report.

Species selected

The range of species for selection was selected after a comprehensive assessment of growth potential and previous utilisation of a large number of Western Australian native timbers. The Forest Products Commission provided expert advice on the wood properties and potential utilisation of these species, but in many cases there was no information available. This advice was taken into consideration when the final list of species was decided.

The original intention was to harvest six logs for each species, two logs from three separate populations, except where listed in Table 1. The defects found in the logs were recorded.

Table 1
Species and number of logs for solid wood testing

Species	No. sample populations	No. logs per population	Total no. sample logs
Acacia aff. redolens[1]	1	2	2
Acacia bartleana Maslin (ms)	2	1,2	3
Eucalyptus accedens	3	2	6
Eucalyptus argyphea	3	2	6
Eucalyptus clivicola	2	2,1	3
Eucalyptus kondininensis	3	2	6
Eucalyptus occidentalis	4	2,1	6
Eucalyptus ornata	3	2	6
Eucalyptus moderata Nicolle (ms)	3	2	6
Melaleuca preissiana	3	2	6
Melaleuca rhaphiophylla	3	2	6
Taxandria juniperina	3	2	6

Processing and assessments

The following procedures were followed:

PART 1

Log dimensions

The measurements made were small end diameter under bark (SEDUB), large end diameter under bark (LEDUB), and log length. Log volume was estimated using Smalian's equation (i.e. the mean of the cross-sectional areas multiplied by log length). Any log faults e.g. sweep, large taper, bumps, branches, decay on the end, etc. were noted, and comments made on whether they were likely to affect recovery.

Sawmilling

Each species was milled separately and board identity maintained throughout the trial. Because of the large number of logs in the trial, through and through sawing was used to produce 28 mm thick slabs from which individual boards were cut. Board sizes produced were 105 mm x 28 mm where possible, then 80 mm or 60 mm width as falldown recovery. Green sawn recovery was estimated for each species, and any anecdotal information was included.

Wood properties

The central slab sawn from the log was used to prepare specimens for wood density and shrinkage assessment. Several 28 mm square sticks were cut and then dressed to 25 mm square. Five specimens of 100 mm length were randomly selected, ensuring that both sapwood and heartwood were represented and that they were free of brittle heart.
The parameters assessed were:
green density, air-dry density and basic density
tangential, radial and longitudinal shrinkage to air-dry conditions.

Mass and dimensions were measured twice a week until the specimens stabilised. With high relative humidity conditions during the winter, the room where the specimens were stored was kept at 30°C. Final drying to obtain oven-dry mass for basic density assessment was at 103°C until constant weight was achieved.

Drying

The boards were kiln dried in batch kilns at Timber Technology. A conservative schedule was recommended for the lower density species, including the Melaleucas, and the species dried were *M. preissiana, M. rhaphiophylla, Taxandria juniperina* and *E. occidentalis* (which had the lowest air-dry density of the eucalypts) (Table 2). A more conservative drying schedule developed for Goldfields high density timbers was used for the higher density species, and included the other eight species in the trial (Table 3). The latter schedule (Siemon and Kealley 1999) was also recommended by Gary Brennan of Farm Forestry Group, Department of Conservation and Land Management. Mild drying conditions are essential in the early stages of drying. Sample boards were prepared to monitor drying rate and degrade, using the method described in the Australian Timber Seasoning Manual (AFRDI 1997). The sample boards of each species were assessed weekly during the drying process for moisture content, surface checking and warping. The drying schedule was adjusted if drying degrade was occurring.

Table 2
Drying schedule recommended for 100 x 28 mm boards of lower density species

Time (days)	DBT Set Point (C^o)	RH Set Point (%)	E.M.C. (%)	Air velocity (m/s)	MC%
To be determined	30	88	19	0.5	Green
	33	84	17	0.5	50 -40
	35	80	15	0.5	40 - 30
	37	76	14	0.5	30 - 25
	40	72	13	1.0	25 - 20
	45	60	10	1.0	20 - 15
	50	45	7	1.0	15 - 10

Table 3
Drying schedule recommended for 100 x 28 mm arid timber boards

Time (days)	DBT Set Point (C^o)	RH Set Point (%)	E.M.C. (%)	Air velocity (m/s)	MC%
	20	95	19	0.2	Green
22	19	91	20.5	0.2	35.8 - 30.7
60	25	89	20	0.2	30.7 - 23.3
76	31	76	14	0.5	23.3 - 18.0
98	35	69	12.2	0.5	18.0 - 15.0
112	44	59	10	1.0	15.0 - 11.3
120	50	45	7.5	1.0	11.3 - 9.9
122					

PART 2

The report is presented in two parts because of the extended times required for drying a range of timber species while attempting to minimise drying defects in Melaleuca. The results of drying and the subsequent aspects of the research, and relevant discussion, will be presented in a second report after the activities are completed.

Dressing

Most boards will be dressed to 80 mm x 20 mm, with those of lower sawn width dressed to 50 mm x 20 mm. The original experimental design allowed larger dimensions to be milled where shrinkage was minimal.

Grading

The boards will be graded using Australian Standard AS 2796.2:1999, and dried dressed graded recoveries recorded.

Hardness

Five measurements will be made per log, using a modified vyce that simulates the conventional Janka hardness test. A tension wrench is used to imbed a steel ball with 5.6 mm radius into the timber. The load in N.m is then converted to kN using a standard equation, which allows comparisons with published Janka hardness data.

Panel manufacture

Test panels will be prepared by gluing boards, with cold pressing with 24 h curing used for high density species. Resorcinol formaldehyde (Resobond RA 3-W (winter grade)) will be used on the high density species, producing a dark red glue line that would cause appearance problems in light coloured timber. In comparison, urea formaldehyde produces a clear glueline and was used for the lighter coloured species.

Cleavage properties will be assessed on a strip cut from the end of the panel, using the procedures for assessing wood failure as outlined in AS 1328.1:1998.

Machining trials

The following machining and finishing tests will be carried out on three panels per species by Swan TAFE at Balga: ripping, cross cutting, planing, routing, trenching, boring, sanding and coating.

General

Colour of the dressed boards will be estimated using the Methuen Colour Handbook, and comments made on grain, texture and figure.

General comments will be made on wood quality and processing characteristics.

In Results and Discussion, Part 1 discusses the log descriptions, sawmilling and wood properties. Part 2 will discuss drying and subsequent components of the research.

RESULTS AND DISCUSSION

PART 1

The report is presented in two parts because of the extended times required for drying a range of timber species while attempting to minimise drying defects. The results of drying and the subsequent aspects of the research, and relevant discussion, will be presented in a second report after the activities are completed.

Wood quality in the logs was a major issue, with many trees considered as unlikely to produce a reasonable log quality and therefore rejected. The defects observed on the surface or the ends of the logs are listed in Appendix 1, while defects observed in the sawn boards are listed in Appendix 2. Gum pockets and borer holes were found in some eucalypts, and larger borer holes in *Taxandria juniperina* (Appendix 1). One *Acacia* spp aff *redolens* log was of poor quality, but it was considered that a reasonable sawn recovery could be achieved and it was retained.

Inspection of the sawn boards confirmed that heart affected the quality of timber in each log. The next major defects were borer galleries and gum pockets, with some rot and sweep.

Log descriptions and sawmilling

The dimensions and comments on the wood quality of the logs harvested are given in Appendix A. The estimates of log volume based on calculations using Smalian's equation are given with the sawmilling recoveries in Table 3. As stated previously, the logs were backsawn to maximise green sawn recovery and make a feature of the board face. The important assessment will be the dried dressed graded recovery.

Table 3
Total log volume, board volume and mean green sawn recoveries of twelve WA native species

Species	No logs	Total log volume (m^3)	Total board volume (m^3)	Mean green sawn recovery (%)*
Acacia aff. redolens	2	0.111	0.075	67.6 (-)
Acacia bartleana Maslin (ms)	3	0.205	0.127	59.0 (-)
Eucalyptus accedens	6	0.390	0.270	68.4 (9.9)
Eucalyptus argyphaea	6	0.282	0.193	67.1 (8.8)
Eucalyptus clivicola	3	0.125	0.077	63.2 (-)
Eucalyptus kondinensis	6	0.381	0.234	61.2 (7.7)
Eucalyptus occidentalis	6	0.583	0.349	61.1 (7.9)
Eucalyptus ornate	6	0.433	0.242	57.2 (17.0)
Eucalyptus moderata Nicolle (ms)	6	0.385	0.186	54.5 (13.9)
Melaleuca preissiana	6	0.653	0.373	57.3 (8.5)
Melaleuca rhaphiophylla	6	0.442	0.234	51.7 (11.7)
Taxandria juniperina	6	0.398	0.225	57.9 (9.4)

* Standard deviation of individual green sawn recoveries where more than five logs

While heart is included in the mean green sawn recoveries, it was evident that it would need to be docked out when dried dressed graded recoveries were estimated. The *M. rhaphiophylla*, *E. ornata* and *E. moderata Nicolle (ms)* green sawn recoveries had high standard deviations because the sample of those species included a single log with significant defects. The dried dressed graded recoveries of timber from each species will provide the most relevant information on their potential commercial use.

Wood properties

The mean values for green density, air-dry density and basic density are given in Table 4. All of the eucalypts had low green moisture content because of the high wood density, and there are only small differences between green density and air-dry density. Of the eucalypts, *Eucalyptus occidentalis* had the largest standard deviations in air-dry and basic densities. In comparison, *E. moderata Nicolle (ms)* had the most uniform values and therefore the smallest standard deviations.

Melaleuca preissiana timber showed greater variation than *M. rhaphiophylla*, while *Taxandria juniperina* wood was medium density.

Table 4
Wood density properties (mean values and standard deviations) of twelve Western Australian timbers

Species	Log No	Mean MC%	Green density (kg/m3)	Air-dry density (kg/m3)	Basic density (kg/m3)
Acacia aff. redolens	66 - 67	30	1001 (-)*	890 (-)	768 (-)
Acacia bartleana Maslin (ms)	61 - 63	45	1207 (-)	1014 (-)	835 (-)
Eucalyptus accedens	13 - 18	32	1167 (28)	1039(44)	883 (47)
Eucalyptus argyphaea	19 - 24	32	1096 (74)	1059 (66)	828 (56)
Eucalyptus clivicola	55 - 57	30	1155 (-)	1094 (-)	886 (-)
Eucalyptus kondinensis	31 - 36	28	1180 (36)	1145 (43)	921 (50)
Eucalyptus occidentalis	37 - 42	45	1119 (53)	1001 (108)	771 (87)
Eucalyptus ornata	43 - 48	33	1168 (33)	1097 (49)	878 (38)
Eucalyptus moderata Nicolle (ms)	73 - 78	31	1206 (32)	1154 (38)	919 (28)
Melaleuca preissiana	1 - 6	121	1067 (30)	820 (113)	489 (51)
Melaleuca rhaphiophylla	25 - 30	140	1054(28)	622 (53)	440 (40)
Taxandria juniperina	7 - 12	100	995 (75)	636 (37)	498 (32)

* Standard deviation of individual wood density values where more than five logs

The mean shrinkage values (Table 5) were very large in *M. preissiana* (23.2 per cent and 11.2 per cent respectively for tangential and radial shrinkage) and large in *M. rhaphiophylla* (15.0 per cent and 6.7 per cent respectively). Consequently, these species are not recommended for situations where sawn timber production is one of the required products.

The shrinkage in the eucalypts ranged from *E. accedens* (3.1 per cent and 1.5 per cent respectively) to *E. occidentalis* (9.1 per cent and 4.5 per cent respectively).

Table 5
Shrinkage from green to 12 per cent MC of twelve Western Australian timbers

Timber species	Tangential shrinkage (%)	Radial shrinkage (%)	Longitudinal shrinkage (%)
Acacia aff. redolens	2.2 (-)	1.3 (-)	0.08
Acacia bartleana Maslin (ms)	5.8 (-)	2.4 (-)	0.01
Eucalyptus accedens	3.1 (1.2)	1.5 (0.3)	0.04
Eucalyptus argyphaea	6.5 (0.6)	4.0 (0.7)	0.01
Eucalyptus clivicola	5.7 (-)	2.9 (-)	0.01
Eucalyptus kondinensis	6.4 (2.2)	3.5 (1.1)	0.01
Eucalyptus occidentalis	9.1 (1.7)	4.5 (0.7)	0.28
Eucalyptus ornata	6.6 (0.7)	3.7 (0.9)	0.06
Eucalyptus moderata Nicolle (ms)	6.2 (0.4)	4.4 (0.7)	0.07
Melaleuca preissiana	23.2 (7.5)	11.2 (5.2)	1.40
Melaleuca rhaphiophylla	15.0 (2.9)	6.7 (2.4)	0.26
Taxandria juniperina	8.2 (1.2)	4.4 (1.0)	0.01

* Standard deviation of individual green sawn recoveries where more than five logs. The SDs for longitudinal shrinkage are not given because of the very low values involved.

PART 2

Drying

The timber was dried in two batch kilns. The *Melaleuca* timber is comparatively low density compared with the eucalypts, and was dried with the less conservative drying schedule (Table 2). However, surface checking commenced almost immediately although the equilibrium moisture content was 19 per cent. *M. preissiana* is particularly susceptible, and significant extra time at a higher EMC was required. Consequently, the temperature was decreased from 30ºC to 20ºC and relative humidity increased from 90 per cent to 95 per cent.

The timber was kept in these conditions for ten days, but the *Melaleuca* timber continued to deteriorate. Although it eventuated that the timber would not recover, because of this species the drying rate for the other species in that kiln was significantly slowed.

During the different stages of drying, the high density eucalypt timber that was being dried using the Goldfields timber schedule (Table 3) behaved well. Surface checking was negligible.

A full report on drying will be given when the process is completed.

The following aspects will be reported later in PART 2:

- Dressing
- Grading
- Hardness
- Panel manufacture
- Machining trials
- General e.g. colour, grain, texture, figure.

APPENDIX 1

Defects in logs of twelve Western Australian timbers sampled for wood property and processing assessments

Log no.	Rot width (mm)	Rot thickness (mm)	Rot length (mm)	Borer gallery diameter (mm)	Borer gallery length (mm)	Sweep (mm/m)	Other defect
Melaleuca preissiana							
01	-	-	-	-	-	-	-
02	-	-	-	40	180		-
03	-	-	-	-	-	-	-
04	60	full	200	-	-	-	-
05	-	-	-	-	-	-	70 mm bump-
06a	-	-	-	-	-	65	-
06b	50	full	400	-	-	30	-
Taxandia juniperina							
07	-	-	-	-	-	-	-
08	-	-	-	40	480	-	-
09	-	-	-	-	-	-	2 bulls eye borer holes 20 x 50
10	50	full	70	-	-	-	-
11	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-
Eucalyptus accedens							
13	-	-	-	-	-	-	-
14	-	-	-	40	900	25	Some small borer holes
15	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-
Eucalyptus argyphaea							
19	-	-	-	-	-	-	6 gum pockets 5 x 30
20	-	-	-	-	-	-	5 gum pockets 5 x 30
21	-	-	-	-	-	15	8 gum pockets 5 x 30
22	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-
24	-	-	-	-	-	-	15 gum pockets 5 x 20
Melaleuca rhaphiophylla							
25	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-
30	-	-	-	-	-	60	-
Eucalyptus kondininensis							
31	-	-	-	-	-	-	-
32	-	-	-	-	-	-	-
33	-	-	-	-	-	20	1 gum pocket 10 x 50
34	-	-	-	-	-	-	-
35	-	-	-	-	-	22	-
36	-	-	-	-	-	-	-

Eucalyptus occidentalis								
37	-	-	-	-	-	-	-
38	30	28	200	-	-	-	-
39	50	28	50	-	-	-	30 mm branch
40	-	-	-	-	-	60	-
41	-	-	-	30	full	-	-
42	-	-	-	-	-	-	4 gum pockets 5 x 30
Eucalyptus ornata							
43	-	-	-	-	-	-	-
44	-	-	-	70	full	-	-
45	40	28	70	-	-	-	-
46	-	-	-	-	-	-	1 gum pockets 10 x 200, 8 gum pockets 5 x 40
47	-	-	-	-	-	-	15 gum pockets 3 x 60
48	-	-	-	45	250	-	8 gum pockets 10 x 50, 1 gum pocket 15 x 80
Eucalyptus clivicola							
55	-	-	-	-	-	-	-
56	-	-	-	-	-	-	-
57	-	-	-	-	-	-	-
Acacia bartleana Maslin (ms)							
61	-	-	-	-	-	-	-
62	-	-	-	-	-	-	60 mm branch
63	-	-	-	60	90	-	-
Acacia aff redolens							
66a	-	-	-	-	-	-	branch off 66b
66b	-	-	-	-	-	130	-
67	-	-	-	-	-	-	-
Eucalyptus moderata Nicolle (ms)							
73	-	-	-	-	-	-	-
74	-	-	-	50	full	30	10 mm taper
75	-	-	-	-	-	-	-
76	-	-	-	-	-	-	-
77	-	-	-	-	-	-	-
78	-	-	-	-	-	-	-

APPENDIX 2

Log volumes, board volumes, green sawn recoveries from individual logs and reasons for downgrade in logs of twelve Western Australian species

Species	Log no.	Log volume (m^3)	Board volume (m^3)	Green sawn recovery (%)	Reason for recovery loss from log
Melaleuca preissiana	01	0.093	0.066	70.4	heart, borer galleries
	02	0.076	0.044	57.6	heart
	03	0.042	0.019	45.8	heart
	04	0.086	0.053	61.8	heart, rot
	05	0.146	0.084	57.4	heart
	06	0.210	0.107	51.0	heart, sweep
Taxandria juniperina	07	0.067	0.037	54.4	heart, borer galleries and holes
	08	0.044	0.032	71.0	heart
	09	0.052	0.033	63.3	heart removed
	10	0.085	0.039	45.9	heart, rot
	11	0.065	0.041	62.8	heart
	12	0.085	0.043	50.0	heart
Eucalyptus accedens	13	0.059	0.043	73.2	heart
	14	0.075	0.043	57.0	heart, borer galleries / holes, sweep
	15	0.066	0.054	82.1	heart
	16	0.115	0.081	70.9	heart
	17	0.042	0.030	70.5	heart
	18	0.033	0.019	56.7	heart
Eucalyptus argyphaea	19	0.054	0.040	73.8	heart, gum pockets
	20	0.050	0.037	73.7	heart, gum pockets
	21	0.062	0.037	59.2	heart, gum pockets, sweep
	22	0.025	0.014	54.5	heart
	23	0.044	0.029	65.8	heart
	24	0.047	0.036	75.7	heart, gum pockets
Melaleuca rhaphiophylla	25	0.076	0.044	57.7	heart
	26	0.075	0.051	67.8	heart
	27	0.081	0.047	58.3	heart
	28	0.097	0.048	48.9	heart
	29	0.065	0.025	37.8	heart
	30	0.048	0.019	39.9	heart, sweep
Eucalyptus kondininensis	31	0.053	0.026	49.4	heart
	32	0.048	0.034	70.7	heart
	33	0.090	0.053	58.5	heart, sweep, gum pocket
	34	0.067	0.039	57.7	heart
	35	0.050	0.032	63.0	heart, sweep
	36	0.073	0.050	67.6	heart
Eucalyptus occidentalis	37	0.068	0.042	62.4	heart
	38	0.186	0.105	56.5	heart, rot
	39	0.093	0.067	71.3	heart, branch stub
	40	0.086	0.042	49.1	heart
	41	0.091	0.054	59.7	heart, borer gallery
	42	0.059	0.039	67.4	heart, gum pockets

(cont)

Species	Log no.	Log volume (m^3)	Board volume (m^3)	Green sawn recovery (%)	Reason for recovery loss from log
Eucalyptus ornata	43	0.056	0.035	63.3	heart
	44	0.087	0.021	23.8	heart, borer gallery
	45	0.079	0.055	68.8	heart, rot
	46	0.069	0.038	55.8	heart, gum pockets
	47	0.060	0.041	68.6	heart, gum pockets
	48	0.082	0.052	62.6	heart, gum pockets, borer gallery
Eucalyptus clivicola	55	0.036	0.026	72.6	heart
	56	0.042	0.026	63.7	heart
	57	0.047	0.025	53.2	heart
Acacia bartleana Maslin (ms)	61	0.106	0.071	67.1	heart
	62	0.061	0.038	61.9	heart, branch stub
	63	0.038	0.018	48.0	heart, borer gallery
Acacia aff. redolens	66	0.055	0.041	74.5	heart, branch stub
	67	0.056	0.034	59.9	heart
Eucalyptus moderata Nicolle (ms)	73	0.060	0.038	64.4	heart
	74	0.137	0.037	27.3	heart, borer gallery, sweep
	75	0.054	0.030	55.0	heart
	76	0.046	0.028	59.3	heart
	77	0.041	0.026	64.5	heart
	78	0.047	0.027	56.2	heart

Search Report

Appendix 6

Investigation of timber properties of selected Western Australian species

Part Two

Forest Products Commission

SEARCH PROJECT

WOOD PROPERTIES AND POSSIBLE SOLID WOOD PRODUCTS FROM SELECTED WESTERN AUSTRALIAN TIMBERS

PART 2: DRYING, GRADING, MACHINING, HARDNESS

G.R. Siemon and P. Piper
June 2004

SUMMARY

Twelve Western Australian native species were assessed for their sawn timber potential and wood properties, as part of the nationally funded Search Project. The species assessed were *Acacia aff. redolens, A. subfalcata (*now *A. bartleana), Eucalyptus accedens, E. argyphea, E. clivicola, E. kondininensis, E. occidentalis, E. ornata, E. semivestita (*now *E. moderata), Melaleuca preissiana, M. rhaphiophylla* and *Taxandria juniperina.*

Part 1 discussed log descriptions (including defects), green sawn recoveries, and wood density and shrinkage. Part 2 discusses the drying behaviour, dressing, grading, panel production and machining trials that were subsequently carried out, and describes the colour, grain and texture.

INTRODUCTION

After the report on Part 1 was prepared, there were taxonomic changes made to some species. The modifications are shown in Table 1.

Table 1
Current botanical and common names of the twelve lower rainfall species assessed

Species	Common name
Acacia aff. redolens	Wattle
Acacia bartleana (formerly A. subfalcata)	Golden tooth wattle
Eucalyptus accedens	Powderbark wandoo
Eucalyptus argyphea	Silver mallet
Eucalyptus clivicola	Green mallet
Eucalyptus kondininensis	Kondinin blackbutt
Eucalyptus occidentalis	Flat-topped yate
Eucalyptus ornata	Silver mallet
Eucalyptus moderata (formerly E. semivestita)	Wheatbelt redwood
Melaleuca preissiana	Preiss's paperbark (moonah)
Melaleuca rhaphiophylla	Swamp paperbark
Taxandria juniperina	Warren River cedar

As stated in the summary, Part 1 discussed log descriptions (including defects), green sawn recoveries, and wood density and shrinkage. Part 2 discusses the drying behaviour, dressing, grading, panel production and gluing, and machining trials that were subsequently carried out. Assessments of colour, grain and texture were also made.

Methods

Drying

As stated in the previous report (Part 1), the research is presented in two parts because of the extended times required for drying a range of timber species while attempting to minimise drying defects in *Melaleuca preissiana* in one of the batch kiln charges. The other charge included the high density eucalypts, which were known to need extended drying times. The drying schedule was therefore modified from the originals given in the Part 1 report, and details are given in Results and Discussion.

Dressing

Most boards were dressed to 80 mm x 15 mm, with those of lower sawn width dressed to the relevant width although this reduced final recoveries. The wood quality was the major concern and the original experimental design allowed larger dimensions to be milled where shrinkage was minimal.

Grading

The boards were graded using Australian Standard AS 2796.2:1999 (Standards Australia 1999), and dried dressed graded recoveries recorded. Boards were graded into select medium feature, high feature or reject.

Hardness

A minimum of six measurements was made per species on either a board or the docked ends of glued panels. The measurements were made using a modified vyce that simulates the conventional Janka hardness test. A tension wrench was used to imbed a steel ball with 11.2 mm diameter to 5.6 mm into the timber. The load in N.m was then converted to kN using an equation developed at Harvey (i.e. Janka hardness load (kN) = 0.22 x Load (N.m) – 0.828), which allows comparisons with published Janka hardness data.

Panel manufacture

Test panels were prepared by edge-gluing boards and restraining them with woodworking clamps. The original working plan specified using resorcinol formaldehyde (‘Resobond RA 3-W (winter grade)’) for the high density species, which produces a dark red glue line that would cause appearance problems in light-coloured timber. In comparison, urea formaldehyde would produce a clear glueline and would be more suitable for the lighter coloured species.

However, a new aliphatic resin emulsion adhesive (‘Titebond’) became available, and this was used for gluing all species. The gluelines were assessed by cleaving a strip cut from the end of two panels of each species, using the procedures for assessing wood failure as outlined in AS 5067-2003, which is more relevant for this assessment than AS1328.1:1998 (Standards Australia 1998).

Machining trials

The following machining and finishing tests were carried out on a panel of each species by Timber Technology staff at Harvey: sanding, ripping, docking, dressing, routing and boring.

The grading system used was as follows:

1	Excellent	No further work
2	Very Good	Minor chipping and fluffiness
3	Good	Lots of small chipping, fluffy or a few deep chips
4	Fair	Lots of small chipping, fluffy and larger chips or large chips requiring extensive work
5	Poor	Deep chipping, extensive and almost not worth repairing

General

Colour of the dressed boards was estimated using the Methuen Handbook of Colour, and comments made on grain and texture.

RESULTS AND DISCUSSION

Drying

The estimated initial moisture contents of the sample boards prepared for monitoring of drying are given in Table 1.

Table 1
Estimated initial moisture contents of sample boards

Species	Log No	GWT	ODWT	MC
Acacia aff. redolens	66	289.24	208.10	39.0
Acacia bartleana (formerly A. subfalcata)	62	119.59	80.15	49.2
Eucalyptus accedens	15	120.98	83.07	45.6
Eucalyptus argyphea	19	137.54	93.02	47.9
Eucalyptus clivicola	56	149.16	111.54	33.7
Eucalyptus kondininensis	33	128.47	98.40	30.6
Eucalyptus occidentalis	40	105.88	61.55	72.0
Eucalyptus ornata	43	139.01	97.44	42.7
Eucalyptus moderata (formerly E. semivestita)	75	101.88	73.56	38.5
Melaleuca preissiana	1	94.52	44.10	114.3
Melaleuca rhaphiophylla	27	116.90	53.29	119.4
Taxandria juniperina	7	114.21	58.70	94.6

The timber was dried in two separate batch kilns, because of space availability and the large variations in wood density. It was not possible to maintain the drying schedules proposed originally, because of the species mixture in the charge. The following schedules were developed as drying progressed. The schedule used for lower density species (Table 1) was significantly different to the original because of the immediate drying degrade and drying behaviour of *Melaleuca preissiana*, although a concrete weight (580 kg/m2) was placed on the bundle before drying was commenced. This excessive movement in the species continued, and a heavier weight used after four weeks of very slow drying.

The conservative schedule proposed for the six high density eucalypts and two acacias resulted in very limited degrade in the form of checking (Table 2). The timber in each batch kiln was dried to 12 per cent moisture content.

Table 1
Drying schedule used for 100 x 28 mm boards of lower density species*

Date	DBT Set Point (C^o)	RH Set Point (%)	E.M.C. (%)	Air velocity (m/s)
8 May	10	95	23+	0.2
12 May	30	88	19	0.2
5 June	Heavier weight used			
10 July	33	84	17	0.2
11 Sept	37	76	14	1.0
21 Oct	Steamed			
23 Oct	40	72	12	1.0
6 Nov	Finish			

* *Melaleuca preissiana, M. rhaphiophylla, Taxandria juniperina,* with *E. occidentalis* included to make up the required volume in the stack.

Table 2
Drying schedule used for 100 x 28 mm arid timber boards*

Date	DBT Set Point (C^o)	RH Set Point (%)	E.M.C. (%)	Air velocity (m/s)
8 May	10	95	23+	0.2
12 May	19	91	21	0.2
10 July	25	86	18.5	0.2
11 Sept	31	76	14.5	0.5
16 Sept	31	76	14.5	0.5
21 Oct	Steamed			
23 Oct	35	69	12	1.0
6 Nov	Finish			

* All other species

The conservative drying approach minimised the amount of drying defect that was likely to occur with boards of a range of different species and therefore different drying behaviour. The drying curves for each of the sample boards (one per species) from May to late October are shown in Figure 1. The timber was dried for a further two weeks but due to an oversight, the final moisture contents when drying was terminated on 6 November were not estimated.

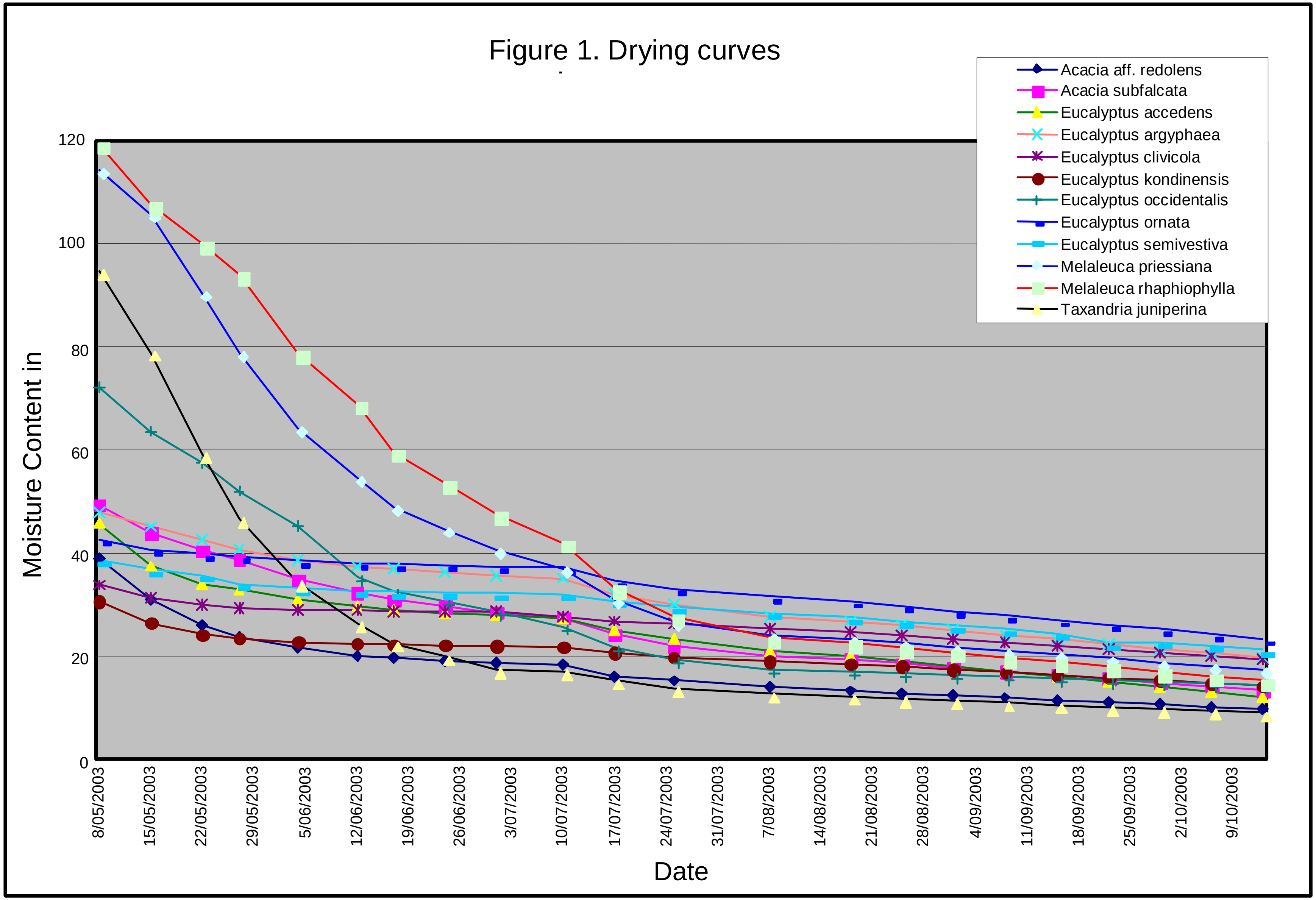


Figure 1. Drying curves
Acacia aff. redolens
Acacia subfalcata
Eucalyptus accedens
Eucalyptus argyphaea
Eucalyptus clivicola
Eucalyptus kondinensis
Eucalyptus occidentalis
Eucalyptus ornata
Eucalyptus semivestiva
Melaleuca priessiana
Melaleuca rhaphiophylla
Taxandria juniperina
Moisture Content in
0
20
40
60
80
100
120
8/05/2003
15/05/2003
22/05/2003
29/05/2003
5/06/2003
12/06/2003
19/06/2003
26/06/2003
3/07/2003
10/07/2003
17/07/2003
24/07/2003
31/07/2003
7/08/2003
14/08/2003
21/08/2003
28/08/2003
4/09/2003
11/09/2003
18/09/2003
25/09/2003
2/10/2003
9/10/2003
Date

Janka hardness tests

As discussed in Methods, the Janka hardness properties were estimated by reading the load (N.m) recorded on a torque wrench to imbed the 11.2 mm diameter steel ball into the wood sample to 5.6 mm depth. The load in N.m was then converted to kN using an equation developed at Harvey (i.e. Janka hardness load (kN) = 0.22 x Load (N.m) – 0.828), which allows comparisons with published Janka hardness data.

Table 3
Janka hardness tests of twelve lower rainfall species

Species	No. specimens tested	Torque wrench reading (N.m)		Estimated Janka hardness (kN)
		Mean	**SD**	
Acacia aff. redolens	16	49.6	8.0	10.1
Acacia bartleana (formerly A. subfalcata)	17	73.4	8.6	15.3
Eucalyptus accedens	6	52.1	13.1	10.6
Eucalyptus argyphea	6	73.2	13.0	15.3
Eucalyptus clivicola	10	69.0	10.1	14.4
Eucalyptus kondininensis	6	61.4	18.8	12.7
Eucalyptus occidentalis	6	56.4	6.1	11.6
Eucalyptus ornata	6	70.6	7.0	14.7
Eucalyptus moderata (formerly E. semivestita)	10	77.1	8.1	16.1
Melaleuca preissiana	10	22.3	4.0	4.1
Melaleuca rhaphiophylla	10	22.4	3.9	4.1
Taxandria juniperina	10	27.3	4.1	5.2

There is no doubt that the method gives a good ranking, and that the estimates are generally accurate. However, the estimate for *E. accedens* is low in comparison to the published figure of 15 kN for wandoo (*E. wandoo*) (Bootle 1983). Other comparative figures from this reference include jarrah (*E. marginata*) 8.5 kN, karri (*E. diversicolor*) and radiata pine (*Pinus radiata*) 3.3 kN.

Grading

The boards were graded to the specifications of Australian Standard AS2796.2:1999 (Standards Australia 1999), into select, medium feature, high feature or reject. The features, characteristics and defects used to classify the boards are summarised in Table 5.

The highest recoveries of select grade timber came from *Eucalyptus moderata* and *E. kondininensis* with 78 per cent and 73 per cent recoveries respectively, followed by *E. argyphea* with 63 per cent. The two *Acacia* species had very low recoveries of select grade, as did the two *Melaleuca* species and *Taxandria juniperina*. Including medium feature grade timber with the select grade, *E. clivicola* gave the best results with 95 per cent (although there were only nineteen boards), while *E. moderata* gave the excellent result of 94 per cent. The lowest recovery was 29 per cent from *Acacia* sp. aff. *redolens*.

The major defects found in the timber from the twelve species were tight knots, gum pockets, borer holes, and drying checks. *E. accedens* had the largest occurrence of boards with tight knots (24 per cent), and *E. ornata* the highest occurrence of gum pockets (35 per cent). Eleven of the twelve species had borer holes (the exception was *E. moderata*), with *Taxandria juniperina* having the highest incidence. The *Melaleuca* species and *Taxandria juniperina* had most seasoning checks.

Table 5
Summary of timber grading to AS2796.2:1999

Species	No boards	Tight knots	Loose knots /knot holes	Epicormic check	Tight gum veins	Loose gum veins	Gum pockets	Kino	Stain	Wane	Borer holes	Borer canals	Checks	Rot	Enclosed bark	Encased knots	Grade			
																	Select	**Medium feature**	**High feature**	**Reject**
Acacia sp. aff. redolens	24	2	2								9		4		5		**3**	**4**	**7**	**10**
Acacia bartleana (formerly A. subfalcata)	33		4		2	1	5			1	15		3	2	1	1	**3**	**26**	**0**	**4**
Eucalyptus accedens	72	17	2						1	4	10		3	7		1	**28**	**25**	**5**	**14**
Eucalyptus argyphea	56	2	4	5	4	3	22		1		3		1				**11**	**27**	**10**	**8**
Eucalyptus clivicola	19	1					1				3		2				**12**	**6**	**1**	**0**
Eucalyptus kondininensis	64	5	3				2	1		4	1	1				1	**47**	**10**	**6**	**1**
Eucalyptus occidentalis	92	13	19				3			6	13		5	4			**38**	**30**	**8**	**16**
Eucalyptus ornata	77	2	4		5	6	27			1	4						**28**	**20**	**11**	**18**
Eucalyptus moderata (formerly E. semivestita)	64	2	4		1	6				3							**50**	**10**	**2**	**2**
Melaleuca preissiana	48	1	2	1						4	5	4	16	1			**16**	**22**	**5**	**5**
Melaleuca rhaphiophylla	55	5	3				2			2	6	1	8	2	4		**24**	**10**	**8**	**13**
Taxandria juniperina	70	5	3	1					1		24		10	2	6		**18**	**36**	**3**	**13**

Panel manufacture and glueline assessment

Three panels for machining trials and demonstration purposes were manufactured from each species, except for *A. redolens* and *E. clivicola* where only two small logs were available. The intention was to obtain final dimensions of 600 x 600 mm, with sufficient material on the ends for glueline assessment.

The panels were assembled overlength using 'Titebond' adhesive and carpenter's clamps. The ends were then trimmed and glueline integrity assessed by estimating the percentage wood failure in accordance with Australian Standard 5067-2003 (Standards Australia 2003). The minimum requirement for gluelines with wood density less than 600 kg/m3 is average wood failure of not less than 70 per cent and individual gluelines of not less than 30 per cent. For wood density over 600 kg/m3, the minimum requirement for is average wood failure is not less than 50 per cent and for individual gluelines not less than 30 per cent. The results are given in Table 6.

The panels for demonstration purposes were face glued onto plywood sheets to reduce movement with seasonal changes during the year.

Table 6
Gluing properties of twelve lower rainfall species
(based on AS 5067-2003)

Species	No gluelines 30%+	Wood failure %	
	(total 15)	Mean	SD
Acacia aff. redolens	11	39	16
Acacia bartleana (formerly A. subfalcata)	3	16	11
Eucalyptus accedens	0	1	1
Eucalyptus argyphea	5	26	34
Eucalyptus clivicola	1	6	9
Eucalyptus kondininensis	2	12	18
Eucalyptus occidentalis	1	9	18
Eucalyptus ornata	0	5	4
Eucalyptus moderata (formerly E. semivestita)	0	4	4
Melaleuca preissiana	13	53	29
Melaleuca rhaphiophylla	15	77	23
Taxandria juniperina	15	100	0

The results indicated that *Melaleuca preissiana, M. rhaphiophylla* and *Taxandria juniperina* gave the best gluing results, followed by *Acacia* sp. aff. *redolens*. The high density species, that is the eucalypts and *A. bartleana* could not be successfully glued in accordance with the requirements of AS 5067-2003 (Standards Australia 2003).

Machining trials

The results of the machining trials are given in Table 7. The activities assessed were sanding, sawing with the grain, sawing across the grain, moulding edges, routing circles, routing crosses and boring.

Table 7
Machining properties of twelve lower rainfall species

Species	Sanding	Sawing with grain (ripping)	Sawing across grain (docking)	Moulding edges	Routing circles	Routing crosses	Boring
Melaleuca preissiana	1*	1	1	1	1	1	1
Taxandria juniperina	1	1	1	1	2	1	1
Eucalyptus accedens	1	1	1	1	1	1	1
Eucalyptus argyphea	1	1	1	1	2	1	2
Melaleuca rhaphiophylla	1	1	1	1	2	1	1
Eucalyptus kondininensis	1	1	1	1	2	1	1
Eucalyptus occidentalis	1	1	1	1	2	1	1
Eucalyptus ornate	1	1	1	1	2	2	1
Eucalyptus clivicola	1	1	1	1	2	1	1
Acacia bartleana	1	1	1	1	2	1	1
Acacia aff. redolens	1	1	1	1	2	1	1
Eucalyptus moderata	1	1	1	1	1	1	1

*1	Excellent	No further work
2	Very Good	Minor chipping and fluffiness
3	Good	Lots of small chipping, fluffy or a few deep chips
4	Fair	Lots of small chipping, fluffy and larger chips or large chips requiring extensive work
5	Poor	Deep chipping, extensive and almost not worth repairing

Colour, grain, texture

The colours of timber samples from each species were assessed by comparing them with the standard colours in the Methuen Book of Colour. The grain was noted, and texture of each species was assessed as fine, medium or coarse. The results were as follows (Table 4).

Table 4
Colour assessment of twelve lower rainfall species
(using Methuen Book of Colour)

Species	Inner heart	Colour description	Grain	Texture
Acacia aff. redolens	6C4	Brownish orange	Straight	Fine/medium
Acacia bartleana (formerly A. subfalcata)	6C4	Brownish orange	"	Fine/medium
Eucalyptus accedens	5B3	Greyish orange	Slightly interlocked	Fine
Eucalyptus argyphea	6C4	Brownish orange	"	Fine
Eucalyptus clivicola	5B4	Greyish orange	"	Fine
Eucalyptus kondininensis	6C4	Brownish orange	"	Fine
Eucalyptus occidentalis	6B4	Greyish orange	"	Fine
Eucalyptus ornata	7D4	Light brown	"	Fine
Eucalyptus moderata (formerly E. semivestita)	8E4	Reddish brown	"	Fine
Melaleuca preissiana	8E5	Greyish orange	Straight	Medium
Melaleuca rhaphiophylla	7D5	Light brown	"	Medium
Taxandria juniperina	5B3	Greyish orange	"	Medium/coarse

General

The results of the trial indicated that the eucalypts assessed all have potential depending on specific requirements of the site. For example, *E. occidentalis* is a salt tolerant species, but recoveries of select and medium feature grade timber are lower than those from species such as *E. moderata* and *E. kondininensis*. There were difficulties in gluing all the eucalypts, but the machining properties are good.

Melaleuca preissiana was by far the most difficult timber to dry, and could not be recommended for value-adding purposes, compared with *M. rhaphiophylla* which behaved much better during drying. Gluing properties and machining behaviour were above average.

Taxandria juniperina is a good medium density timber with excellent gluing properties, but there was concern about the incidence of borer holes in the timber.

Overall the trial indicated that most of these twelve species have potential for plantation establishment in Western Australia.

REFERENCES

Bootle, K.R. (1983). Wood in Australia. Types, properties and uses. McGraw-Hill, Sydney.

Standards Australia (1998). Glued laminated structural timber. Part 1. Performance requirements and minimum production requirements. AS/NZS 1328.1:1998.

Standards Australia (2003). Timber – Non-structural glued laminated - Performance and production requirements. AS 5067-2003.

Search Report

Appendix 7

Large-scale *Acacia* seed industry

Graeme Olsen

Graeme Olsen October 2003

Can *Acacia* seed become a large-scale industry?

Abstract

A large-scale *Acacia* seed industry, based on suitable species in the *Acacia* genus, could provide substantial land management benefits in dryland agricultural areas in southern Australia. This paper discusses market opportunities for Acacia seed, and some production issues that determine its potential profitability.

Acacia seed could be sold in a number of different sized markets, ranging from niche markets for bushfood and other specialty uses, to small to medium-sized markets for nuts, snack foods and pulses, and large markets for staple grains, oilseeds, food ingredients and stockfeed. At each step up in market size there is a corresponding step down in market price.

Acacia seed has some attributes that make it attractive in small markets, but these attributes are unlikely to attract a significant price premium in bulk markets for staple foods, food ingredients or stockfeed.

Major Australian grain and seed crops such as wheat, barley and canola are produced at very low cost in highly mechanised, extensive farming systems. These industries are under constant pressure to maximise yield, improve quality, minimise costs, and export most of their output into competitive global markets. A large-scale *Acacia* seed industry would be subject to the same pressures.

The existing *Acacia* seed industry is very small. It is based on tall shrub and tree *Acacia* species with a long history of traditional use as food by Australian Aborigines, and includes both wild harvesting and small-scale cultivation. Scaling up production will involve a change in methods, including the development of mechanised harvesting.

Acacia seed production could be suited to both of the systems that are likely to be used by farmers to integrate perennial crops into their activities:

Phase farming, in which acacias could be included for a short period (perhaps three to five years) in the sequence of crops grown in a paddock, would suit short-statured Acacia crops grown purely for seed.

Alley farming, with annual crops grown in alleys between belts of perennial plants would suit a wider range of seed production systems. As well as the short-statured, dedicated seed crop described above, alley systems also suit longer lived seed crops, such as tall shrub and tree crops, perhaps grown for multiple products. However, the feasibility of developing efficient harvesting techniques for tall trees and shrubs would need to be assessed.

The development of row-crop harvesters should bring significant reductions to harvesting costs for the *Acacia* seed species in current use. This harvester development path could suit a small to medium-sized industry based on high value seed, but it will reach its limits long before becoming competitive with broad-acre grain production systems harvested by headers.

A more promising development pathway for large-scale crops is to develop an *Acacia* crop with a different morphology – one that has many features in common with broad acre crops, enabling it to be harvested by equipment with similar efficiency to conventional grain harvesters. Desirable features in the plant include short stature, high ratio of seed production to vegetative growth, formation of pods and seeds at or near the top of the plant, large seed size, synchronous seed ripening, and reduced or inhibited pod shattering.

When developing a new crop, it is important that key aspects of farming system design are considered simultaneously. Important issues for *Acacia* seed development are species selection, crop design, management methods and harvester development.

At a broader level, requirements for new crop development include:

- suitable germplasm
- efficient, integrated farming systems
- appropriate growing, harvesting and processing technology
- acceptable product quality
- market penetration

Does *Acacia* seed have the potential to become a major food crop? It's too early to say, but further investigation is warranted. *Acacia* is an extremely diverse genus, with about 1,000 different taxa identified in Australia. A proper investigation of this variability may find suitable species or populations from which successful new crops can be developed.

In conclusion, it seems likely that further development of existing tall *Acacia* seed species and associated harvesting technology will enable the industry to grow from a niche industry to a small industry, but this pathway will not lead to the development of a large industry. To achieve that goal, and its associated land management benefits, a different development path is needed – one that selects and develops new germplasm better suited to efficient management and handling.

Background - salinity

Options for managing dryland salinity

The extensive development of dryland salinity in cleared agricultural areas in southern Australia (National Land and Water Resources Audit 2001) demonstrates the unsustainable nature of current agricultural practices based on annual crops and pastures. Potential management strategies for salinity can be divided into three categories:

- measures that treat the source of the problem, by reducing the amount of rainfall that drains into the soil below the root zone (recharge control),
- measures that reduce the adverse effects of salinity, using engineering treatments such as pumping and drainage to manage the discharge of saline water, and
- coping strategies, including development of new management systems for salt-affected land and water.

An integrated approach to salinity management will require treatments from all three categories to be developed and implemented. The treatments most likely to be implemented by farmers will be those with the most attractive commercial outcomes.

Role of perennial crops

An increased coverage of perennial plants in agricultural areas would reduce groundwater recharge, and simultaneously address other aspects of agricultural land management such as erosion control and soil structure decline.

The proportion of land that would need to be covered with perennial plants, to arrest productivity losses due to salinity, varies from region to region and from site to site. It depends on many factors, including landscape, soil, hydrogeology, rainfall, management practices, the degree of recharge control sought in each case, and the availability and effectiveness of complementary salinity treatments, including engineering works.

In medium to low rainfall areas with flat landscape and soils of low transmissivity, restoring the water balance would require a leaf area index approaching that of the original native woodland (Hatton and Nulsen 1999), perhaps requiring revegetation of up to 80% of the landscape (George et al. 1999; Hatton and Salama 1999). In practice, permanent revegetation on this scale with widespread, low productivity perennials, is incompatible with agriculture and cannot be implemented within farm businesses.

A more attractive alternative is to develop a variety of new farming systems, combining engineered water management techniques with smaller areas of high productivity perennial crops, to simultaneously reduce recharge and manage discharge in the most cost-effective way, optimising water management for each situation. Modelling work in Western Australia suggests that this approach would not prevent the spread of salinity in many of the more intractable situations, but it would slow its spread, and 'buy time' (George et al. 2001).

In order to give farmers the tools to optimise water management in their farming systems, investment is needed in the development of new, profitable perennial crops, and in the development of a suite of affordable and effective engineering techniques for water control.

Short-cycle crops, or crops that are harvested regularly, are more likely to be attractive to wheatbelt farmers than traditional long-cycle forestry crops. The short period between establishing the crop and receiving income reduces the period that debt needs to be carried, and avoids the high level of uncertainty associated with longer term investments. Accordingly, research into new perennial crops is focusing on those that could provide early and regular returns.

The process of searching for perennial species and processing industries suited to medium and low rainfall agricultural areas is still in its infancy. Two publicly funded research initiatives in this area are the National Heritage Trust's 'Search' project, managed by the Department of Conservation and Land Management in Western Australia, and a national 'Florasearch' project supported by the Joint Venture Agroforestry Project, and the Cooperative Research Centre for Plant-based Management of Dryland Salinity.

Scale and pattern of perennial crops

The scale at which perennial crops are implemented, and the patterns in which they are arranged on farms will determine how effective they are at contributing to salinity management, but also have implications beyond that of using surplus water.

First, in order to be profitable, and competitive with other agricultural enterprises, perennial crops need to grow at a productive rate and use resources efficiently. New farming systems could include intensive arrangements of high productivity perennial crops, to produce the required leaf area (and water use), while leaving space for other agricultural crops. Alley farming layouts based on wide-spaced belts of short-cycle perennial plants, and phase farming in which a short, periodic perennial plant phase is incorporated into the sequence of annual cropping, are two such designs (Bartle 2001; Harper et al. 2000).

In practice, maximising the commercial performance of perennial crops implies a trade-off between minimising the area they occupy while maximising the water available to them from three potential sources in the soil - groundwater (if it is sufficiently shallow and not too saline), infiltrated water in the unsaturated zone, and transported water delivered naturally by surface and shallow sub-surface flow, or artificially by engineering intervention.

Since perennial crops will be most productive when not limited by water, the most profitable arrangements of perennial crops are likely to fall short of complete recharge control. In situations where complete recharge control is essential, farmers may need to choose less profitable crop arrangements with a higher than optimal perennial plant component, or use supplementary measures such as pumps or drains.

Second, the area and productivity of perennial crops will determine the amount of saleable material they produce, and hence the size and location of processing plants, and the type of markets that are accessible.

To put the scale of potential new industries in context, consider the implications of developing ten million hectares of new, woody perennial crops (approximately 20% of the agricultural area in southern Australia's low and medium rainfall zone). These crops could produce 75-150 million dry tonnes of above-ground biomass per year – up to fifteen times Australia's export of woodchips. If the crops produced commercial seed, then some 10 million tonnes could be produced each year – a new industry half the size of the Australian wheat industry. Finding commercial uses for such large amounts of produce would be a major challenge.

Few large or many small industries?

The large scale on which short-cycle perennial crops need to be grown if they are to make a significant contribution to salinity management, and the corresponding large amounts of produce they would supply dictates that these crops be targeted at large industries with large markets (Bartle 2001). An alternative view is that a larger number of smaller, higher value industries might be more advantageous to farming communities than developing new, large-scale commodity-based industries with tight margins and downward trending prices.

It is worth briefly examining this issue, as the higher returns that may be achievable in smaller industries appear to be more attractive than the lower margins likely to be earned in global commodity markets, where large-scale production and high production efficiency is an essential requirement for profitability. So, what is the potential for improved environmental performance in agriculture through the aggregation of many small industries? Given the scale of the problems afflicting dryland agriculture, the potential for new small industries to contribute is small. For example, a target of 10 million hectares of commercial perennial crops would require 10,000 new niche industries of 1,000 hectares each, or 1,000 new small industries of 10,000 hectares each, or 100 new medium-sized industries of 100,000 hectares each. These targets seem unlikely to be achieved.

Therefore, it seems that the target of improved sustainability throughout agriculture will require a large investment in new, large-scale industries. Smaller industries will however still have an important role providing important economic benefits in their regions, and local sustainability benefits. Some small industries are likely to be developed locally by private investors and entrepreneurs, independent of public funding, or be produced as co-products along with one of the larger industries.

In terms of environmental benefits, large industries could provide regional benefits, while small to medium industries could provide benefits at the sub-catchment level. Very small, or niche industries are likely to provide benefits at the farm scale only.

In conclusion, a mixture of industry sizes is likely to be needed to achieve the full range of economic and environmental benefits, with larger industries contributing most of the environmental benefits, and smaller industries making significant contributions to local economies.

Background – global food markets

Introduction

Acacia seed has a history of indigenous food use in Australia (Maslin *et al.* 1998). Recent interest in starting a new agricultural industry to grow *Acacia* seed (Hele 2002) leads to the question: What opportunities are there for *Acacia* seed in global food markets? This depends on the scale of production that is envisaged, and the outlook for global food markets. As a first step, a quick appraisal of world food markets is required.

The large size of global food markets, and the large international trade in food is an attraction for potential new industries. However, global production capacity comfortably exceeds demand at present, causing strong competition between suppliers. Global food production is limited by the inability of consumers in rich countries to eat more, and the inability of consumers in poor countries to buy more. It is not currently limited by production capacity. Therefore, any new food entering the market will need to displace part of the current production of a competing product.

The future commercial prospects of food crops will be affected by changes in population growth, economic development and agricultural productivity, how they are distributed, and how the interaction of these factors affects the balance between food supply and demand for different types of crops. Some of these issues are discussed briefly below.

Population and food abundance

Growth of the Earth's population from six billion to approximately eight billion over the next 30 years (United Nations 2001) will increase the demand for food. Developing countries will provide most of the increase in food demand as their populations grow and living standards rise. Food is however expected to be more abundant - agricultural output is expected to grow at 1.5% per year (FAO 2000), while population is expected to grow more slowly at an average of only 1.0% per year over the three decades. (United Nations 2001). However, these estimates need to be treated cautiously. Bongaarts (2002) points out that declines in fertility in developing countries in the latter part of the twentieth century were larger and more pervasive than forecast, and that the course of fertility decline from here on is difficult to forecast. Small differences in forecast fertility rates have a large effect on forecast population growth rate and size.

Although the intake of staple foods per person is forecast to continue increasing, the rate of increase will slow rapidly. Saturation in food consumption per person has been reached in the developed world, and is gradually approaching in developing countries. By 2030, 94% of people in developing countries are expected to be 'well fed', up from 82% in 1995/97 and 63% in 1969/71 (FAO 2000). Most of those who remain undernourished in 2030 will live in poor countries in Sub-Saharan Africa with low rates of economic growth, and are unlikely to be able to afford imported food.

This combination of rapidly falling rate of population growth, slowing rate of increase in food consumption per head, and rising agricultural production is likely to keep downward pressure on commodity prices, and result in strong competition between suppliers. Official forecasts of grain prices in 2010 show no real increase (World Bank 2002). Global food issues are changing from a struggle to supply enough food for the world's population to issues of distribution, equity and sustainability of production systems (du Guerny 2000).

Despite the slowing rate of growth of total demand for food, the traded volumes of staple foods should increase strongly as many developing countries become more dependent on imported food (FAO 2000).

Cereals

Cereal imports by developing countries are expected to increase from 107 million tonnes in 1995/97 to 270 million tonnes in 2030, with most of the increase supplied by the traditional exporters – North America, Western Europe and Australia (FAO 2000).

The outlook for individual cereals varies. Growth in demand for rice will slow, but a higher growth rate will persist for wheat, as wheat-eating countries are expected to have higher population growth rates than rice-eating countries. Coarse grains will also experience high growth rates, as demand for animal feed increases in developing countries. Global growth in meat consumption has grown at 2.8% per year during the past several decades, driven by the rapid growth in meat consumption in developing countries (5-6% per year). However, this rate of growth is expected to slow markedly to an average of only 1.8% per year over the next 30 years, as meat consumption in China and Brazil approaches a plateau similar to that of developed countries, while low rates of growth in meat consumption persist in India. However, even this reduced growth rate in meat consumption will be sufficient to stimulate increased demand for, and trade in coarse grains, due in part to the continuing transition of livestock production from grazing to intensive stall-fed systems using concentrated feeds. In total, 44% of the expected increase in demand for cereals to 2030 will be for stockfeed. Poultry will continue to be the fastest growing sector, growing 2.6% per year compared to 1.1% for bovine meat (FAO 2000).

Oil crops

Oil crops will be less affected by the reducing rate of demand for staple foods, and are expected to make up 33% of the growth in food demand in the next two decades, compared to a 20% share during the past two decades. Production of soybean, palm oil, canola and sunflower, currently the major oil crops, will continue to expand (FAO 2000).

Opportunities for *Acacia* seed in food markets

Introduction

Acacia seed (or ‘wattle’ seed) has been proposed as a potential new commercial industry for farmers in low and medium rainfall areas of Australia (Australian Native Produce Industries 2001a). It has a number of attractions:

- Seeds from a number of *Acacia* species have a history of use as food.
- *Acacia* seed has a number of interesting attributes, including nutty flavour, and high protein, starch and oil content.
- *Acacia* seed could be suited to the full spectrum of markets, from boutique markets based on its unique characteristics, to large markets for generic food ingredients exploiting its nutritional strengths.
- Edible seed is a high value product that can be transported long distances to markets.

- Australia could exploit its rich genetic resource of *Acacia* species to select and breed productive cultivars for commercial use. Of the 1,000 (approx.) *Acacia* species in Australia, about 350 are found in the temperate dry zone, which includes much of the dryland agricultural areas of southern Australia (Maslin et al. 1998).
- Many *Acacia* species suitable for seed production are native to Australia’s temperate dry zone and would be unlikely to become weeds if grown in localities where they occur naturally.
- Being perennial plants, Acacia species could improve agricultural sustainability while producing a commercial return.
- Acacia plants are well adapted to the Australian environment.
- Some Acacia species have potential to produce other products apart from seed, offering the possibility of developing multiple-purpose crops. Potential large-scale uses include paper, panel board and bioenergy production, while smaller scale products could include fodder, tannins and gums.

This paper reviews the market options for Acacia seed, and discusses their implications for crop development.

Current *Acacia* seed industry

At present, Acacia seed is sold in very small quantities into niche food markets, mostly marketed as ‘bushfood’. The Australian market is estimated to be 12 to 20 tonnes per year, with farm gate prices of $12 to $25 per kg for clean seed (Simpson and Chudleigh 2001). Production methods are high-cost, with most seed harvested manually from natural stands. A few private growers harvest seed from small plantations, and a start has been made to improve production efficiency.

Food safety and nutritional issues

An essential step in evaluating any new food of plant origin is to explore its nutritional characteristics, its potential to be toxic to consumers, and variability in these factors due to genetic and environmental influences.

Acacia seed has a long history of use by indigenous Australians as food (Devitt 1992; cited in Harwood 1994) and like other widely-used bush foods, is likely to be safe if consumed in modest quantities as part of a mixed diet, and if handled and prepared in ways that avoid or destroy any toxic contaminants or constituents (Hegarty et al. 2001).

The wide range of individual human tolerance to different chemical compounds, combined with natural variability in newly cultivated species could lead to isolated cases of illness, even in crops found to be safe for most of the population (Hegarty *et al.* 2001). As a new food crop became better established in the market, these issues would diminish – the crop would become more uniform as a result of plant breeding, and susceptible sections of the population would learn of their susceptibility to the new food and avoid it.

However, if one of the recognised edible *Acacia* seed species were to expand beyond its current niche market, and develop into a large-scale food crop that made up a significant part of some consumers' diets, it would need closer examination to ensure that it satisfied food safety criteria. Similar investigations would be needed to bring new species, without a long history of edible usage, into commercial use. Requirements would include compliance with the Australia New Zealand Food Standards Code (Commonwealth of Australia 2002) or other relevant regulations, regulatory approval in importing countries, and the consequent need to ensure uniform and reliable product quality, to earn and maintain those approvals.

As well, there are numerous other issues to be considered if *Acacia* seed is to become a major food, including maximising nutritional content, minimising or overcoming anti-nutritional factors, ensuring compatibility with food processing methods, and satisfying subjective considerations such as taste and texture. Simpson and Chudleigh (2001) discuss these issues in more detail, and conclude that a large amount of research and development is needed in this area.

Potential markets for *Acacia* seed

Maslin *et al*. (1998) describe seventeen species with potential for seed production, and list several food and industrial uses with potential to expand the industry - flavouring in confectionery, sauces, seasoning, cream and ice-cream; flour in biscuits, bread and pasta; coffee substitute; edible oil; cosmetics such as soaps and facial scrubs; and animal and fish feeds.

Future opportunities discussed in Simpson and Chudleigh (2001) include small markets such as bushfoods and low glycaemic foods, medium-sized markets for flour, and large markets for generic food ingredients such as starch, oil and protein.

The nature of any future *Acacia* seed industry will depend largely on the scale of production and the size of target markets. For example, species selection, production methods, and marketing requirements are likely to be quite different for an industry providing high-volume, low-value seed for commodity food markets, compared to an industry supplying small markets for low-volume, high-value specialty foods.

Various different markets for *Acacia* seed are discussed below. In each case it is assumed that Acacia seed is suitable for the proposed end use, and that issues of nutrition, food safety and regulatory approval have been resolved.

Table 1 contains a summary of features commonly found in food markets of various size. Three different market sizes are considered:

- niche markets for high-priced specialty products
- small to medium-sized markets for specific grains and seeds
- large volume, low value markets for generic food ingredients and stock feed

Table 1. Features of different sized markets for perennial crops.

	Market size		
	Niche	**Small to medium**	**Large**
Price received by growers	High	Moderate	Low
Relative importance of product's price	Low	Moderate	High
Relative importance of marketing strategy	High	Moderate	Low
Potential for value adding by growers	High	Moderate	Low
Scale of land management benefit	Farm scale	District or sub-catchment	Catchment or larger
Justification for public investment	Low	Moderate	High

Niche markets

Acacia seed can be marketed in domestic and global niche markets on its novelty value ('bush food'), or for its special taste ('nutty') or special nutritional characteristics (gluten-free, caffeine-free, low glycaemic index). These markets could grow quickly from their current low level, and sustain an industry based on high-cost, horticultural production methods. Increasing wealth in the developed world, and in many developing countries offers a diversity of market opportunities, although many of these could be fickle, as they are subject to changes in fashion, and changes in public perception of nutritional issues.

Issues that could confront niche markets for Acacia seed include the following:

- Industries with high-value products are vulnerable to over-investment in production, which can quickly over supply markets and depress prices to unprofitable levels.
- *Acacia* seed grown for niche markets is likely to be produced in small-scale, high-cost production systems. These production systems could be vulnerable to low-cost competition in future, if large-scale *Acacia* crops are developed for fibre or fodder, and if seed is harvested from them as an opportunistic by-product.
- Export markets are likely to attract foreign competitors, many of whom have access to *Acacia* genetic material.
- For some customers, part of the attraction of bush foods lies in their production in natural systems. Producing them in cultivation may diminish their value to those customers.
- Marketing and distribution becomes complex when targeting small markets beyond the local area.

Success in niche markets often depends to a large extent on marketing skills, not just the price of the product. ‘Being cost-efficient isn’t the most important factor for surviving in a niche market… Marketing is at least 50 percent of your business…’ (Kent 2002).

Many of the production and marketing strategies used in niche marketing aim to distinguish the product from others, in order to increase its value (USDA n.d.). Examples include choosing a production process that will appeal to customers (such as ‘organic’ production, or ‘wild’ harvesting), developing a new product, producing a new variant of a conventional product, segregating the product into a number of different streams with different attributes for different target markets, producing higher quality products, treating or processing the product in various ways (from changing its presentation by grading, washing, polishing etc, to processing it into various different products), packaging it in a distinctive way or in particular sized packages, using promotional, sales and follow-up methods that differ from those used by larger producers, or offering a different standard and style of customer service. Many of these strategies are relevant in the development of niche markets for *Acacia* seed.

The total tonnage of *Acacia* seed that could be sold in niche markets is likely to be small, even if it were successfully marketed in a number of different niches (Simpson and Chudleigh 2001). The industry required to grow it would be small-scale, and the environmental benefits produced would be localised, farm-scale benefits for participating growers. For example, if niche markets for *Acacia* seed expanded two orders of magnitude from their present size, the total production required would be only one or two thousand tonnes, requiring a growing area of approximately one to two thousand hectares, assuming a yield of 1 tonne per hectare per year.

In conclusion, a niche industry that is well managed, and promoted effectively, can be profitable for its participants. This scale of industry provides opportunities for private investment and privately controlled industry research and development.

Summary – niche markets

Features of potential niche markets for *Acacia* seed include:

- Marketing is often more important than price, so high prices may be achievable,
- Small-scale, high cost production systems can be profitable
- Markets are vulnerable to competition and over-production
- The area of productive trees required is very small
- Land management benefits are confined to the farm scale
- Niche markets provide opportunities for small-scale private investment

Small to medium-sized markets

Markets for tree nuts, snack foods, confectionary, and pulses fall in this category. Each has a high value segment based on whole nuts or seeds, where the product is consumed as a clearly identifiable food item, and one or more lower value segments in which lower quality, or broken nuts and seeds are used in food manufacturing or other industrial processes. The markets for whole seeds are attractive due to their moderate size, and the relatively high prices paid – which although much less than prices paid for niche products, are much higher than prices paid for commodity food crops.

Whole tree nuts

The Australian market for tree nuts is quite small. Annual consumption is estimated to be about 24,000 tonnes of shelled tree nuts, based on a domestic nut production of about 18,000 tonnes per year, plus imports of 13,000 tonnes (mainly cashews) less exports of 7,000 tonnes (mainly macadamia nuts).

International trade in tree nuts is substantial. Cashews, almonds and hazel nuts are the three most traded nuts, making up two-thirds of the total global trade of 1.1 million tonnes per year (shelled basis, including internal trade within the European Union). Average global export price for shelled nuts is about A$6 per kg, but for individual nuts, average prices vary from less than A$4 for chestnuts, to more than A$10 for macadamia nuts and pistachios.

Details for individual crops are shown in Table 2. These figures are average values, and include both high value nuts sold as whole nuts, and lower valued nuts (usually smaller or broken) used in manufactured products such as confectionery, breakfast cereals, ice cream, and baked products (Johnson 1997).

Table 2. Production and trade data for tree nuts (shelled basis).

Crop	Global production (t)	Global imports (t)	Global export price (A$/t)	Australian production (t)	Australian imports (t)	Australian exports (t)
Almond	782,000	257,000	5,460	8,000	1,390	1,490
Brazil nut	28,000	22,000	4,460	n.d.	610	20
Cashew	351,000	290,000	6,610	n.d.	5,760	60
Chestnut	451,000	82,000	3,970	n.d.	70	10
Hazel	278,000	202,000	5,390	n.d.	1,870	20
Macadamia	[2]	n.d.	[1]	[2]	0	[2]
Pecan	no data	n.d.	[3]	[4]	n.d.	[3]
Pistachio	195,000	75,000	10,760	[5]	340	50
Walnut	467,000	87,000	5,570	30	2,170	30
Other	291,000	88,000	8,450	n.d.	470	n.d.
Total	**2,862,000**	**1,103,000**	**6,000**	**18,240**	**12,680**	**7,110**

All data are 1995-2000 averages (FAO 2002), unless otherwise stated.

Note: Global imports include internal trade between EU countries.

n.d.: no data

Shelling ratios used to convert data to shelled basis were: Almond 0.596, Hazel 0.388, Macadamia 0.226, Walnut 0.414 (all USDA 2001), Brazil nut 0.5 (estimate), Cashew 0.3 (Grundon 2000), Pistachio 0.46 (weighed sample), Chestnut 0.9 (Xinan Chemical Industrial Group, China).

[1] 2001 US farm gate price (USDA 2001, 2002)

[2] 1997-2001 averages (USDA 2001, 2002)

[3] 1997 data (Daleys Fruit Tree Nursery 2001)

[4] Data for 2000 (Mooreeonline 2002; Stahmann Farms 2000)

[5] Production potential of 1,500 tonnes nut-in-shell per year (Australian Pistachios 2002)

Acacia seed growers, using horticultural growing methods, should be able to operate profitably at the prices paid for the major tree nuts. However, it is hard to see *Acacia* seed capturing a large share of the high value, whole-kernel part of the market, given the strong market position of existing nut types, and the quite different shape, size and flavour of *Acacia* seeds. Nut size is important in this market segment - all the major tree nuts are large enough to be picked up and eaten as individual nuts.

Even if *Acacia* seed could capture 10% of the Australian tree nut market – an ambitious goal – the total amount required would be only a few thousand tonnes per year, supporting only a small industry. The global market is a more attractive target, since a 1% share of global trade would require the production of about 10,000 tonnes of *Acacia* seed, requiring about 10,000 hectares of trees.

Snack foods and confectionery

A more realistic target for *Acacia* seed could be the lower-priced portion of the snack food and confectionery market, which although less valuable, is also less discerning, and more accepting of smaller sized produce. Competitors in this category include peanuts (or 'groundnuts'), sesame seeds, sunflower seeds, lower grade tree nuts, and other diverse products.

Peanuts: Australia's annual consumption of shelled peanuts is about 32,000 tonne, of which about 90% is grown locally (FAO 2002). About half is used in peanut paste (Australian Broadcasting Commission 2000), while most of the rest is consumed as salted peanuts or in manufactured snack foods. Australian import prices average A$1.30 per kg for shelled peanuts (FAO 2002).

Sesame seeds: Australian consumption of sesame seed is 7,000 tonnes per year. About 1,000 tonnes are grown locally (NRE 1998) while the rest is imported at an average price of A$1.75 per kg (FAO 2002). White sesame seeds are used in snack foods, and as garnish on bread, and attract a higher price, while brown seeds are used for sesame oil and tahini (Department of Primary Industries 2002a).

Sunflower seeds: The sunflower seed industry is moderately large, with global production of 25 million tonnes per year. Australia is a minor contributor, producing 140,000 tonnes and exporting 7,000 tonnes per year at $1.56 per kg. (FAO 2002 - averages for 1995-2000).

Most sunflower seeds are used for oil production (Department of Primary Industries 2002b), for either:

- polyunsaturated oil high in linoleic acid, used in margarine and cooking oil, or
- higher valued mono-unsaturated oil with good frying characteristics, from new varieties with a high oleic acid content (over 80%).

In contrast to this large oilseed industry, a small specialty crop of sunflower seeds with lower oil content and larger seeds is grown for the confectionery and birdseed markets. The largest seeds supply the nut-in-shell market, and have the highest value, medium-sized seeds are hulled for use in baking and confectionery, and the smallest seeds are sold as birdseed. Average price premium over oilseed varieties has been 29% over 20 years in the USA (O'Brien 1997).

The combined Australian market for peanuts, sesame seeds and sunflower seeds is small – less than 200,000 tonnes per year, of which perhaps 25,000 tonnes is used for snack food and confectionery. Global markets are more substantial – total world imports are 1.3 million tonnes of peanut kernels at A$1.20 per kg, 0.6 million tonnes of sesame seed at A$1.30 per kg, and 4 million tonnes of sunflower seed at A$0.45 per kg (FAO 2002), although most of this is for oil production.

If *Acacia* seed were to supply 10% of the Australian markets for snack food and confectionery grade peanuts, sesame seeds and sunflower seeds, a small industry of 2-3,000 hectares would suffice, while capture of 1% of global imports of the same products could possibly support an *Acacia* seed industry of 20-30,000 hectares. If an average price greater than $1 per kg could be achieved, these markets may be profitable for growers using horticultural production methods.

Pulses

Given the small Australian population, and the low usage of dry beans in Australian cuisine, it is likely that a medium-sized *Acacia* seed industry would need to export most of its produce in this market category. About three quarters of Australia's existing production of 880,000 tonnes of dry peas and beans, chickpeas and lentils is exported (FAO 2002). Optimisation of price is possible by astute marketing. For example, The Lentil Company, based in Horsham, Victoria, markets two lentil varieties, but in 20 different lines, each differentiated by size, quality, or post-harvest treatment, and sells lentils in more than 30 different countries (Blair 1998).

Although global trade volumes for these foods are an order of magnitude larger than for nuts, export prices are an order of magnitude lower. For example, global exports total 7.5 million tonnes per year, at prices between $300 per tonne and $700 per tonne. Details for individual crops are shown in Table 3.

Table 3. Production and trade tonnages for medium sized Australian crops.

Crop	Global exports (million t)	Australian production (t)	% exported	% of global trade	Australian export price (A$ per t)
Dry peas	3.23	405 000	61	8	301
Broad beans	0.43	144 000	87	29	349
Chick peas	0.60	225 000	91	34	442
Lentils	0.84	66 000	41	3	573
Dry beans	2.42	41 000	95	2	671
Total	**7.52**	**881 000**	**73**		**395**

Note: Global trade figures include internal EU trade.
All data are 1995-2000 averages (FAO 2002).

Of the various pulse markets, many are likely to be out of reach of *Acacia* seed growers because of their low export price. Most pulses sell for well below A$500 per tonne in international markets. Two exceptions are dry beans and lentils. Both are small industries in Australia, with a combined annual production of about 110,000 tonnes, but their combined global trade is approximately 3.3 million tonnes per year. If *Acacia* seed could supply 2% of these markets, then a moderately large industry of 66,000 hectares could be supported.

Market prospects - small to medium-sized markets

To capture part of the small, high-value export markets for nuts and snack food components, and the larger, but lower-valued markets for pulses would require changes in tastes and habits by consumers, a process that is likely to be both slow and difficult. Simply providing a new alternative food at an equal or lower price is unlikely to stimulate dietary change, as consumers are accustomed to the flavour, texture and appearance of existing foods, and the preparation methods they require. Moving *Acacia* seed beyond being a curiosity food into the mainstream would require sustained, effective, and culturally specific marketing campaigns in a range of target markets, in direct competition with a diverse range of well-established, popular foods. Success in these markets may be possible, but it is likely to be gradual and hard-won.

Assuming that *Acacia* seed were successful in expanding into these small and medium-sized markets, the likely size of an *Acacia* seed industry could be in the thousands, or even tens of thousands of hectares. A perennial plant industry of this size could provide significant land management benefits on a sub-catchment scale, and could attract some public investment in its development.

Summary – small to medium-sized markets

Features of potential small and medium-sized markets for *Acacia* seed include:

- The favourable combination of moderate-sized markets and moderately high prices could support an *Acacia* seed industry in the thousands, or even tens of thousands of hectares.
- Land management benefits could be provided at the sub-catchment scale.
- Price becomes important in these markets. Large sections of the pulse market are already too low-priced for *Acacia* seed produced using horticultural methods.
- A major challenge would be to gain market acceptance for a new food in markets that are already supplied by well-established, popular nuts, pulses and other seeds. This marketing challenge would be complex and varied.

Large markets

Potential large markets for Acacia seed include staple grains, food ingredients and stockfeed. Price, quality and reliability are the main selling points in large commodity markets. Given the slowing rate of increase in demand for food, and the existence of surplus food production capacity in many countries, these markets are likely to remain very competitive.

However, the projected increase in food trade is likely to be in Australia’s favour, as it is already one of the world’s major food exporters, and has a large excess of productive capacity over domestic demand. *Acacia* seed could share in this projected growth in trade, but would need to compete with other major grains.

As demonstrated later in this paper, *Acacia* seed will only be successful in these markets if new low-cost production systems can be developed that make it competitive with existing staple food crops, especially grains and oilseeds. Horticultural methods of production are unable to produce seed at commodity market prices.

Three types of large food market are discussed briefly below – staple food grains, generic food ingredients and stockfeed. Following this brief discussion, grains with large markets are discussed in more detail in later sections.

Production and trade figures for the major grains are given in Table 4.

Staple food grains

The most important food grains are wheat and rice - both have global production rates of almost 600 million tonnes per year. Wheat is the most traded, with 19% of global production being exported, compared with 13% for maize (including a large stockfeed component), and 4% for rice (FAO 2002).

Acacia seed would be expected to face considerable initial resistance in the market, both in Australia and from importing countries accustomed to particular grains in their diet, as it is not sufficiently similar to other grains to be a direct substitute. However, educational campaigns in appropriate ways to use *Acacia* seed in food dishes and baking products, accompanied by skilful marketing campaigns could establish it as a mainstream food, and lead to its wider acceptance.

Generic food ingredients

Generic food ingredients include starch, protein and oil. For these markets the nutrition and processing characteristics of *Acacia* seed, and their uniformity, are more important than aesthetic considerations, as most of these products are used in processed foods where they are blended with ingredients from other sources, and then disguised by various additives (colours, flavours, thickeners, emulsifiers, etc.).

Acacia seed is similar other legumes in terms of protein and starch content. Tests carried out on 58 samples representing 26 species gave average results of 23% crude protein, 26% available carbohydrate and 32% fibre (Brand and Maggiore 1992; cited in Maslin et al. 1998). The oil content of *Acacia* seed is higher than in most legumes, with most of the oil being unsaturated (Brand and Maggiore 1992; cited in Simpson and Chudleigh 2001).

Stock feed

Stockfeed, an indirect human food market, is a relatively undiscriminating market. A share could be captured by Acacia seed if it could be produced with an attractive combination of price and nutritional value. Asian markets are a potential target for Australian producers, although there has been little growth in Asian imports of Australian feed grains over the past decade. However, almost half of the expected growth in demand for coarse grains in the next three decades will be for stockfeed (FAO 2000), so this segment of the market offers growth potential for Australian farmers. Strong competition can be expected from well-established, high quality stockfeed such as maize.

Market prospects – large markets

Of the three large market segments described, generic food ingredients and stockfeed would be the easiest for *Acacia* seed to expand into because the criteria for success are technical in nature, such as nutritional content and compatibility with manufacturing processes. However, they are the most demanding on price, and are extremely competitive markets. Staple food grains for human consumption attract higher prices but must meet the expectations of human consumers. As discussed previously, changing the dietary habits of consumers is a difficult marketing challenge.

If *Acacia* seed could capture a significant share of any of these major markets, an industry measured in hundreds of thousands of hectares, or perhaps even millions of hectares could result, with correspondingly large, catchment-scale land management benefits. A new industry at this scale would be likely to attract significant public investment in its development.

However, as discussed above, markets for grains will remain highly competitive, with no real increase in grain prices forecast for the coming decade.

Summary – large markets

Features of large markets for *Acacia* seed include:

- Large markets and high expected growth rates for traded grain could support an *Acacia* seed industry in the hundreds of thousands, or even millions of hectares.
- Land management benefits could be provided at the catchment scale.
- Price is crucial in these markets. All are beyond the reach of *Acacia* seed produced using horticultural methods. New lower cost production systems would be required.
- Other major challenges include the production of seed with uniform quality and desirable characteristics for processing industries.
- In the case of grains for human consumption, changing consumer tastes presents a marketing challenge.

Australian grain, seed and pulse crops

A brief analysis of existing Australian grain, seed and pulse crops is necessary to allow an assessment of the prospects for *Acacia* seed to become a large-scale commercial crop. Factors considered here are market size, price, yield and cost of production.

Production and trade

Grain growing is one of the world's great industries, with farmers producing more than two billion tonnes of cereals each year. When oilseeds and pulses are added, total annual production rises to approximately 2.4 billion tonnes. Two nations, China and the USA produce more than one third of that total – China producing 500 million tonnes and the USA 415 million tonnes per year.

Most grain production is consumed within its country of origin, with only 13% being traded across national borders. The most traded crops are wheat (108 million tonnes), maize (77 Mt), soybeans (39 Mt), rice (23 Mt), barley (21 Mt), canola (8 Mt), sorghum (7 Mt) and sunflower seed (4 Mt) (FAO 2002).

Australia is only a minor grain producer, with an annual output of 38.4 million tonnes of grains, seeds and pulses - less than 2% of global production.

However, due to its small population and efficient low-cost production systems, Australia has surplus produce available to export at attractive prices, and is able to compete successfully against heavily subsidised competitors. About 70% of Australia's wheat crop is exported, along with about 40% of its total output of all other grains, seeds and pulses. Therefore, despite its small total production, Australia is an important food exporter, holding a 14% share of global trade in wheat, and a 7% share of total global trade in grains, seeds and pulses.

Crop statistics are given in Table 4. and major trading countries in selected grains and oil seeds are shown in Table 5.

Australia is reasonably well placed to export into these markets, because many countries in its region are significant importers of seed. For example, there are substantial markets for wheat in the Middle East and Asia, maize in Asia, barley in the Middle East and North Asia, and soybeans, canola and sorghum in Japan. If *Acacia* seed could capture part of these markets, it would create an opportunity for large-scale production for Australian producers.

Table 4. Production and trade tonnages for Australian food crops

Crop	Australian production (Mt)	Australian exports (Mt)	Global production (Mt)	Global exports (Mt)	Global export price (A$)
Wheat	21.66	15.21	583.9	108.0	221
Barley	5.94	3.25	141.5	21.3	193
Oats	1.56	0.17	28.0	2.5	179
Sorghum	1.56	0.26	60.8	7.0	171
Lupins	1.52	0.75	1.7	0.8	224
Cotton seed	1.40	0.34	53.9	1.1	247
Canola	1.30	0.79	36.5	7.9	381
Rice	1.25	0.60	579.9	23.5	492
Triticale	0.59	0.00	8.6	0.1	243
Dry pea	0.40	0.25	11.4	3.2	297
Maize	0.33	0.02	584.4	76.7	191
Chickpea	0.23	0.21	8.5	0.6	716
Sunflower seed	0.14	0.01	25.7	4.0	406
Broad bean	0.14	0.13	3.4	0.4	402
Soybeans	0.08	0.00	146.7	38.8	345
Lentil	0.07	0.03	2.9	0.8	663
Peanuts	0.04	0.00	31.7	1.2	1,074
Millet	0.04	0.02	27.7	0.2	327
Dry bean	0.04	0.04	17.0	2.4	719
Safflower	0.03	0.01	0.8	0.1	568
Rye	0.02	0.00	21.9	2.1	159
Linseed	0.01	0.00	2.5	1.0	386
Total	38.4	22.1	2,379	304	

Note: Global trade figures include internal EU trade.

Figures are for whole seeds only, and do not include processed products such as flour, oil and meal. Global export quantities for these processed products are:

flour: wheat 9.7, maize 1.1, oilseeds 0.9, other cereals 0.3 Mt,
oil: soybean 6.8, sunflower 3.7, canola 2.8 Mt,
meal: soybean 35.2, canola 4.3, sunflower 3.3 Mt.

All data are 1995-2000 averages (FAO 2002).

Table 5. Trade in selected grains, seeds and pulses (million tonnes)

Commodity	Major exporters [1]	Major importers [1]	Australia's customers [2]
Wheat	USA ....28.8 Canada ....17.5 France ....15.9 Australia ....15.2 Argentina ....8.2 Germany ....4.3 UK ....3.4 Kazakhstan 3.0	Brazil.... 6.6 Italy .... 6.3 Egypt .... 6.0 Japan.... 6.0 China .... 5.1 Iran .... 4.9 Algeria.... 3.7 Indonesia .... 3.6 Korea.... 3.0 Belgium.... 3.0	Indonesia....2.1 Iran....2.0 Iraq....1.7 Gulf States ....1.5 Japan ....1.3 Egypt....1.2 Korea ....1.0 Pakistan....0.9 India....0.9 Malaysia 0.8
Barley	France ....4.2 Australia ....3.3 Germany 2.9	Saudi Arabia.... 4.3 China .... 1.9 Japan.... 1.6	
Sorghum	USA ....5.5 Argentina ....0.7 Australia 0.3	Mexico .... 3.2 Japan.... 2.4 Spain 0.4	Japan Taiwan
Maize	USA ....49.4 Argentina ....9.1 France 7.5	Japan.... 16.2 Korea.... 8.3 Taiwan.... 6.5	
Canola	Canada ....3.4 France ....2.0 Australia 0.8	Japan.... 2.1 China .... 1.2 Germany.... 1.2	
Soybeans	USA ....24.3 Brazil ....7.5 Argentina 2.5	China .... 6.1 Netherlands .... 5.0 Japan.... 4.9	
Pulses	Canada ....1.8 France ....1.0 China....0.7	Spain .... 0.7 India .... 0.6 Belgium.... 0.6	

[1] Import and export data are 1995-2000 averages (FAO 2002).

[2] Averages from 1996/97 to 2000/01 for wheat and flour combined (ABARE 2001).

Of the many dryland crops grown in southern Australia, only five produce more than one million tonnes per year – wheat, barley, oats, lupins and canola – and over 60% of their combined output is exported. Average crop yields are between 1 and 2 tonnes per hectare (Table 6), and average prices received by growers range from $110 per tonne for oats to $340 per tonne for canola (ABARE 2001).

Production costs for grain crops are very low due to the large size of most farms, and the extensive, low input farming methods used. For example wheat costs about $110 per hectare to grow and $30 per hectare to harvest. This is an approximate contract costs for a 1.7 tonne per hectare crop on a Western Australian wheatbelt farm, excluding overheads and GST (Table 7).

Australia’s competitive strengths

Australia’s competitive strength in grain and seed industries stems from its development of low-cost production systems based on extensive, low-input agriculture. Factors which support Australia’s competitive position include:

- large average farm size with low labour input
- flat terrain suited to highly mechanised operations
- relatively low land prices
- well-educated, entrepreneurial farmers
- investment in agricultural research and extension (much of it publicly funded)
- investment in infrastructure to service agriculture

Table 6. Crop yields for Australian grains, seeds and pulses

Crop	Area (ha)	Yield (t/ha)	Production (Mt)
Wheat	**11.5**	**1.9**	**22.2**
Barley	3.3	1.9	6.3
Oats	0.8	1.8	1.5
Sorghum	0.6	2.8	1.7
Triticale	0.3	2.0	0.7
Maize	0.07	5.1	0.4
Total coarse grains	**5.1**	**2.1**	**10.5**
Canola	1.1	1.3	1.4
Cottonseed	0.5	2.1	1.0
Linseed	0.01	0.9	0.01
Peanuts	0.02	1.7	0.04
Safflower	0.03	0.7	0.02
Soybeans	0.04	1.9	0.08
Sunflower	0.12	1.1	0.13
Total oilseeds	**1.8**	**1.5**	**2.7**
Lupins	1.32	1.1	1.5
Field peas	0.34	1.1	0.4
Chickpeas	0.25	0.8	0.2
Faba beans	0.14	1.4	0.2
Mung beans	0.06	0.7	0.04
Navy beans	0.005	1.1	0.005
Total pulses	**2.2**	**1.1**	**2.4**
Total - all crops	**20.6**	**1.8**	**37.8**

All figures are averages of five years (1996/97 to 2000/01). Source: (ABARE 2001) Note: figures differ slightly from FAO figures in previous tables.

Table 7. Average wheat costs and returns.

Activity	*DIY ($/ha)	Contractor ($/ha)
Seed (80 kg @ $160 per tonne of cleaned seed)	13	13
Seeding	10	25
Herbicide (1 L Roundup® @ $5)	5	5
Herbicide (1 L Hoegrass® @ $22)	22	22
Herbicide spraying (2 passes)	5	10
Fertiliser (90 kg super @ $210)	19	19
Fertiliser (60 kg urea @ $323)	19	19
Fertiliser application	with seed	with seed
Cost of establishment	**93**	**113**
Harvesting	8	30
Transport to bin (1.9 t/ha x $5)	10	10
Transport to port (1.9 t/ha x $15)	28	28
Other charges (1.9 t/ha x $29)	55	55
Cost of harvesting, handling and marketing	**101**	**123**
Gross return (1.9 t/ha @ $190 pool price)	**361**	**361**
Total variable costs (sum of above costs)	**194**	**236**
Gross margin	**167**	**125**

* DIY costs do not include labour or machine depreciation.
Interest on money borrowed to finance the crop, or to buy the land is not included.

Sources:
Farm Budget Guide 1999. (Agriculture Western Australia 1999).
Ryegrass Integrated Management model (RIM), UWA (1999). David Pannell et al.
Margins and Break-evens (2001). Touchstone Consultancy Pty Ltd.
Australian Commodity Statistics 2001. (ABARE 2001).

Table 8. Market prices for Australian grains, seeds and pulses.

Crop	Export value ($/t)	Stockfeed value ($/t)
Wheat	[1]225	[2]171
Barley		162
Oats		133
Sorghum		158
Triticale		162
Maize		189
Average coarse grains	221	158
Average oilseeds	357	
Lupins	208	
Field peas	300	
Chickpeas	450	
Average pulses	295	
Total - all crops	237	

[1] Unit value of exports (Australian Commodity Statistics 2001, Table 212)
[2] Sydney cash price
All figures are averages of five years (1996/97 to 2000/01)
Source: Australian Commodity Statistics 2001 (ABARE 2001)

Using other grain and seed crops as a yardstick for *Acacia* seed

For *Acacia* seed to become a perennial crop large enough to produce significant salinity benefits, it would need to become one of Australia's major grain and seed producing industries. Although it could replace some domestic consumption of products such as wheat, oats, lupins, sorghum and maize, and perhaps capture some of the domestic oilseed market, an *Acacia* seed industry would need to export a large proportion of its output into fiercely competitive global markets that are distorted by heavily subsidised produce from the USA and Europe.

Acacia seed could exploit the same advantages that apply to other major dryland crops. It would need to take advantage of these factors and develop low-cost production systems of similar efficiency to annual grain and seed crops.

Acacia seed would face the same pressures as the other major crops to continually improve production efficiency – to maximise yield, improve quality, and reduce costs. It would also need to conform to a similar production pattern, of low cost production in highly mechanised, extensive, low yielding dryland farming systems.

Assuming that *Acacia* seed is accepted readily into large-scale markets, the three most important factors in determining its success as an agricultural crop will be yield per hectare, market price, and its cost of production. These issues are examined below.

Crop yield

Little reliable information is available for *Acacia* seed yields. Figures for annual production, many of them anecdotal, range from 200 kg per hectare to 8 tonnes per hectare for dryland systems (Australian Native Produce Industries 2001a, b; Higgins and Portelli 1998; Maslin *et al.* 1998; Simpson and Chudleigh 2001). There is some consensus that 1 tonne per hectare may be an achievable average yield, and speculation that 2 tonnes or more per hectare may be a realistic target for the future.

Some discussion of this issue is warranted. A good starting point is to examine the yields of existing broad-acre crops. See Table 6.

The average yield for all grain seed and pulse crops in Australia is approximately 1.8 tonnes per hectare. The only crops with significantly higher yields are grown under irrigation, or grow in summer rainfall areas - maize 5.1, and sorghum 2.8 tonnes per hectare. The legume crops (pulses) have lower average yields than the grain and seed crops, averaging only 1.1 tonnes per hectare.

Will Acacias be different?

What arguments are there to suggest that large-scale *Acacia* seed crops will produce higher yields in southern Australia than the major annual crops? There are arguments both for and against.

Arguments against

- Conventional crops have been through a long period of domestication and development to maximise their seed production. Acacias are unlikely to yield as well because they have not been through such a development process. However, this disadvantage could be expected to be overcome by a sustained crop improvement program to develop *Acacia* crops with yields superior to today's wild populations.
- Perennial crops such as acacias usually take at least 18 months and sometimes several years before bearing heavy seed crops. Inclusion of the early non-bearing or low-bearing year(s) will lower average yields.
- Annual crops use the strategy of minimising vegetative growth (within the constraints of needing to be self-supporting, and needing to compete with other plants for light, water and nutrients) and maximising seed production (to carry genes into the next generation). Most perennials would be expected to have lower annual seed production due to their much greater investment in infrastructure (roots, trunks and branches, and foliage).

> "A trade off between persistence and productivity seems likely with perennial farming systems. Persistence will almost inevitably involve a greater investment in biological infrastructure, particularly woody above- and below-ground biomass, with a consequent decrease in harvestable product." (Lefroy 2001)

Arguments for

- Perennials are able to make better use of available water. Where sufficient soil moisture is accessible during the summer drought of southern Australia, Acacias should be able to grow through this period. The question remains however: How much of this ability to grow year-round can be converted into increased seed yields?

- A perennial crop that produced 1.5 tonnes per hectare of seed every year could have a higher average yield than a grain crop producing 2 tonnes per hectare, because the ground under the grain crop would need to be rested periodically, with pasture or a lower yielding crop such as lupins.
- Some of the shorter-lived *Acacia* species (mostly uni-nerve species, which includes all the prospective edible seed species identified by Maslin et al, (1998) may behave more like annuals. Their strategy is to live a short life, but to produce copious amounts of hard-seeded seed. Perhaps once they have established sufficient vegetative mass they are able to produce seed at higher rates than most perennials. However, the ratio of seed production to vegetative growth may be low for the first couple of years.
- Lefroy (2001) cites one example where a perennial grass gave a high seed yield, contradicting the generally accepted hypothesis that annuals have higher seed production than perennials.

  > "Jackson and Jackson (9) are dissenting voices on the subject of trade-offs between perenniality and harvestable yield. Their work demonstrating that perenniality and high seed yield are not mutually exclusive trade-offs in Eastern Gamma grass *Tripsacum dactyloides* is an exciting finding that opens the door to the prospect of perennial grain agriculture. Whether their example has general applicability to other species and life forms remains to be tested. If it does, it would present a serious challenge to life history theory and highlight the dangers of eliminating possibilities for landscape redesign on the grounds of theoretical ecology."

It is clear that more work is needed to clarify the potential seed yield of Acacias.

Some examples of perennial seed yield

An analysis of seed yields of other woody perennials could shed light on the potential yield of *Acacia* seed.

Cunningham *et al*. (2001) based their economic analysis of the seed gum potential of *Cassia brewsteri* on seed yields of 0.9 t/ha at age 11 (6 kg pod per tree x 417 trees per hectare x 35% of pod weight), rising to a plateau of 2.3 t/ha at age 16 (from 16 kg pod per tree). This estimate was based on sample harvests of seed from plants in wild populations, which yielded from 0 to 5kg per tree, in a dry year. The authors assumed that seed yields from cultivated stands could increase to 2.3 t/ha, as a result of careful selection of germplasm, appropriate site selection and husbandry, and occasional irrigation.

Curtis *et al.* (1998) investigated the economics of carob production in the Murray Valley, using a figure for pod yield of 10.4 t/ha in their analysis of a dryland option (500 - 700 mm annual rainfall). This equates to a seed yield of between 0.7 and 2.0 t/ha (likely value approx. 1.1 t/ha), based on estimates that seed comprises 7-20% of the dry weight of carob pods (most likely value 11 - 12%).

These two examples suggest that seed yields in medium to low rainfall dryland agriculture for these species would be about one tonne per hectare, after a decade of establishment. Acacias may however perform better, especially those that mature early and have a relatively short lifespan.

Further collection of data on other woody perennial plants, and measurement of seed yields from established *Acacia* stands would be useful to clarify this issue.

Market price of *Acacia* seed

Reported wholesale prices per kg of *Acacia* seed include \$5 - \$15 (Maslin *et al.* 1998), \$10 (Australian Native Produce Industries 2001a) and \$12 - \$25 (Simpson and Chudleigh 2001). Maslin et al (1998) reported an instance where the price of wild harvested seed was double that of plantation grown seed. For the purposes of this document, the current average wholesale price for clean *Acacia* seed is assumed to be about \$10 per kg, or \$10,000 per tonne.

For comparison, approximate gross prices for the major grain, seed and pulse crops in Australia are listed in Table 8. Nett prices are somewhat lower, after deducting transport and handling costs, and industry levies. Approximate nett prices per tonne received by growers are: wheat \$150, oats \$110, barley \$130. Nett prices for high oil and high protein crops are: lupins \$140, soybeans \$200 (very approx.), canola \$340, field peas \$250, chick peas \$400.

For *Acacia* seed to expand beyond its niche market and become a major crop in Australia’s agricultural landscape, it will have to compete on price with other grain and seed crops. Its current price will need to fall by two orders of magnitude to compete with other large-scale crops.

Acacia seed has some attributes, such as particular flavour or nutritional characteristics, that may make it more highly valued than some other seeds and grains in small, specialised markets, enabling it to achieve modest price premiums in those markets. However, prices in large markets are more likely to be based on bulk nutritional analysis, and manufacturing criteria such as ease of handling, ease of seed coat removal, performance and behaviour during processing, and compatibility with other materials. Acacia seed may even attract a slightly lower price than other bulk grains and seeds if it requires special treatment prior to use.

A reasonable guess for a market price for *Acacia* seed in large markets is \$150 to \$200. A slightly higher composite price may be obtainable if the oil, protein and starch components can be readily separated, and sold into individual markets. There is some scope for this. For example, most of the oil is reported to be contained in the eliosome attached to the outside of the seed coat, an appendage that may be easy to remove during processing.

The importance of market price is that:

- it sets the upper limit for production costs that growers can bear, and thereby determines the type of growing systems that can be used, and
- it is a major determinant of whether or not growers will find the crop attractive to grow instead of some other crop or grazing enterprise.

Production costs

An examination of the costs for each stage in the production of an existing large-scale crop helps set targets and priorities for Acacia seed development. Table 7 contains approximate costs and returns for a medium to large-scale wheat crop. Establishment costs are estimated at approximately $113 per hectare (using contract labour and machinery). Of this, $13 is for seed and $25 is for seeding. Contract harvesting costs vary depending on terrain, cropping area and yield. The estimate used here ($30 per hectare) is towards the lower end of the range, and is a figure that would apply to a large-scale operation. In total, on-farm production costs are about $140 per hectare.

How do these production costs compare with those for an *Acacia* seed crop? Simpson and Chudleigh (2001) included an economic analysis of a hypothetical large-scale Acacia seed enterprise in their report. Assumptions used were:

- Seed cost: $300 per hectare, based on 20,000 seeds per kg, a seed cost of $10,000 per tonne, and a very low seed establishment of 0.1%
- Seeding cost: $80 per hectare, including ground preparation costs
- Harvest cost: $500 - $3,125 per hectare, depending on method. The lower harvesting costs were for whole biomass harvesting ($500) and finger stripping ($750), while the butt-shaking method was the most expensive ($3,125).

Based on these assumptions, total on-farm cost for *Acacia* seed production was in the range $880 - $3,505 per hectare. These costs are some 6 to 25 times the on-farm costs of conventional grain crops. Clearly, costs of production in this range rule *Acacia* seed out of large markets. How can these production costs assumed in Simpson and Chudleigh (2001) be reduced?

Seed

The seed cost will reduce greatly if establishment rates are higher than those assumed by Simpson and Chudleigh (2001). Revegetation consultants in WA have commented that an establishment rate of 0.1% is very pessimistic for *Acacia* seeds, and that a rate of 10% or higher could be expected for high quality, treated seed.

Also, the cost of seed will fall as more efficient production systems are established. Simpson and Chudleigh assumed that seed would cost $10 per kg to buy, but that over the life of the project, the grower would sell harvested seed for $1 per kg. As seed prices fall, new growers will be able to establish *Acacia* crops more cheaply, further lowering their costs of production.

The combination of these two factors should lower seed costs significantly.

Seeding

There appears to be no scope for planting seedlings to establish Acacias on a large scale - the costs are too high. However, on the positive side, there appears to be no major impediment to using conventional air seeding equipment for large-scale sowing of *Acacia* seed, which would enable *Acacia* crops to be established at similar cost to conventional crops.

Harvesting

Harvesting remains the largest cost, and the most difficult cost component to reduce. Much of the current production is harvested manually from wild populations, but this technique is not practical for a large industry. Mechanised systems that have been considered for adaptation to harvesting *Acacia* seed include:

- whole biomass harvesting, in which the seeds would be separated from the harvested biomass as a by-product
- butt shaking - using a machine that grips the trunk and shakes it to dislodge seed into collecting trays
- finger stripping - using a machine that either passes plastic fingers up through the outer foliage of tall aacias or through the tops of short aacias to remove pods
- slapper/bow rod technology used in mechanised grape harvesting
- conventional header used to harvest pods from the tops of low *Acacia* plants
- vacuum seed harvesting, as used for clover seed harvesting

Each of these technologies have different limitations, requirements and potential, as discussed below.

Whole biomass harvesting

The possibility of producing both edible seed crops and biomass for industrial use is attractive, and is one way of bringing down the cost of harvesting – assuming the seed can be separated efficiently from the harvested biomass. However, there are a number of issues that reduce the feasibility of this option:

- Only a small percentage of the total seed produced would be harvested, because harvesting for whole biomass is likely to be carried out throughout the year, not just at seeding time This could be partly overcome by selecting or breeding for longer pod retention on the tree, and non-shattering pods.
- Seed harvesting would be intermittent. In a coppicing crop, harvesting of a particular stand is likely to be scheduled only every two or three years. Acacias grown as a phase crop would be harvested only once, at the completion of their three, four, or perhaps five year phase.
- The species selected for biomass production would be chosen mainly on their wood characteristics, to suit their usage in fibre products or energy generation. These species may not be sought after for edible seed.
- It will be hard to attract investment to improve the yield, quality and uniformity of seed production of a crop whose primary purpose is to produce other products, and from which only a small percentage of the total seed production is harvested.
- The cultural practices adopted for biomass crops may favour vegetative growth over seed production (although there is some evidence suggesting that canopy biomass is a direct determinant of seed production (Gaol and Fox 2001).

Despite these weaknesses, it is a method that is worthy of further consideration. Any seed that is collected during biomass harvesting could be segregated at a processing plant, to produce an additional supply of low cost seed. For large biomass industries covering several million hectares, the amount of seed that could be captured this way could still be quite large. For example, a two million hectare crop bearing one tonne of seed per hectare could supply over 100,000 tonnes of seed as an opportunistic by-product, assuming that harvesting is spread evenly throughout the year, and that the harvesting window for seed is three weeks.

Butt shaking

This technology appears to have several limitations that rule it out of contention for a large-scale production. Butt shaking works best for heavy, high-value products growing on relatively rigid trees with a single stem. It is being developed for olive harvesting but there is anecdotal evidence that it is proving difficult to refine for that industry. Its prospects for efficient harvesting of a light product such as Acacia seed from a flexible tree seem low. If the pods or seeds are tightly held they will prove hard to dislodge by shaking, while if they are loosely held they risk being shaken free by windy weather before they can be harvested.

The main limitation of this method is that each tree needs to be harvested separately, with no obvious scope for making the process continuous. Therefore, it will always be a high-cost method, regardless of how much it is developed. For example, to compete with conventional grain harvesting at $30 per hectare, butt shaking costs would have to be less than 5c per tree (assuming 625 trees per hectare). Using a machine costing $100 per hour, each tree would be allotted less than 2 seconds, an unattainable target using this technology.

Slapper/bow rod

There may be scope for this technique (Australian Native Produce Industries 2001a), depending on whether or not it can be converted from a system suited to harvesting a high yielding, high-value crop such as grapes (10 tonne per hectare at $1,000 per tonne, worth $10,000 per hectare in total) to a system that efficiently harvests a low-value, low yielding crop such as *Acacia* seed (1 to 2 tonne per hectare worth perhaps $150 per tonne, giving a maximum value of $300 per hectare). The low value per hectare of broad acre crops, including large-scale *Acacia* seed production, places a very stringent discipline on harvester design. Again, the architecture of the *Acacia* plant, and its pod arrangements are likely to have a large effect on the suitability of this method.

Finger stripping

This technique has potential for low cost production if the process can be made continuous. The best prospects for continuous harvesting could be for short *Acacia* crops with most of the pods near the top of the plants. A harvester could then pass over the plants, removing the pods from the tops of each plant as it passes. Simpson and Chudleigh (2001) briefly describe a system using plastic fingers with keyhole cut-outs, to strip pods from the plant, while allowing small stems and foliage to pass through.

Another option is to use similar technology to harvest pods from the sides of tall Acacias. In this case, plants with most of their pods on the sides would need to be selected or bred. Again, continuous harvesting systems would need to be developed to keep costs down.

Conventional header

Conventional headers designed for grain crops are very efficient, and are already part of the capital equipment of most large farms. One way of lowering *Acacia* seed harvesting costs is to select and breed Acacia plants that are suited to harvesting with this existing equipment. An ideal scenario would be to have an *Acacia* harvesting season immediately before or after cereal grain harvesting, using the same equipment, perhaps with some ‘bolt-on’ modifications to make the machinery more efficient for harvesting *Acacia* seed. In reality, this simple concept is likely to need considerable development. A modified harvesting front end could be needed - perhaps using more robust cutting equipment suited to more woody material. The machine may also need to handle more vegetative material than is common in grain harvesting. However, a combination of plant selection and breeding, with some machinery development, might produce a workable system.

Vacuum harvesters

An alternative is to vacuum up seed from under *Acacia* trees and shrubs after it has fallen, perhaps using technology adapted from clover seed harvesting. However, it would be essential to develop strategies to limit ant predation, especially by ants that bury the seed. More analysis is needed to clarify the following issues:

- Harvesting costs using vacuum harvesters
- Land management consequences of large-scale soil disturbance by vacuuming (organic matter loss etc.)

Harvesting summary

‘Stop-start’ harvesting system that treat one tree at a time may be satisfactory for boutique and small industries, where the product can be sold into small but high-priced markets, but they are too expensive for a large-scale industry that needs to compete on price with annual crops harvested using ‘continuous travel’ systems such as headers or vacuum collection systems.

Investment in stop-start harvesting systems suited to tall shrubs and small trees will lock the *Acacia* seed industry into a high cost structure that will exclude it from large-scale markets.

Continuous harvesting could be possible using several different approaches - stripping pods or seeds from the sides of tall plants, or vacuuming fallen seed from below tall plants, or removing pods and seeds from the tops of small plants. Using conventional headers, perhaps with some modification, is particularly attractive, and could be a very low cost method for harvesting seed from small, close-spaced plants. However, this approach would require a large investment in selecting and breeding *Acacia* crops that have suitable morphological and physiological features - many of which will be similar to those found in annual crops.

There will be trade-offs in productivity associated with any reduction in plant size. For example, a reduced number of pods per plant would reduce output per plant, while growing the small plants at higher densities would increase output per hectare. How production per hectare would be affected by the interaction of these opposing trends is not clear. There is some evidence from tagasaste that total dry matter production per hectare from dwarf ‘sports’ grown at high density was much less than that from normal tagasaste (Lefroy, pers. comm.). However, further work is needed to investigate this issue for seed production, and for different mechanisms of dwarfing.

In order to develop an *Acacia* seed production system that can be harvested at a competitive cost, the potential to modify the plant to suit a highly efficient harvesting system should be fully explored before embarking on the development of less efficient harvesters to suit existing *Acacia* seed plants.

Optimising harvesting efficiency

Harvesting efficiency is not optimised in isolation. It is also affected by the species being grown, and the layout and silvicultural practices employed. These additional three elements of the production system need to be considered simultaneously.

For example, in a system using a continuous harvester travelling between rows of *Acacia* trees, simultaneously harvesting seed from trees on both sides, factors that need to be integrated in order to optimise the whole system, include:

- row spacing matched to harvester width,
- spacing between trees (within rows) optimised for a combination of harvesting efficiency, and tree productivity (to minimise competition for resources, but maximise resource capture),
- preference for species bearing most seed on the sides of the tree,
- trees pruned if necessary to maintain uniformity, and keep seed bearing branches within reach of the harvester,
- rows oriented to avoid adverse effects (if any) from excessive shading.

If instead, a harvester were designed to collect seed from only one side at a time, or if it straddled each row of trees and removed seed from both sides of the row simultaneously, then a different set of constraints on species selection, layout and silviculture would apply.

In all systems, the productivity of harvesting is likely to be increased by improving the shape of the plant, either by pruning, or by plant breeding.

Pathway to a low-cost *Acacia* seed industry

In a previous section, we saw that each large step up in market size for edible seeds and grains is accompanied by a large step down in price. It seems likely that the integrated production system that is optimal for one industry size would have a quite different combination of species, layout, silviculture and harvesting technology from the production system best suited to a different-sized industry.

Therefore, if the aim is to develop a large-scale *Acacia* seed industry, simply scaling up a small existing industry may not be the best pathway. For example, the development of efficient, continuously travelling row-crop harvesters would bring significant reductions to harvesting costs for the *Acacia* species currently used to produce seed, and would suit a small to medium-sized industry based on high value seed. However, it is very unlikely to lead to a harvesting system that is competitive with broad-acre systems based on headers. A better approach is to start from first principles and consider all the elements required for a low-cost, large-scale industry.

Interrelated conditions that need to be satisfied to develop a large-scale edible seed crop include:

- efficient, integrated farming systems
- appropriate growing, harvesting and processing technology
- suitable germplasm selection and development
- adequate product quality, including acceptance as a safe food
- market penetration

Using this approach, a suitable production system for the southern wheatbelt is likely to have the following features:

Crop layout

Any new perennial crop needs to fit into workable farming systems. That will usually mean integrating the new crop with existing annual crops and pastures, since these traditional activities will remain a part of the farming system for many decades, and will probably remain the largest sources of farm income for some time. Therefore systems designed to include new perennial crops will be driven mostly by the efficiency with which they can be managed, rather than by optimisation of their biophysical interactions. In particular, it is essential that integrated farm layouts allow the continued efficient use of cropping machinery.

Interactions between annual crops and woody perennials will vary greatly with climate, crop type, soil type, landscape and hydrology. In the long term, optimisation of these complex interactions will add to the profitability and effectiveness of integrated systems.

Dispersed layouts (either spatially or temporally) would be preferred, to maximise productivity and minimise drought risk. Most of the medium to low rainfall zone is too dry to support high density plantations on annual rainfall alone. Although plantations could be successful for a short period in this zone by using stored water in the soil as well as rainfall, productivity will drop once the soil water is depleted.

There are two likely layouts for perennial crops - phase cropping and alley farming.

Phase cropping

Phase cropping with involves periodic mining of stored soil water by three to five year episodes of perennial plants across the whole paddock, or part of a paddock, after which they are removed and replaced by other crops in the sequence (usually annuals). The cycle would be repeated periodically, with the length between perennial phases determined by factors such as the relative profitability of the different crops in the sequence, and the time taken for sub-soil moisture levels to recover after each perennial phase.

Phase cropping presents an opportunity to develop an *Acacia* seed crop based on small bushes that can be grown at high densities, and can be harvested by machinery similar to a conventional header. Harvested material would be a mixture of seed, pods, foliage and twigs. After separating the seed, the remaining biomass could be returned to the ground, or retained for use in bioenergy production.

Depending on the plant's growth form, it may be possible to harvest the plants at pod level each year for several years, then harvest it at ground level at the conclusion of the phase, and use the harvested woody material for paper pulp or panel board, plus bioenergy for any unused residue. This final harvest, of more robust, woody material, would require a different type of harvester, probably similar to the machinery under development for the oil mallee industry.

For those phase crops grown primarily for wood or other biomass products, some seed could be collected opportunistically (and cheaply) at harvest, when it coincided with seed ripening.

Alley farming

Perennial crops grown in rows or belts within alley farming layouts are less constrained by water availability than perennial phase crops. They can exploit some of the water and nutrients that leak past the root zone of the adjoining annual plants, and therefore have a longer productive life than phase crops. For example, oil mallees growing in this configuration in the wheatbelt are proving to be productive, and are expected to be long-lived and provide many periodic harvests.

The potential for perennial plants grown in belts to live a long, productive life widens the range of products that can be produced in these systems:

- Solid timber can be produced by long-cycle crops of large trees and shrubs,
- Many biomass products can be produced from short-cycle crops based on coppicing species
- Seed can be produced in many different ways - as a major product, or as a co-product, from large trees and shrubs, or from small bushes, and by dedicated harvesting or opportunistically during biomass harvesting.

Some of the modes in which *Acacia* seed could be produced are discussed below.

Long -cycle trees and tall shrubs

These plants could be grown mainly for seed, mainly for other products, or a combination of the two.

Seed could be harvested annually by machines that strip pods or seed from the sides of tall acacias, or vacuum it from beneath them. As discussed earlier, only continuous harvesting methods are likely to produce Acacia seed at a competitive cost. In this system, rows of acacias would need to be grown far enough apart to allow machinery access to both sides, if seed production were the major purpose of the crop. However, if seed were only a minor product, plants could be grown at closer spacing, with seed harvesting limited to the outer rows where it can be done most efficiently.

Short -cycle coppicing species

Coppice crops would normally be grown to produce one or more biomass products, perhaps with seed as a secondary product.

Seed harvesting from these crops would be limited to the years in which the coppice had regrown sufficiently to produce large quantities of seed - probably year two or three after each coppice harvest. Similar techniques to those used for long-cycle crops could be employed. Some opportunistic harvesting of seed could also occur when the coppice harvest coincided with seed ripening, but this would apply to only a small proportion of the total crop harvested in any year (assuming year-round coppice harvesting).

Low perennials for seed production

The plants that would be suited to this system are similar to those discussed for phase cropping above. Crop management and harvesting could also be similar. The main difference here is that the plants could have a longer life than phase crops, and be harvested for seed until their productivity declined with age, rather than until they exhausted the water available to them. Belt widths would be chosen to maximise efficiency of production (one harvester width, for example), while minimising drought risk.

Harvesting method

The combination of crop layout, crop type and species will determine the type of harvesting that is feasible, which in turn will have a major effect on seed production cost. A number of options have been briefly discussed above, some of which would produce seed as a co-product from crops whose main purpose was fibre, and others that would be dedicated to seed production. The different options would cover a wide range of harvest costs.

However, if seed is to be the sole or major product from an *Acacia* crop, and large-scale, low cost production is required, the harvesting options become constrained. Because *Acacia* seed is a low yielding crop (perhaps 1.25 tonnes per hectare), the harvester would need to employ similar design principles to a cereal header – high ground speed, high manoeuvrability, and a wide front. It would straddle the crop, move continuously, and remove only pods and seed if possible.These requirements set tight specifications for species selection.

Species selection

Earlier sections of this report lead to the conclusion that the most prospective development path for an *Acacia* seed crop is to choose an efficient production system first, then find or develop plants that suits that system, rather than the reverse - starting with a few species that are currently used for *Acacia* seed, and trying to develop efficient growing and harvesting systems that suit those species. An assumption underlying this conclusion is that other acacias not currently considered to be suitable for edible seed production, or lacking a history of usage, nevertheless have the potential to produce commercial quantities of edible seed of acceptable quality if adequately developed.

Once an efficient production system is selected, a list of features that the crop plant should have can be built up, to provide a template against which to test different species, and to guide the selection and development of germplasm.

The discussion above indicates that the cost of seed production is likely to be lowest for a crop that can be direct seeded, and is sufficiently short in stature to be harvested from above by a continually moving harvester. Features that would need to be selected for, or bred into a commercial *Acacia* seed crop of this type include:

- Large seeds
- Reliable, synchronous propagation from seed
- Uniform shape and height
- Short plants, probably erect,or possibly prostrate
- Most pods at or near the top of the plant
- Uniform ripening
- Non shattering pods, or ability to ripen after harvesting when green
- Ability to regrow after harvesting
- High ratio of seed production to vegetative growth
- High seed production per hectare (not necessarily per plant)

Species suited to the harvesting method described above would be very different from the *Acacia* species currently used for seed production.

Other attributes to consider during species selection include onset of seeding at a young age (essential for phase farming), resistance to pests and diseases, tolerance of environmental stress, suitable root architecture to maximise exploitation of soil water, desirable nutritional and food processing characteristics, plus factors related to management in a farming system, such as palatability to stock, toxicity to stock, weed risk, nitrogen fixing ability, and tolerance of herbicides and insecticides.

Most woody perennial crops in medium to low rainfall areas will be unprofitable unless all parts of the plant are used. The most profitable new crops are likely to be those that produce multiple products. However, perennial grain crops may be an exception. If plants can be found or developed that produce a high ratio of seed to vegetative mass, then their profitability may be maximised by enhancing seed production at the expense of any co-products.

Potential for combined *Acacia* seed and timber production

Acacias have the potential to produce a wide range of commercial products - gums, tannins, seed, fodder, wood for use in solid, particle and fibre products, and biomass for use in the production of bioenergy or commodity chemicals. In medium to low rainfall areas, most woody plant crops are unlikely to be profitable unless they produce more than one of these products, and unless all parts of the plant have a commercial use.

Will the same constraint apply to a *Acacia* seed crop? For a small industry the answer is probably yes, with scope to combine annual seed production (at a high cost of production) with longer term production of wood and other biomass products. However, for a large-scale Acacia seed industry, competing with annual grains and seeds, it seems less certain that a multi-purpose plant would be the most competitive option. Market forces may drive plant development towards maximising seed production and its efficiency of collection, which could be at the expense of other co-products.

Development of seed and grain crops

A crop such as wheat has undergone several thousand years of selection and development to enhance characteristics that make it easy to grow, harvest and sell. These include easy establishment, uniform growth, dwarf vegetative structure, improved disease resistance, enhanced response to fertiliser, synchronous seeding, non-shedding seed heads, uniformity of product, high protein and starch content, elimination of rogue genes, inbreeding to enable plants to 'breed true', etc.

The list of desirable characteristics has changed through history as production systems have become more mechanised and capital intensive, and less labour intensive. Some of the characteristics found in modern seed and grain crops have been bred into the plant specifically to enhance its suitability for mechanised establishment and harvesting. Development of efficient machinery and chemical treatments has proceeded in tandem with plant development.

A similar (but faster) development process will be needed for any new seed crop such as *Acacia* seed.

Despite the large number of acacias in Australia, and the wide range of variability within many species, it is almost certain that an *Acacia* species with all these attributes will not be found in nature. Therefore, like all other large-scale grain and seed crops, an *Acacia* seed crop would need to be developed from a selection of the most promising germplasm. Inevitably, the crop plant produced by this process would differ in many ways from its wild forbears. Using modern selection and plant breeding methods, the time needed to develop an *Acacia* seed crop could be quite short - perhaps as little as a decade.

Conclusion

Further development of existing tall *Acacia* species and associated harvesting technology could enable the *Acacia* seed industry to grow from a niche industry to a small industry, but this pathway will not lead to the development of a large industry. To achieve that goal, and its associated land management benefits, a different development path is needed – one that selects and develops new germplasm better suited to efficient management and handling.

Key steps in developing a large *Acacia* seed industry would be to:

- search the *Acacia* flora of Australia for species that have desirable characteristics for large-scale, low-cost cropping systems,
- explore their potential for improvement by careful selection and breeding,
- integrate species selection, farming system development, and harvester development, to optimise all three simultaneously.

Is this just a dream? Perhaps, but further investigation is warranted. *Acacia* is an extremely diverse genus, with about 1,000 different taxa identified in Australia, and much variation within some of those taxa. An investigation of Australian acacias would be likely to find a number with suitable morphology and growth habit, and sufficient genetic variability to encourage plant breeders to attempt to enhance their desirable characteristics and reduce their weaknesses. There may be scope for more radical genetic intervention to speed up the process.

However, an exploration of the *Acacia* flora is only the first step. New crop development requires substantial investment of time, money and expertise to produce a pool of genetic material with desirable characteristics.

It is unrealistic to expect *Acacia* seed to become a major new crop overnight. All the major agricultural crops have undergone unconscious selection, leading up to their domestication, long periods of informal development since first domesticated (Diamond 1998), and formal plant breeding in more recent times, to produce crops that are easy and reliable to establish and grow, easy to harvest, have high yields, and produce high quality uniform products. The domestication of wild *Acacia* species would require many of the same steps, but could take advantage of modern techniques for genetic investigation and plant breeding to hasten the process.

References

ABARE (2001). Australian commodity statistics 2001. Canberra, Australian Bureau of Agricultural and Resource Economics.

Agriculture Western Australia (1999). Farm Budget Guide 1999, Farm Weekly.

Australian Broadcasting Commission (2000). Dick Smith's tasy new adventure. 16 April 2002. http://www.abc.net.au/landline/stories/s119778.htm

Australian Native Produce Industries (2001a). Commercially viable wattle production and dryland salinity, Unpublished discussion document**:** 14.

Australian Native Produce Industries (2001b). Wattle research grid: preliminary outline, Unpublished discussion note.

Australian Pistachios (2002). The pistachio industry. 16 April 2002. http://www.aus-pistachio.com.au/

Bartle, J (2001). Mallee eucalypts - a model, large scale perennial crop for the wheatbelt. Outlook 2001, Parkroyal Hotel, Canberra, Australia, ABARE.

Bhati, UN (1998). Market report 4 - Cost of tree seedlings and cuttings, ANU Forestry

Blair, P (1998). The niche marketing of Australian TLC lentils: a model for other pulse crops. 15 August 2002. http://www.newcrops.uq.edu.au/newslett/ncnl1023.htm

Bongaarts, J (2002). The end of the fertility transition in the developing world. Expert Group Meeting on Completing the Fertility Transition, New York, United Nations, Population Division.

Brand, JC and P Maggiore (1992). The nutritional composition of Australian *Acacia* seeds. Australian dry-zone acacias for human food. C Harwood. Canberra, Australia, Australian Tree Seed Centre, CSIRO Division of Forestry**:** 54-67.

Commonwealth of Australia (2002). Food Standards Code, Anstat Pty. Ltd.

Cunningham, D, K Walsh and E Anderson (2001). Potential for Seed Gum Production from Cassia brewsteri. RIRDC Project No. UCQ-12A, Rural Industries Research and Development Corporation

Curtis, A, D Race and B Booth (1998). Carob Agroforestry in the Low Rainfall Murray Valley. Report 98/008, Rural Industries Research and Development Corporation

Daleys Fruit Tree Nursery (2001). Making your land profitable with pecan nuts. 16 April 2002. http://www.daleysfruit.com.au/newjun.html

Department of Primary Industries (2002a). Growing sesame in the South Burnett. 14 August 2002. http://www.dpi.qld.gov.au/fieldcrops/2888.html

Department of Primary Industries (2002b). Sunflower production in Queensland. 14 August 2002. http://www.dpi.qld.gov.au/fieldcrops/7416.html

Devitt, J (1992). Acacias: a traditional aboriginal food source in Central Australia. Australian dry-zone acacias for human food. C Harwood. Canberra, Australia, Australian Tree Seed Centre, CSIRO Division of Forestry**:** 37-53.

Diamond, J (1998). Guns, germs and steel. London, Vintage, The Random House Group Limited.

du Guerny, J (2000). Transition to sustainability in the twenty-first century: Meeting food needs. Conference of the World's Scientific Academies, Tokyo.

FAO (2000). Agriculture: Towards 2015/2030. Technical Interim Report

FAO (2002). FAOSTAT online statistical database. 16 March 2002. http://apps.fao.org/

Gaol, M and J Fox (2001). Reproductive potential of Acacia species at Sanford Rock Nature Reserve - variation between years. Poster paper. Dalwallinu Acacia Symposium, Dalwallinu, Western Australia.

George, RJ, CJ Clarke and TJ Hatton (2001). "Computer-modelled groundwater response to recharge management for dryland salinity control in Western Australia." Advances in Environmental Monitoring and Modelling **2**(1): 3-35.

George, RJ, RA Nulsen, R Ferdowsian and RG P. (1999). "Interactions between trees and groundwaters in recharge and discharge areas - A survey of Western Australian sites." Agricultural Water Management **39**: 91-113.

Grundon, NJ (2000). The Australian cashew industry. An information system. Report 00/15, Rural Industries Research and Development Corporation**:** 184

Harper, RJ, TJ Hatton, *et al.* (2000). Phase Farming with Trees: a Scoping Study of its Potential for Salinity Control, Soil Quality Enhancement and Farm Income Improvement in Dryland Areas of southern Australia. Report 00/48. Canberra, Australia, Rural Industries Research and Development Corporation

Harwood, CE (1994). "Human food potential of the seeds of some Australian dry-zone Acacia species." Journal of Arid Environments **27**: 27-35.

Hatton, TJ and RA Nulsen (1999). "Towards achieving functional ecosystem mimicry with respect to water cycling in southern Australian agriculture." Agroforestry Systems **45**((1-3)): 203-214.

Hatton, TJ and R Salama (1999). Is it feasible to restore the salinity affected rivers of the Western Australian wheatbelt? Second Australian Stream Management Conference - The challenge of rehabilitating Australia's streams, Adelaide, South Australia.

Hegarty, MP, EE Hegarty and RBH Wills (2001). Food safety of Australian plant bushfoods. Report 01/28, Rural Industries Research and Development Corporation**:** 76

Hele, A (2002). "Issues in the commercialisation of wattle seed for food." Conservation Science W. Aust. **4**(1): 181–184.

Higgins, I and M Portelli (1998). Farming native vegetation for salinity controlhttp://home.vicnet.net.au/~bushfood/pages/salinity.pdf

Johnson, DC (1997). "United States Is World Leader in Tree Nut Production and Trade." Fruit and Tree Nuts Situation and Outlook(FTS-280): 35-41.

Kent, K (2002). Niche market survival. Success hinges on more than just cost efficiency. Iowa Farmer Today. Cedar Rapids, Iowa.

Lefroy, E (2001). Applying ecological principles to the re-design of agricultural landscapes. 10th Australian Agronomy Conference, Hobart, 2001, Hobart, Tasmania.

Maslin, BR, L Thompson, MW McDonald and S Hamilton-Brown (1998). Edible Wattle Seeds of Southern Australia, CSIRO Australia.

Mooreeonline (2002). Mooreeonline. 16 April 2002. http://moreeonline.net.au/mainpage.htm

National Land and Water Resources Audit (2001). Australian dryland salinity assessment 2000. Canberra, National Land and Water Resources Audit**:** 129

NRE (1998). Sesame. 16 April 2002. http://www.nre.vic.gov.au/web/root/domino/infseries/infsheet.nsf/ec560317440956e24a2568e3000bb3d9/3247e987ff5a1d784a2565c100647ffb?OpenDocument

O'Brien, D (1997). Sunflower marketing in the High Plains, Kansas State University**:** 15

Simpson, S and P Chudleigh (2001). Wattle seed production in low rainfall areas. Report 01/08, Rural Industries Research and Development Corporation**:** 34

Stahmann Farms (2000). Stahmann Farms. 16 April 2002. http://www.stahmannfarms.com.au/about.htm

United Nations (2001). World Population Prospects: The 2000 Revision. Draft. New York

USDA (2001). World horticultural trade and U.S. export opportunities, United States Department of Agriculture**:** 69

USDA (2002). World horticultural trade and U.S. export opportunities, United States Department of Agriculture**:** 38

USDA (n.d.). Alternative enterprises - value-added agriculture. 15 August 2002. http://www.agmrc.org/business/vaainfo.pdf

World Bank (2002). Commodity price data (Pinksheets), World Bank

Search Report

Appendix 8

Assessment of south-western Australian *Acacia* species for farm forestry

Bruce Maslin

DRAFT 01 May 2001

Preliminary assessment of south-west Western Australian Acacias for potential in farm forestry

By B.R. Maslin

Introduction

Aim. To assess indigenous *Acacia* species in south-west Western Australia for inclusion in demonstration trials for widescale farm-forestry plantings in the W.A. wheatbelt, with an emphasis on their suitability as a source of wood for MDF production and biomass for energy production.

Methods. The entire south-western *Acacia* flora (350+ species) was considered for this project. Species were assessed against the criteria listed below. Initial screening was done based on my personal knowledge of the species (supplemented by herbarium label information, published and unpublished literature and through discussions with colleagues) and this was then followed up by a field inspection of prospective candidates.

Three **field trips** specific to the project were undertaken and, apart from gathering relevant field information about the species, seed was collected where possible:

22-28 November 1999: Geraldton – Mount Magnet – Dalwallinu – Hyden – Busselton

25 June – 1 July 2000: Kalgoorlie – Esperance – Hyden

4–5 December 2000: Esperance

Additional field information was acquired during field work associated with the *A. microbotrya* project that was commenced in late 2000.

Herbarium and seed vouchers were taken in most cases and details of these collections are noted under each taxon. Voucher specimens have been lodged at the W.A. Herbarium.

The main **criteria used to assess species** were as follows:

- growth form (tree, tall shrub, small shrub);
- biological characteristics (i.e. growth rate, longevity and coppicing/suckering ability): <u>very often these attributes were unknown and had to be estimated</u>;
- stems architecture (particularly number arising from ground level, their diameter at breast height (dbh) and straightness (it is *suspected*, but not confirmed, that multi-stemmed plants will have a higher coppicing potential than those with single stems);
- ecological preferences and distribution (it was considered desirable to select widespread species with wide edaphic tolerances over geographically restricted, habitat-specific species);
- wood colour: <u>not all species were assessed for this characteristic</u>.

Based on these criteria **species were subjectively ranked** (low, medium or high) as to their potential suitability in widescale planting for commercial purposes (this proved difficult because apart from MDF products and energy production we do not yet know what these commercial possibilities might be, therefore MDF and energy assumed primacy in the ranking process). The suitability (potential and actual) of species for use in revegetation is also recorded (i.e. effectiveness in salinity & erosion control and suitability as windbreak & wildlife refuge). It is very important that the **weed potential** of any species used in widescale plantings be thoroughly assessed prior to any extensive use.

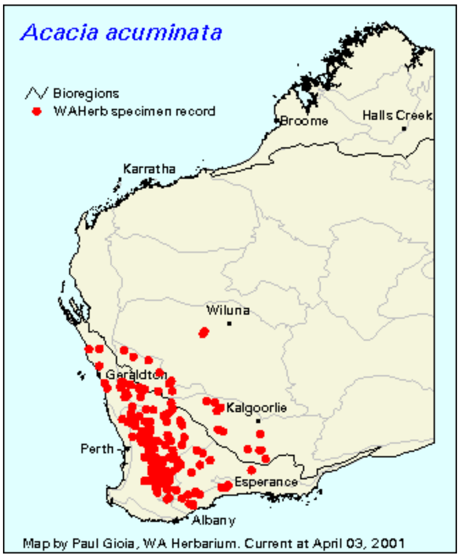
Note: Except for *A. hemiteles* and *A. redolens* (which are considered particularly good for general revegetation) no species considered to be useful *only* for nature and wildlife conservation purposes are included here. There are many other species in the south-west that have good revegetation potential but are not discussed here because they do not meet any (or only few) of the above-listed criteria. For example, salt tolerant taxa such as *A. ligustrina*, *A. patagiata* and *A. mutabilis* subsp. *stipulifera* (see Craig *et al*. 1990 & 1991) are not included here because of their low stature and rather low woody biomass.

The **geographic focus of this report** is on species which predominate in the agricultural zone of the Western Australian wheatbelt. Although a few Arid Zone species such as *A. murrayana* and *A. victoriae* are included there are many more taxa from this region that are omitted, for example, Mulga (*A. aneura* and its allies) and Gidgee (*A. pruinocarpa*).

Results. Not every south western arborescent or semi-arborescent species of *Acacia* is included in this report, only those which I subjectively judged as meeting a sufficient number of the criteria are discussed. Nevertheless, probably most (?all) of the most important taxa are discussed below. It is important to remember that the assessment of taxa here is based on field characteristics and other information that I have been able to derive from published and unpublished sources; how well or otherwise these taxa will perform in cultivation remains to be assessed. Also, in most cases information concerning biological and wood characteristics is either absent or very incomplete; these important attributes will need to be obtained for species considered worthy of progressing further by SEARCH.

Acacia acuminata **(Jam)**

WA Herbarium taxon ID: **3200**



Note. Details of *A. acuminata* (Jam) and its variants are given in Maslin *et al*. (1999) and the species will therefore not be dealt with comprehensively here. Also, a summary of the biology, ecology and uses of Jam is given in Barrett (1995).

Habit. Tall shrub or tree 2-7 (-10) m tall; multi-stemmed from ground level or with a +/- straight bole 0.3-1.5 (-2) m long and 10-30 (-45) cm dbh; stems and main branches straight to sub-straight; occasional pendulous forms occur in parts of the range.

Distribution and habitat. Murchison River south to Borden and Ravensthorpe and east to Yalgoo, Kalgoorlie and Balladonia. Jam is normally very common in the areas where it occurs and can form quite large, monotypic stands. It generally grows on medium- to heavy-texture soils, i.e. loamy clay or sandy loam (pH5.5-7), often in lower parts of landscape (commonly near watercourses or around base of granite rocks) or low hilly country. Some plants from near Corrigin occur in shallow sand over laterite but this is probably an unusual habitat for the species. *Acacia acuminata* appears to be slightly to moderately salt tolerant.

Variation. As discussed in Maslin *et al*. (1999) there are complex variation patterns within this species. There are three main variants (typical variant, narrow phyllode variant and small seed variant) which are separated by finely graded morphological differences (which are broadly supported by genetic data); each variant has a discrete (but sometimes overlapping) geographic range and morphological attributes. A complex mosaic of forms occur in the Geraldton region (some of these may involve hybridity with *A. burkittii*).

Affinities. Closely related to *A. burkittii* (see below); also allied to *A. oldfieldii* (see below) and *A. drepanophylla* (not included in this report) but the relationship is probably less close. *Acacia jibberdingensis* (see below) is probably not far removed taxonomically from *A. acuminata*.

Biology. Moderately fast growth rate and moderately long-lived (I would estimate in excess of 50 years). Coppicing ability absent or low (in a recently burnt area just south of Brookton many plants can be seen as regenerating from around base of burnt main stems); unlikely to sucker. It is drought and frost tolerant but will not tolerate waterlogging (Barrett 1995); it is killed by fire (Hussey, pers. comm.). Roughly (1987) noted that *A. acuminata* is a promiscuous host with nodulation by 75-100% of the 20 *Rhizobium* strains tested. The species is sometimes lightly infected with Gall Rust while in the southern part of its range it is commonly infected by the aerial parasite, *Amyema preissii*. As summarised by Barrett (1995) larvae of the Bag-Shelter Moth can cause severe defoliation, and eventually death; also, locusts, wingless grasshoppers, rabbits, native and feral animals can also cause severe grazing damage. A detailed review of germination techniques for *A. acuminata* is provided in Barrett (1995). Pod crops are variable; in some years pods fail to develop; plants that do set fruit often set heavy crops and seed is very easy to collect (shaking technique).

Wood. The wood of *A. acuminata* has the odour of Raspberry Jam when freshly cut. The heartwood is dark chocolate brown and the sapwood pale yellowish. The wood is finely textured with an attractive grain (often with fiddleback); it has an air dry density of 1 214

kg/m^3, based on 1 sample tested (G. Pronk, pers. comm.). For further details regarding wood characteristics see Bootle (1983: 290).

General Uses. *Acacia acuminata* is generally considered well-suited for revegetation in the wheatbelt, particularly for well-drained loamy soils (see Wilcox *et al*. 1996 and Lefroy *et al*. 1991); it often regenerates well in previously cleared areas once grazing animals are excluded (amount of regeneration dependent upon how long the land has been under pasture). *Acacia acuminata* is currently under trial (by Jon Brand) for suitability as a Sandalwood host plant. Advocated by some people for human food because the seed is said to have a good “nutty” flavour; however, not recommended by Maslin *et al.* (1998) because of unreliability of pod crops. Possibly suited for small poles.

SEARCH relevance. Medium to high priority. Jam is an important wheatbelt species, if for no other reasons than it is so common and reaches tree stature. Its role as a Sandalwood host is currently being assessed, and it is likely to be important in that industry. Its dark coloured heartwood would probably make it unsuited for use in MDF production. Although Jam has suitable woody biomass its suitability as a fuel stock for energy production may depend upon it attaining acceptable growth rates under cultivation; other acacias such as *A. saligna, A. microbotrya* etc. may well do better in this regard. Nevertheless, Jam is likely to exhibit reasonable growth rates under cultivation and because it is genetically diverse, has reasonably wide ecological tolerance, is easy to germinate and apparently does not sucker, it may well be a useful inclusion in the SEARCH program. It will, however, be important to use the appropriate variant/provenances when using this species (special care should be taken if seed from the Geraldton area is used as there is much unresolved taxonomic complexity in this area). As noted in Maslin *et al.* (1999) growth form of this species (in nature, and therefore probably also in cultivation) can vary depending upon spacing between plants (i.e. a more upright habit occur when plants are closely spaced). It is relevant to mention here that Jam is a plurinerved species and can be expected to behave differently from uninerved species such as *A. saligna* and *A. microbotrya*; these are quite different taxonomic group and the included species can be expected to differ significantly with respect to biological, ecological, morphological, etc. characters.

Seed collections (provenance name in quotes) and vouchers

<u>Typical variant</u>

"Paynes Find", 10 km NW of Paynes Find, 29° 10' 20"S, 117° 39' 43"E, B.R. Maslin 7945, 24 Nov. 1999 (seed voucher).

<u>Narrow phyllode variant</u>

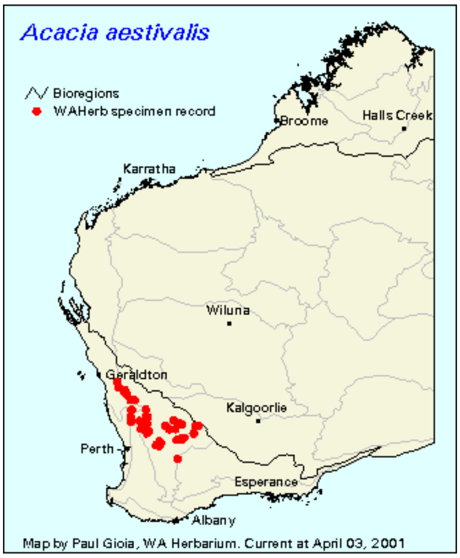
"Cleary", 2.5 km E of Cleary, 30° 26' 05"S, 117° 40' 15"E, 25 Nov. 1999, B.R. Maslin 7951 (seed voucher)

"Merredin", 8 km N of Merredin on road to Nungarin, 31° 24' 50"S, 118° 15' 24"E, 11 Dec. 1999, J. Carslake [seed collected, no herbarium voucher taken].

"Kalannie", 33 km E of Kalannie, 1 km up Endomorre Lane from the T junction with Scotsman Road, 10 of Dec. 1999, J. Carslake [seed collected, no herbarium voucher taken].

Acacia aestivalis

WA Herbarium taxon ID: **3206**



Habit. Bushy shrub or tree to c. 3 m high. Most plants appear to sucker aggressively, at least in roadside situations. Apparently non-suckering arborescent plants are reported to occur NE of Mingenew (Pat Ryan, *pers. comm.*) but I have not inspected these; under cultivation (with regular watering) these plants reach about 8 m tall with stems to 0.3-0.4 cm diam.

Distribution and habitat. Occurs from near Mingenew SE to Corrigin and E to Bullfinch. The species is scattered (not uncommon) throughout its geographic range and is most often seen as forming dense, monotypic, clonal stands along road verges. Grows in clay and loam, often in low-lying areas, frequently in *Eucalyptus salmonophloia* woodland.

Affinities. A member of the *A. microbotrya* group of species.

Biology. Commonly (?always) suckering; likely to resprout if coppiced or pollarded. Pods tend to occur scattered over the plants and seed collection may therefore prove difficult.

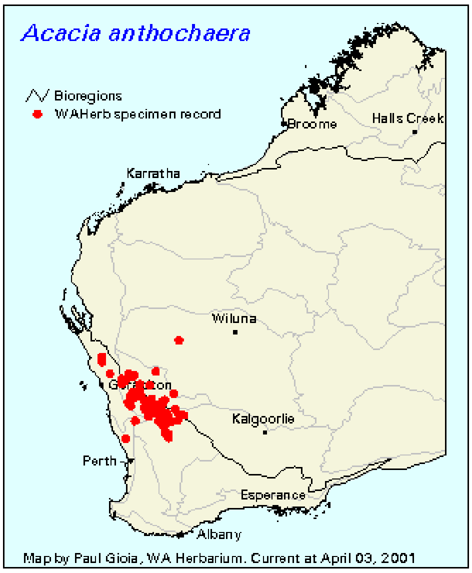
SEARCH relevance. I did not adequately assess this species. The arborescent, apparently non-suckering form from north-east of Mingenew certainly is an impressive plant in cultivation. *Acacia aestivalis* could be expected to have growth/wood etc. characteristics similar to *A. microbotrya*. I do not know whether suckering is specific to particular populations (apart from the Mingenew plants I have observed, just S of Moora, a natural stand of what appeared to be non-suckering plants) or whether it is related to the age of the stand (i.e. the suckering habit becomes less evident as stands mature).

Herbarium voucher. No voucher taken for SEARCH project.

Seed collections. None made for SEARCH project.

Acacia anthochaera **(Kimberly's Wattle)**

WA Herbarium taxon ID: **12247**



Habit. Tall, narrowly obconic or rounded shrub 2-4 m tall, maturing to bushy tree to 8 m tall (but arborescent forms are not commonly encountered). The shrubs have six or more +/- straight, sparingly to moderately branched main stems arising from ground level (each stem 6-10 cm in diameter at its base and 4-8 cm dbh), the crowns are rather dense, 2-4 m wide and occupying from 40-100 % of the total plant height. The trees have often slightly crooked trunks and main branches, the trunks may remain undivided to about 1 m above ground level and reach 30 cm in diameter at their base (10-20 cm dbh).

Distribution and habitat. Occurs from near Yuna south-east to Cowcowing, also near Galena. Grows in flat, low-lying areas, in red-brown sand or loam; soils vary from slightly to highly saline (it sometimes occurs on the margins of salt lakes). *Acacia anthochaera* is especially common (on appropriate soils) in the Mullewa – Kalannie region.

Variation. Relatively invariate, however, some plants in the zone of geographical overlap between *A. anthochaera* and *A. hemiteles* are problematic and suggest that hybrids may occur between these two taxa (BRM 7928, listed below *A. affin. anthochaera*, may be an example of this putative hybrid).

Affinities. A member of the "*Acacia prainii* group" (see Maslin 1995 for discussion), three members of which are included in this report, namely, *A. anthochaera*, *A. hemiteles* and *A. prainii*.

Biology. This species appears to have a moderate to moderately fast growth rate. Its coppicing ability is unknown (but possibly may do so) and it has not been recorded to root sucker under natural conditions. I suspect that *A. anthochaera* would be moderately long-lived (perhaps 30+ years). In good years pods are produced in large quantity; they are held terminally on the branches making them easily accessible for collection (shaking/threshing techniques); good annual pod crops are produced fairly regularly. The seeds are medium-sized to large and although retained in the pods following dehiscence are easily separated by shaking or hand stripping; seeds are easy to germinate.

Wood. Wood characteristics unknown (but probably has a dark heartwood).

General Uses. Because of its large growth form, its occurrence on a wide range of soil types (located in the lower parts of the catchment) and its saline tolerance *A. anthochaera* has good potential for revegetation within the northern wheatbelt at least; it would be useful for salinity and erosion control, visual screens, windbreaks and shelter belts. The stems could be a source of straight posts, small poles and possibly other wood products (if *A. anthochaera* is shown to coppice then its potential as a renewable wood source could be greatly enhanced). *Acacia anthochaera* is one of the lesser-known species suggested by Maslin *et al.* (1998) for trialing as a source of seed for human food.

SEARCH relevance. Medium priority. This species is certainly worth further investigation by SEARCH for use in the northern and central wheatbelt. It has an excellent growth form, produces a good quantity of woody biomass, is a prolific seeder, is reported to be moderately fast growing (would need confirming under trial conditions though) and appears to be somewhat salt tolerant. Although its wood characteristics are unknown it is likely to have a dark coloured heartwood, therefore unsuited to MDF production. However, it may be well-suited to biomass production for energy, and its potential in this regard would be enhanced if the species is shown to have coppicing ability. There is potential for *A. anthochaera* as a source of seed for human consumption, not only because it produces large, reliable pod crops but also because it is not all that far removed taxonomically from *A. victoriae* (which is the industry "standard" for human food).

Seed collections (provenance name in quotes) and vouchers

<u>A. anthochaera</u>

"Mullewa", 46 km E of Mullewa on road to Yalgoo, 28° 27' 20"S, 115° 57' 54"E , 23 Nov. 1999, B.R. Maslin 7937 (two seed samples collected, plants c. 4 km apart; another seed collection from this population made on 9 Dec. 1999 by J. Carslake).

"Mt Gibson", 2 km S of Rabbit Proof Fence on Great Northern Hwy (S of Paynes Find), 24 Nov. 1999, B.R. Maslin (seed collected, no herbarium voucher taken; another seed collection from this population made on 10 Dec. 1999 by J. Carslake).

"Black Road", about 45 km due E of Kalannie, 10 Dec. 1999, J. Carslake (seed collected, no herbarium voucher taken).

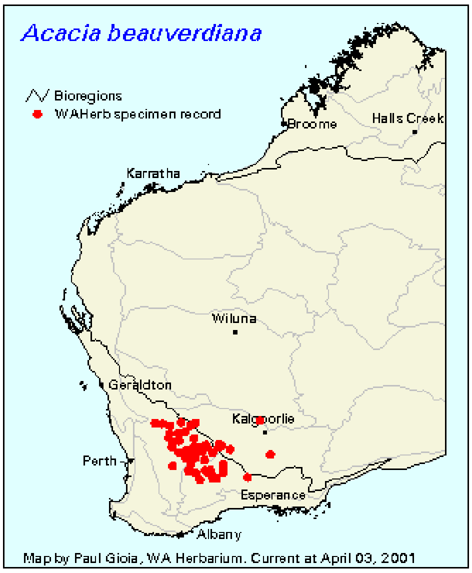
"Kalannie", about 8 km NW of Kalannie on the Kalannie-Dalwallinu Road, 3.5 km N from the Campbell and Kalannie-Dalwallinu Cross Road, 11 Dec. 1999, J. Carslake (seed collected, no herbarium voucher taken).

<u>A. affin. anthochaera</u>

"Three Springs", 2.5 km N of Three Springs on Midlands Road, 29° 31' 11"S, 115° 44' 20"E, 22 Nov. 1999, B.R. Maslin 7928 (immature pods) and 8 Dec 1999, J. Carslake (mature seed but no herbarium voucher taken).

Acacia beauverdiana

WA Herbarium taxon ID: **3236**



Habit. Obconic shrub 3-4 m tall, occasionally a tree to 8 m, 2-6-branched at base, main stems rather straight and 3-6 cm dbh (may reach 13 cm diam. on oldest plants); wood very hard, heartwood light- to mid-brown, sapwood pale yellow.

Distribution and habitat. Occurs from near Bonnie Rock south to near Lake Grace, with a disjunct occurrence near Broad Arrow. Often forms large populations in places where it occurs (especially along road verges). Grows in (usually gravelly) sand or loam, commonly on low rises.

Variation. A broad phyllode variant occurs near Bonnie Rock but the species seems to be relatively invariate.

Affinities. Unknown.

Biology. Little definitive information known. However, it is likely to be moderately long-lived (perhaps 30+ years) and not particularly fast growing; suckering unlikely; coppicing/pollarding ability unknown. Pods prolific and easily collected by hand using shaking/threshing technique; seeds quite small.

Wood. Very hard; heartwood dark coloured; sapwood pale.

General Uses. Probably has revegetation potential for gravelly sandy sites in central wheatbelt.

SEARCH relevance. Medium to low priority. Although this species has good form and produces a good amount of woody biomass the heartwood is dark-coloured and therefore unsuited to MDF production. Also, the growth rate is probably not overly fast (could perhaps match *A. acuminata*) which would tell against the species for biomass production. Notwithstanding these constraints I think that A. beauverdiana is worth trialing for use on light soils in the south-central (and probably also northern) wheatbelt regions, if only for general revegetation purposes.

Seed collections (provenance name in quotes) and vouchers

"Bruce Rock", 8.5 km N of Bruce Rock on road to Merredin, 31° 48' 25"S, 118° 11' 14"E, 4 Dec. 2000, B.R. Maslin 8208 (seed voucher).

"Muntadgin ", about 23 km S of Great Eastern Hwy (from intersection just E of Merredin) on road to Muntadgin, 31° 40' 02"S, 118° 23' 27"E, 4 Dec. 2000, B.R. Maslin 8212 (seed voucher).

"Holt Rock", about 4 km S of Holt Rock then 100 m W along Kulin Road, 32° 41' 49"S, 119° 26' 38"E, 5 Dec. 2000, B.R. Maslin 8216 (seed voucher).

Acacia affin. *beauverdiana*

Habit. Narrowly obconic shrub 3-5 m tall, dividing just above ground level into straight and sparingly divided main stems (7-12 cm dbh); crown bushy.

Distribution and habitat. Known only from the Widgemooltha – Norseman area. Grows in dark brown loam among low rocky hills.

Variation. Invariate.

Affinities. Unknown at this stage. It has a growth form similar to *A. websteri* (see below) but is probably not overly closely related to this species. There is at least a superficial resemblance to *A. beauverdiana* but this relationship requires further investigation. *Acacia* affin. *beauverdiana* represents an undescribed new species.

Biology. No definitive information but probably slow growing and long lived (perhaps 50+ years). Unlikely to sucker; coppicing/pollarding ability unknown. Pods prolific on ground under the plants indicating high fecundity.

Wood. Hard, heartwood dark brown.

General Uses. Unknown.

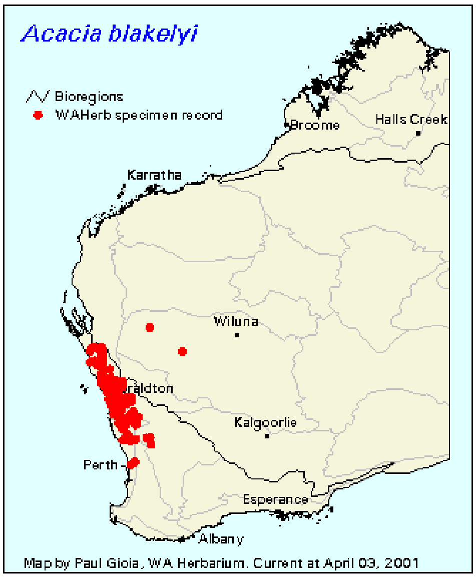
SEARCH relevance. Low priority. Although this species has good form and produce a reasonable amount of woody biomass it is rated as low on account of its probable slow growth rate and dark coloured heartwood; furthermore, it is geographically restricted and has its geographic range well outside the wheatbelt.

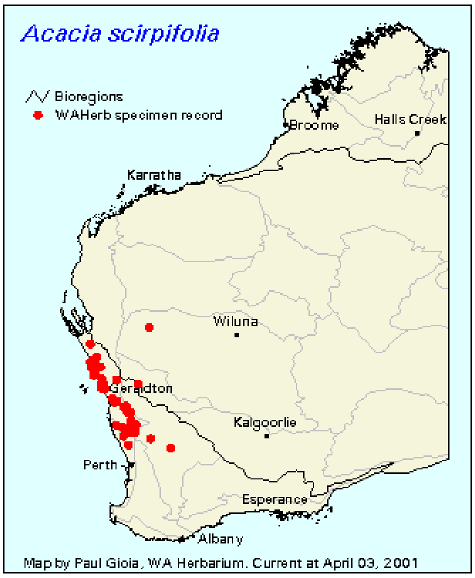
Herbarium voucher (no seed collected)

5 km S of Higginsville on Coolgardie - Esperance Highway to Norseman, 31° 42' 30S", 121° 41' 21"E, 26 June 2000, B.R. Maslin 7972.

Acacia blakelyi* and *A. scirpifolia

WA Herbarium taxon ID: **3242** WA Herbarium taxon ID: **3532**





Acacia blakelyi and *A. scirpifolia* are very closely related and future studies may show that they are best treated as subspecies of a single variable species. For this reason they are treated together here.

Habit. Spreading, much branched shrub or small tree 2–4 m tall; main trunk branching just above ground level into a few to many sub-straight main stems (3-7 cm diam. at base; 4-5 cm at about 1 m above ground) and many short terminal branchlets; crowns often dense and bushy (especially on young plants).

Distribution and habitat. These two species have substantially overlapping, but somewhat restricted, natural distributions extending from near the Murchison River south to the Moora area. *Acacia scirpifolia* occurs on sand and brown sandy loam soil. The southern form of A. *blakelyi* (see below) occurs most commonly in sand or brown loam whereas the northern form is normally found in yellow (gravelly) sand or sometimes in laterite. These two species are often very common in areas where they occur. They germinate readily from seed (no suckering observed) and may form particularly dense stands, especially in disturbed sites (e.g. road verges) and following fire.

Variation. *Acacia scirpifolia* is a rather invariate species but *A. blakelyi* exhibits considerable variation that requires further study. Based on phyllode width, colour and nervature, it appears that two main variants exist within *A. blakelyi*. In the south-western part of its range (principally in the Eneabba area) the species has narrow, green, 1-nerved phyllodes; these plants can sometimes be confused with *A. scirpifolia* and they occur commonly in sand and brown sandy loam. The more widespread entity (Murchison River to Wongan Hills) has broad, glaucous, 3-nerved phyllodes and these plants tend to favour yellow sand or lateritic soil.

Affinities. It is possible that these two species have some relationship to *A. saligna*, however, genetic studies would be required to check this.

Biology. Both species commence flowering from an early age. Under natural conditions they produce moderately heavy seed crops of large to very large seeds (40 000–45 000 per kg). Mature pods occur from November to January (the main crops seemingly occurring around mid-December), are easily harvested (shaking/threshing) and the seed is readily separated from the mature pods. Both species can be expected to have a fast or moderately fast growth rate; they appear to be relatively short-lived (perhaps about 10 years), have poor (or no) coppicing ability and are killed by low intensity fire. Some susceptibility to Gall Rust infection has been observed.

General Uses. *Acacia blakelyi* is considered a useful stock fodder and has been used for mine rehabilitation near Eneabba (Langkamp and Plaisted 1987). Both *A. blakelyi* and *A. scirpifolia* were considered by Elliot and Jones (1982) to be useful windbreak species. Considered by Maslin *et al*. (1998) as worthy of consideration for seed for human consumption.

SEARCH relevance. Low to medium priority. These species are not ranked highly primarily because of their relatively low woody biomass. *Acacia scirpifolia* appears slightly better than *A. blakelyi* in having slightly more robust stems and branches, and less foliage in its crown. They would, however, be suitable for situations where fast growth and cover is required, particularly in sandy and light loamy sites (not sure how they would preform in southern wheatbelt regions though); it is quite possible that the stands, once established under cultivation, would self-perpetuate from seed (in fact, there is some evidence that they could even become "weedy" on account of the very large soil seed bank). Despite its heavy pod crops and large seeds the value of *A. blakelyi* and *A. scirpifolia* as "human food" species remains untested. If these species are ultimately shown to be related to *A. saligna* then it is not impossible to envisage a relevance for them in some future genetic improvement program where non-suckering traits were being sought.

Seed collections (provenance name in quotes) and vouchers

<u>A. blakelyi</u>

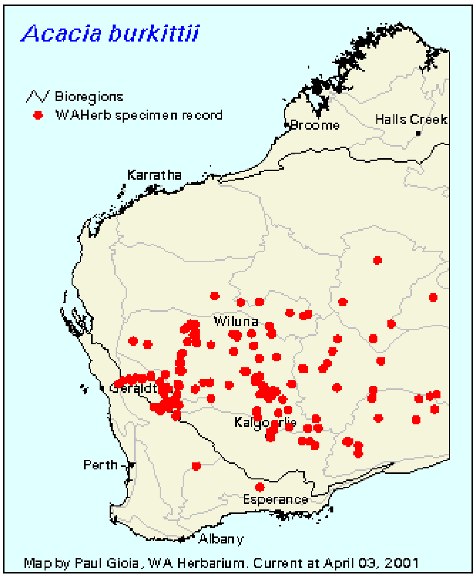
"Lake Indoon", Lake Indoon, W of Eneabba, 29° 51' 38"S, 115° 09' 17"E, 22 Nov. 1999, B.R. Maslin 7926 (seed voucher).

"Eneabba", 10 km S of Eneabba on Brand Highway, 29° 54' 10"S, 115° 15' 20E", 22 Nov. 1999, B.R. Maslin (seed sample; no voucher taken).

<u>A. scirpifolia</u>

"Three Springs", 14.5 km W of Three Springs on the road to Eneabba (at intersection of Wilton Road), 29° 35' 30" S, 115° 40' 12"E, 22 Nov. 1999, B.R. Maslin 7927 (pods immature).

Acacia burkittii



WA Herbarium taxon ID: **3248**

Details of *A. burkittii* are given in Maslin *et al.* (1999) and the species will therefore not be dealt with comprehensively here.

Habit. Multi-stemmed shrub or small tree 1.5-5 m tall, sometimes occurring as a single-stemmed tree 7-8 m tall (with bole to about 1 m).

Distribution and habitat. Widespread and common in the southern Arid Zone from near Yalgoo eastwards through S.A. to N.S.W. Often found on plains in red clay-loam or sandy loam (pH5.5-8) over limestone or hardpan. Also found among rocky hills and around granite outcrops.

Variation. Some variation in phyllode morphology rendering its distinction from *A. acuminata* difficult in places.

Affinities. Very closely allied to *A. acuminata* (could perhaps be treated as an inland subspecies).

Biology. Probably similar to *A. acuminata*.

General Uses. Probably similar to *A. acuminata*.

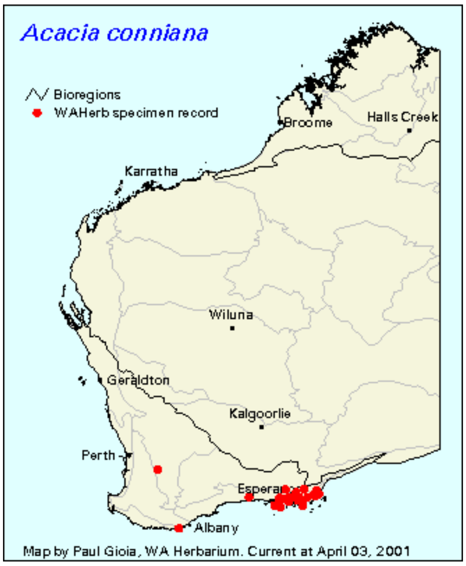
SEARCH relevance. Little attention was paid to this species in this study, primarily because of its Arid Zone distribution. Overall it has a woody biomass similar to that of *A. acuminata*. There is possibly a place for this species in drier inland sites, especially where soils are alkaline (limited testing suggests that *A. burkittii* has a higher alkaline tolerance than *A. acuminata*). The use of this species will probably be determined by how extensively *A. acuminata* is used.

Seed collection (provenance name in quotes) and voucher

"Tenindewa", Yuna - Tenindewa road, 5.5 km N of Geraldton - Mullewa road, 28° 36' 12"S, 115° 19' 20"E, 23 Nov. 1999, B.R. Maslin 7933 (seed voucher).

Acacia conniana

WA Herbarium taxon ID: **3268**



Habit. Dense, bushy shrub or small tree 1.5–6 m high and about the same across, sparingly divided at ground level or up to 1 m above the ground, stems sub-straight and 5-8 cm dbh (few measurements made; could get larger).

Distribution and habitat. Of restricted occurrence east of Esperance (Cape Le Grand to Israelite Bay, also on Mondrain and Middle Is., Recherche Archipelago). Usually found on granite rocks and headlands, often facing the ocean (does not extend more than about 40 km inland from the coast).

Variation. Plant form varies a little in that the stems may be straight or somewhat crooked and twisted (probably related to site conditions).

Affinities. Most closely related to *A. lasiocalyx* (see below).

Biology. Little reliable information available. I suspect a slow to moderate growth rate and reasonable longevity. It is unlikely to sucker; coppicing/pollarding ability unknown. Pods are produced in profusion and are easily collected by hand (threshing/shaking). The phyllodes of *A. conniana* contain relatively high concentrations of cyanogenic glucoside; however, they do not appear to possess an endogenous enzyme that is needed to hydrolyse this into hydrogen cyanide (Maslin *et al.* 1987); there are no reported cases of stock losses involving this species.

Wood. Fairly hard; much pale yellow sapwood and little pale brownish heartwood.

General Uses. Unknown.

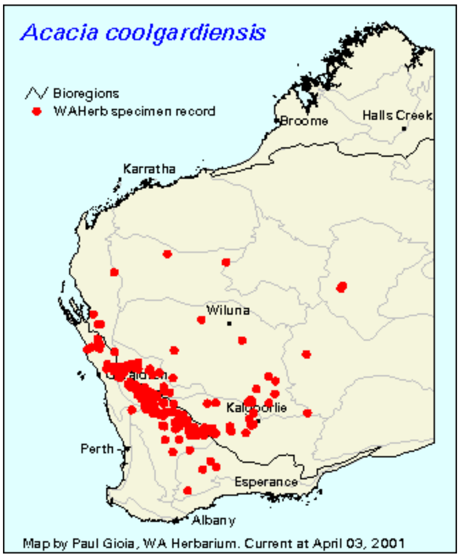
SEARCH relevance. Medium priority. Produces a reasonable amount of woody biomass (wood pale coloured) but the plant form is not as good as *A. lasiocalyx* (they tend to be smaller plants which branch closer to the ground and thus don't form such well-defined boles, also, the trunk diameters do not appear to reach the size of those found in *A. lasiocalyx*). It is not known, however, how these plants will do in cultivation (away from the coastal wind-swept habitats where they often grow naturally). The value of this species may lie in the fact that it could be used in southern regions where *A. lasiocalyx* appears not to do well.

Seed collection (provenance name in quotes) and voucher

"Cape Arid", Little Tagon Beach, Cape Arid National Park, 33° 52' 20"S, 123° 00' 08"E, 5 Dec. 2000, B.R. Maslin 8219 (seed voucher).

Acacia coolgardiensis (Sugar Brother)

WA Herbarium taxon ID: **3269**



Habit. Multi-stemmed shrub or small tree commonly 2-4 m tall but can sometimes reach 7 m high; trunks normally 5-8 cm diameter at base (1-6 cm dbh) and shallowly longitudinally fluted; crowns dense and occupying about 50% of the total plant height.

Distribution and habitat. Widespread and common with the main area of occurrence from near the Overlander Roadhouse and Northampton east to near Wiluna and Kalgoorlie and south to near Holt Rock. The three subspecies (see below) have different, but often overlapping or adjoining distributions, and often different habitat preferences:

subsp. *coolgardiensis* is widely distributed from Nerren Nerren Station and Northampton south-east to near Holt Rock and Menangina Station (about 80 km east of Menzies); grows on a range of sandy or gravelly, coarse-textured, free-draining soils, commonly on upper slopes of the landscape.

subsp. *effusa* occurs from near Mullewa and north of Cleary north-east to near Meekatharra, Wiluna and Menzies; grows in sand or loam, often with a high clay content, on plains and also in low hilly country and around granite outcrops.

subsp. *latior* occurs from Yuna north-east to between Cue and Mount Magnet and south-east to Whitewells Stn (is especially frequent in the Mullewa area); grows in red sand, rocky clay or clay loam and sandy loam, on sandplains, granite hills or gravelly rises.

Acacia coolgardiensis often forms large stands (both natural and in disturbed sites such as along road verges) in areas where it occurs and it shows good natural regeneration in many places.

Variation. *Acacia coolgardiensis* comprises three subspecies, subsp. coolgardiensis (relatively invariate), subsp. effusa (quite variable) and subsp. latior (relatively invariate).

Affinities. Probably most nearly related to species of the *A. aneura* complex, *A. ramulosa* in particular; however, this presumed affinity would need to be confirmed.

Biology. Probably a moderately long-lived species (25+ years). It reproduces from seed and is not known to root sucker; its coppicing/pollarding ability is unknown. Some plants show moderate Gall Rust infection. Commonly sets quite large pod crops (of rather small seeds) which are easily harvested by hand or by simple threshing techniques. Reduced pod set sometimes occur and this could be related to the timing and/or intensity of rainfall events.

Wood. Wood characteristics not examined but it is very likely that this species has a dark coloured heartwood similar to Jam.

General Uses. *Acacia coolgardiensis* has high potential for use in general revegetation work (e.g. soil stabilisation, windbreaks, shade/shelter, visual screens, etc.) on a range of soils in the central and northern wheatbelt. Its growth form, attractive foliage, prolific flowers and longevity makes it well suited to amenity planting in arid and semi-arid areas.

SEARCH relevance. Low to medium priority. Could be of some value for the production of woody biomass where a non-suckering plant is required, however, its growth rates and coppicing ability are unknown. Its relatively thin stems and probable dark-coloured heartwood would tend to render it unsuited to MDF production. Reports suggest that subsp. coolgardiensis produces a very high quality gum (excellent for commercial purposes), however, under natural conditions this species produces very little gum.

Seed collections (provenance name in quotes) and vouchers

subsp. coolgardiensis

"Mullewa", 40.5 km E of Mullewa on the road to Yalgoo, 28° 27' 54"S, 115° 54' 44"E, 23 Nov. 1999, B.R. Maslin 7936 (seed voucher).

"Kalannie", Warren Road, a few km E of Goodlands Road, NE of Kalannie, 25 Nov. 1999, B.R. Maslin (seed collected; no voucher taken).

subsp. effusa

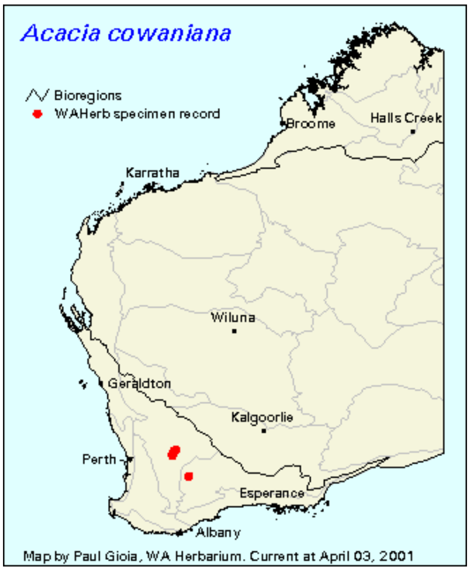
"Paynes Find", 100 km S of Mount Magnet on Great Northern Highway to Paynes Find, 28° 55' 43"S, 117° 48' 48"E, 24 Nov. 1999, B.R. Maslin 7943 (seed voucher).

"Mt Harry", 32 km SW of Paynes Find on Great Northern Highway to Wubin, 29° 19' 30"S, 117° 22' 00"E, 24 Nov. 1999, B.R. Maslin (seed collected; no voucher taken).

"Ninghan", about 57 km SW of Paynes Find on Great Northern Highway to Wubin, 29° 28' 10"S, 117° 11' 48"E, 24 Nov. 1999, B.R. Maslin (seed collected; no voucher taken).

Acacia cowaniana (Cowan's Wattle)

WA Herbarium taxon ID: **12254**



Habit. Tall shrub or small tree usually to 4-5 (-7) m high (however, in extreme conditions such as shallow soil on exposed rock faces, it reaches only 1-1.5 m tall), branching at ground level into 3-6, +/- straight or rather crooked main stems (5-10 cm dbh).

Distribution and habitat. Restricted to a few granite outcrops near Kellerberrin and Kulin; grows in very shallow soil or in rock crevices.

Variation. Invariate.

Affinities. A member of the *A. wilhelmiana* group (see Maslin 1990) which predominates in southern W.A. and S.A.

Biology. Probably slow growing and long lived (perhaps 50+ years). Unlikely to sucker; coppicing/pollarding ability unknown. Pods produced in profusion and easy to collect by hand.

Wood. Hard; heartwood brown and occupying about ½ the stem diameter.

General Uses. Unknown.

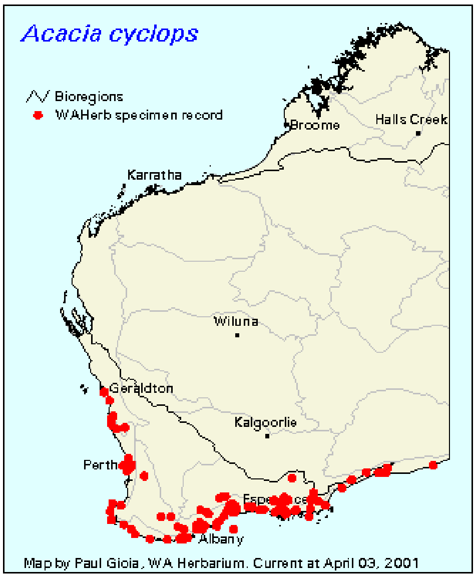
SEARCH relevance. Low priority. Although some plants of this species show fairly good growth form and produce a reasonable amount of woody biomass it not highly rated on account of its probable slow growth rate and dark coloured heartwood; furthermore, it is geographically restricted and (under natural conditions at least) has a narrow ecological tolerance.

Herbarium vouchers (no seed collected)

Mount Caroline, about 0.5 km W of Glenluce Road, about 18 km S of Kellerberrin, 31° 47' 32"S, 117° 38' 49"E, 23 June 2000, B.R. Maslin 7962.

Jilikin Rock, E of Kulin, 32° 39' 53"S, 118° 19' 32"E, 1 July 2000, B.R. Maslin 7990.

Acacia cyclops



WA Herbarium taxon ID: **3282**

Habit. Spreading shrub 1-4 x 2-4 (-6) m or small tree (to 7 m high), single-stemmed to about 1m or sparingly divided at ground level into a few sub-straight or rather crooked main stems (dbh often about 10-15 cm, rarely above 20 cm). Crown dense and bushy.

Distribution and habitat. Widespread and seemingly discontinuous in coastal and near-coastal areas mainly between Denmark and Israelite Bay, but ranging north to Leeman and east to the Yorke Peninsula, S.A. May form thickets in places where it occurs. Mostly found on well-drained coastal sand dunes but around Scaddan and near Esperance it also occurs in water-logged clay soil. It can apparently tolerate highly saline soils: Fox (1985) and Macar *et al.* (1995) provide details of ecological tolerances/preferences for this species.

Variation. Invariate (although see under **SEARCH relevance** below)

Affinities. Unknown.

Biology. An overview of many biological and other characteristics of A. cyclops is given in Fox (1985); other useful information is contained in Ayensu et al. (1980), Gill (1979) & (1985) and Macar et al. (1995). According to Macar et al. (1995) this species takes 7-10 years to reach harvestable size for fire wood in South Africa and it rarely coppices. I suspect that it has at least slight suckering ability. Pods (with seeds attached) are commonly retained on the plants for some time following dehiscence (see Gill 1979 & 1985 for details); seed can be collected by threshing technique, but sometimes they may be a little difficult to dislodge from the pods (may possibly depend upon age of seed). *Acacia cyclops* is a major environmental weed in the South African fynbos; it regenerates prolifically following fire from a huge seed store in the soil.

Wood. Anecdotal field observations show the wood to comprise darkish brown or pale greyish brown heartwood (which may occupy up to about half the stem diam.) surrounded by pale coloured sapwood; the proportion of heartwood to sapwood, and the extent of the heartwood varied significantly between the two samples examined.

General Uses. Useful for coastal dune stabilisation. Produces a dense, high quality firewood (Ayensu *et al.* 1980). Phyllodes browsed by goats and antelope in South Africa but its fodder value is inferior to that of *A. saligna; a*ccording to Craig *et al.* (1991) *A. cyclops* has some potential as a perennial fodder shrub for use in saline areas.

SEARCH relevance. Medium (? to high) priority. *Acacia cyclops* is worth considering for incorporation into the SEARCH program, perhaps for growing in association with *A. saligna*. Unlike many other species included in this report I suspect that A. cyclops might survive quite well on sites in the southern wheatbelt. The species produces a reasonable amount of woody biomass, is widely distributed and is quite salt tolerant (see Craig *et al.* 1990). Field observations suggest that under natural conditions there is some variation in edaphic preference (it is mostly found on coastal sands but around Esperance it can occur on water-logged clays: this is interesting and highlights relevance of provenance variation) and in the amount & colour of heartwood produced; it may be worth having the wood tested for MDF suitability. While *A. cyclops* may not grow quite as fast as *A. saligna* it can produce about the same amount of wood biomass. The weed potential of this species should be thoroughly investigated ahead of any wide scale use of it.

Seed collections (provenance name in quotes) and vouchers

"Condingup", Merivale Road, 0.4 km W of Daniels Road, E of Esperance, 33° 48' 25"S, 122° 38' 47"E, 6 Dec. 2000, D.J. Cooper 11 (seed voucher).

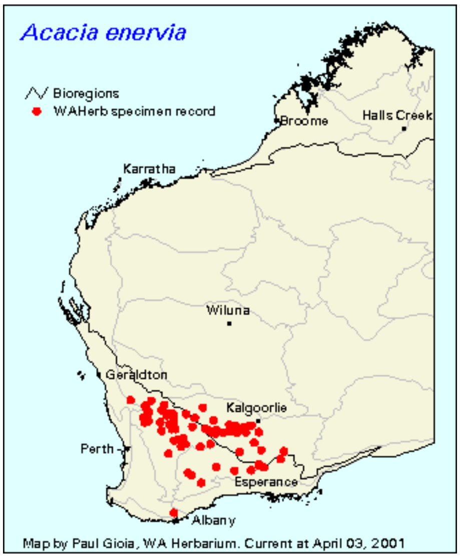
"Wittenoom", 4 km N of Scaddan Road on Wittenoom Road, E of Scaddan, 33° 30' 25"S, 122° 07' 11"E, 6 Dec. 2000, D.J. Cooper 12 (seed voucher).

"Scaddan", Coolgardie-Esperance Highway, 25.7 km N of Gibson, 33° 26' 58"S, 121° 43' 38"E, 6 Dec. 2000, D.J. Cooper 13 (seed voucher).

"Ravensthorpe", 50 m N of junction of South Coast Highway and Armadale-Ravensthorpe Road, W of Ravensthorpe, 33° 34' 29"S, 120° 00' 43"E, 7 Dec. 2000, D.J. Cooper 16 (seed voucher).

Acacia enervia

WA Herbarium taxon ID: **3318**



Habit. Dense, rounded or obconic shrub or small tree 1-4 m tall and 1.5-4 (-6) m wide, single- or multi-stemmed at base (up to 10 stems from ground level), the main stems (mostly 6-11 cm dbh, but up to 16 cm on oldest plants) and branches becoming curved or twisted (at least with age) and much divided, crowns bushy and occupying about 30% of the total plant height with age.

Distribution and habitat. *Acacia enervia* subsp. *explicata* (Jibberding area south to near Lake Grace and east to Coolgardie and Salmon Gums) grows in clay or loam soils mostly in saline situations around salt marshes, flats and lakes; subsp. *enervia* (Kununoppin east to near Coolgardie and south to Frank Hann National Park and near Norseman) grows in sandy loam or loam and it appears to be less salt tolerant than subsp. *explicata* (needs confirming). These subspecies are generally not uncommon in the places where they occur.

Variation. *Acacia enervia* comprises two subspecies, subsp. *enervia* and subsp. *explicata*.

Affinities. Closely allied to *A. inceana* (see below) and not far from *A. lineolata* (not included in this report).

Biology. No definitive information available but this species is likely to be long lived (perhaps 30-50 years) and relatively slow-growing (maximum stem diameter of 12-16 dbh probably being reached in about 20 years). It is unlikely sucker; its coppicing/pollarding ability is unknown.

Wood. Heartwood dark brown.

General Uses. Probably useful for general revegetation purposes in heavy-textured, slightly to moderately saline soils.

SEARCH relevance. Low (?to medium) priority. While this species produces a reasonable amount of woody biomass the trunks and branches or mature plants are much divided and somewhat curved or crooked; also, it has dark-coloured heartwood and is likely to rather slow growing. Nevertheless, subsp. *explicata* at least may have some relevance to SEARCH on account of its +/- salt tolerance. Based on field observations by David Seigler the tannins in subsp. *enervia* would appear worth investigating.

Herbarium vouchers (no seed collected)

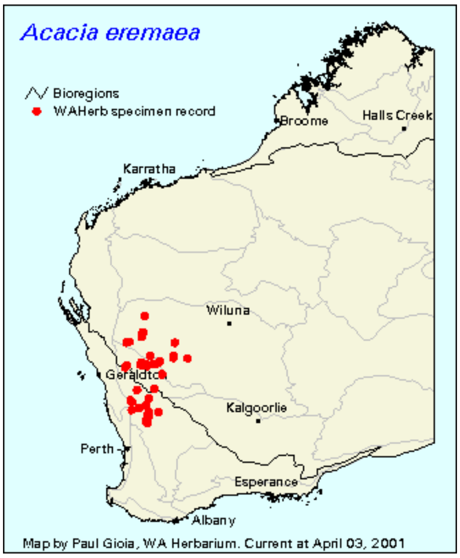
<u>subsp. explicata</u>

6 km E of Cleary (or 16 km W of Beacon), 30° 26' 05"S, 117° 42' 10"E, 25 Nov. 1999, B.R. Maslin 7952.

<u>subsp. enervia</u>

9.5 km SE of Hines Hill on Hines Hill-Korbel Road, 31° 35' 01"S, 118° 07' 36"E, 23 June 2000, B.R. Maslin 7963.

Acacia eremaea (Southern Snakewood)



WA Herbarium taxon ID: **3321**

Habit. Spreading tall shrub or small tree 2-5 m tall, with characteristically gnarled and twisted trunks and main branches, and a dense crown 3-6 m wide which, on oldest trees, is confined to the upper 30% of the plants (young plants are rounded shrubs with the foliage extending to the ground).

Distribution and habitat. Occurs from Boolardy Stn and Cue south to near Wongan Hills. It is not common in the wheatbelt (where it is normally found on sand or sandy loam over sandy clay in association with salt lakes; it is not infrequent in the salt lakes where it occurs) but is common in parts of the adjacent rangeland areas (e.g. Yalgoo - Mount Magnet area).

Variation. Invariate.

Affinities. Related to *A. xiphophylla* (which occurs from Shark Bay to the Pilbara).

Biology. Growth rate unknown but likely to be very slow. Propagate from seed (unlikely to sucker). Coppicing and pollarding unknown.

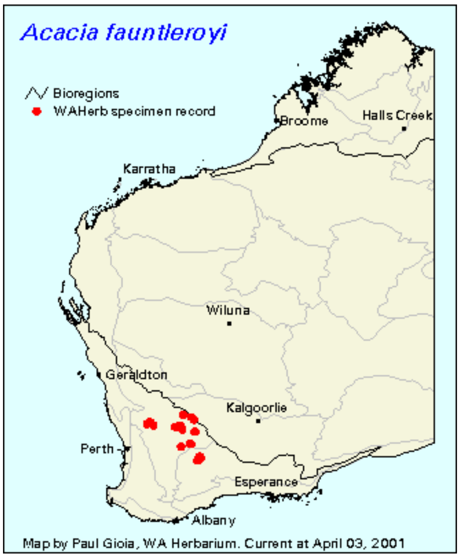
General Uses. Could be well-suited to stabilising the alluvial sands that occur in and around the salt lake systems where this species naturally grows. The dense spreading crowns offer good protection for stock and wildlife in the very inhospitable environments where this species occurs.

SEARCH relevance. Low priority despite the fact that it produces quite a reasonable amount of woody biomass and grows in association with some salt lakes in the northern wheatbelt. Factors working against usage of this species include its likely very slow growth rate, gnarled and twisted trunks and stems, and likely dark-coloured heart wood.

Herbarium voucher (no seed collected)

94 km E of Mullewa on the road to Yalgoo, 28° 22' 03"S, 116° 26' 30"E, 23 Nov. 1999, B.R. Maslin 7939.

Acacia fauntleroyi



WA Herbarium taxon ID: **3334**

Habit. Shrub or small tree 2- 7 m high. Bark 'Minni-Ritchi'.

Distribution and habitat. Of scattered occurrence from Wongan Hills and Bonnie Rock south to Hyden. Grows on or around granite outcrops.

Variation. Invariate.

Affinities. Related to *A. oncinophylla* (which occurs in the Darling Range from Mogumber to Wagerup; not included in this report). May not be too far removed (taxonomically) from *A. inophloia* (see below).

Biology. Probably slow growing and long lived (perhaps 50+ years). Unlikely to sucker; coppicing/pollarding ability unknown.

Wood. Hard; heartwood grey-brown.

General Uses. Unknown.

SEARCH relevance. Low to medium priority. Although this species shows a good growth form and produces a reasonable amount of woody biomass it is probably slow growing, has dark-coloured heartwood and, in nature at least, has a narrow edaphic range.

Herbarium voucher (no seed collected)

The Humps, N of Hyden, 32°18' 12"S, 118° 56' 36"E, 23 Nov. 1999, B.R. Maslin and 30 June 2000, B.R. Maslin 7989.

Acacia hakeoides (Hakea Wattle', 'Western Black Wattle', and more)

WA Herbarium taxon ID: **3359**

Habit. Frequently a multi-stemmed bushy shrub or small tree to 3-4 m tall, it produces suckers if its roots are disturbed; in N.S.W. it sometimes grows to a tree to 10 m but in W.A. it is a much smaller plant (the plant sampled for this project were spindly shrubs 2.5 m tall).

Distribution and habitat. Widespread but scattered in southern Australia from near Esperance eastwards through southern S.A., Vic., N.S.W. and Qld. This species is uncommon in W.A. where it occurs in southern inland, but near-coastal, areas from near Esperance to Eucla. It grows in a variety of soils but commonly on sand or loam.

Variation. Considerable variation occurs in plants from eastern Australia but rather invariate in W.A.

Affinities. Closest relatives are in eastern Australia but it is not far removed taxonomically from *A. pycnantha* (an environmental weed in parts of the southern wheatbelt). It has some affinities with *A. microbotrya* but the relationship is not especially close.

Biology. Reported to have a fast growing; I suspect that it will be relatively short-lived (perhaps 15-20 years). It has a strong propensity to sucker if roots are disturbed and the clumps can be difficult to clear; despite this the plants can occur in nature as scattered bushes rather than in thickets.

General Uses. Nothing special.

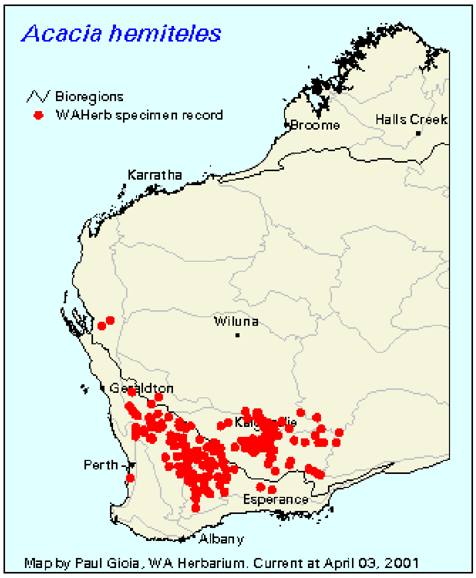
SEARCH relevance. Probably low priority, particularly as it possibly may have weed potential if grown in the right conditions in the south-western wheatbelt. Nevertheless, this is a seemingly fast growing, normally multi-stemmed shrub with well-developed plants probably having about the same amount of woody biomass as a small Mallee eucalypt; I suspect that its wood characteristics would be similar to those of *A. microbotrya.*

Herbarium voucher (no seed collected)

Howick Road, 12 km W of Coolinup Road (just S of Mount Ney, NE of Esperance), 33° 25' 47"S, 122° 27' 37"E, 27 June 2000, B.R. Maslin 7981.

Acacia hemiteles

WA Herbarium taxon ID: **3366**



Habit. Spreading, multi-stemmed, dense shrub (0.5-) 1-2 m tall (occasionally 3 m in open disturbed sites), often broader than high (1.5-4 m across), either domed with the foliage extending to the ground or obconic with flat-topped or sub-rounded crowns occupying 30-50% of the total plant height.

Distribution and habitat. Widely distributed in southern W.A. where it occurs from the Nullarbor Plain west to near Ongerup and Canna in the wheatbelt. Generally common in the places where it occurs. Occupies a wide edaphic range, growing on (gravelly) sand, loam or clay, or sometimes on granite rocks or laterite; in the wheatbelt it is commonly found in the lower parts of the landscape in association with *A. merrallii*.

Variation. It appears that there are two growth forms within this species, one more upright than the other; further study is required**.**

Affinities. A member of the "*Acacia prainii* group" (see Maslin 1995 for discussion), three members of which are included in this report, namely, *A. anthochaera*, *A. hemiteles* and *A. prainii*. Related most closely to *A. anthochaera*.

Biology. A moderately fast-growing, hardy species which is able to withstand extended dry periods. Its coppicing ability is unknown and it has not been recorded to root sucker under natural conditions. The pods are usually produced in large quantities and are held terminally, thus accessible for collection.

General Uses. *Acacia hemiteles* is recommended by Wilcox *et al*. (1996) as being suitable for revegetation on a variety of soil types in the Midlands and northern wheatbelt regions of Western Australia; it is also regarded as being suited to revegetating drainage lines in these areas. This species has been widely used in rehabilitation in the goldfields area of Western Australia where it has demonstrated variable performance; however, once established it plays an important role in soil stabilisation.(Rusbridge *et al.* 1996). *Acacia hemiteles* is one of the lesser-known species suggested by Maslin *et al.* (1998) for trialing as a source of seed for human food.

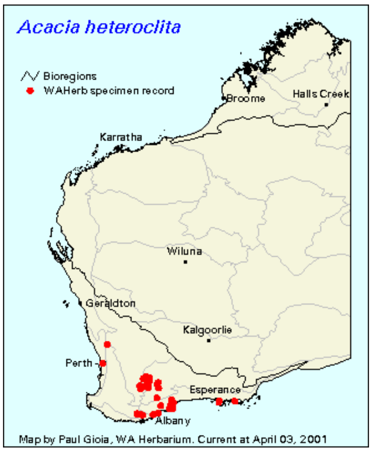
SEARCH relevance. Of low priority on account of diminutive size and low woody biomass. However, *A. hemiteles* can be useful as a fill-in shrub for situations where a hardy, fast-growing plant is required for cover and soil stabilisation (particularly in loam or loamy clay soils which are not highly saline).

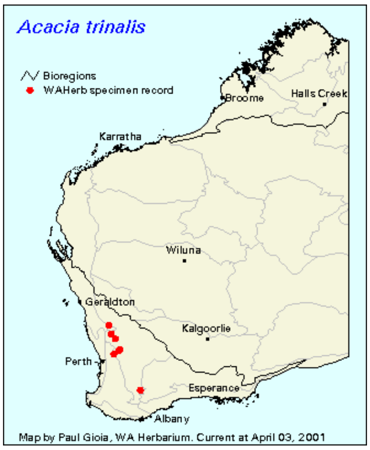
Herbarium voucher (no seed collected)

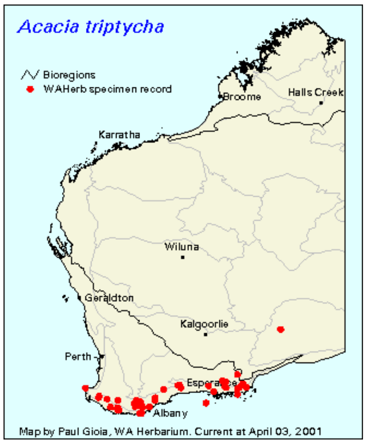
8.5 km N of Bruce Rock on road to Merredin, 31° 48' 25"S, 118° 11' 14"E, 4 Dec. 2000, B.R. Maslin 8209.

Acacia heteroclita*, *A. trinalis* and *A. triptycha

WA Herbarium taxon ID: **15475** *(A. heteroclita)*
WA Herbarium taxon ID: **14625** *(A. trinalis)*
WA Herbarium taxon ID: **3582** *(A. triptycha)*







Note. These three closely related species were not examined in the field as part of this study. However, they occur in a group which is otherwise not represented in this report and therefore are noted here for future reference. They are all shrubs or small trees not exceeding 4 m in height; I do not think that any of them produce a excessive amount of woody biomass and although their wood characteristics are unknown I suspect that they all have a dark heartwood.

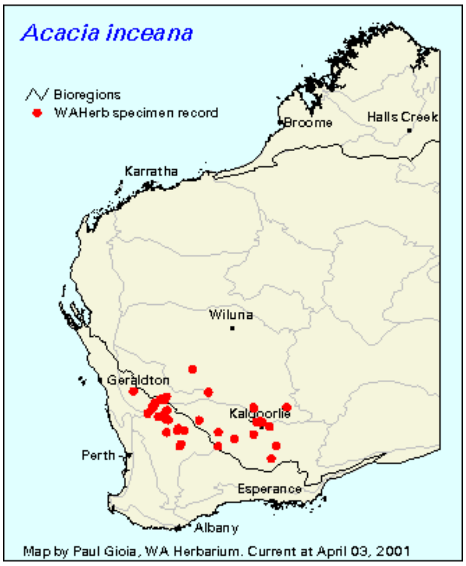
Acacia heteroclita. Shrub or small tree 1–4 m high. Occurs sporadically from Kulin south to the Porongurup Range and east to Cape Le Grand National Park and nearby islands. Comprises two subspecies, subsp. *heteroclita* (widespread) and subsp. *valida* (endemic in Porongurup Range).

Acacia trinalis. Multi-stemmed shrub or bushy tree 1.5–4 m high. A poorly collected species, restricted to the area between near Marchagee south-east to the Mortlock River (near Goomalling). Grows in or near areas with saline conditions in more or less swampy areas in brown sand and clay loam.

Acacia triptycha. Bushy shrub to small tree 0.6–4 m high. Occurs sporadically from Mt Frankland east to near Ponier Rock and Cape Arid National Park. Grows usually in association with granite or quartzite in granitic sand or reddish-brown clay-sand over quartz.

SEARCH relevance. Probably low priority.

Acacia inceana



WA Herbarium taxon ID: **18106**

Habit. Rounded multi-stemmed shrub with main stems fairly straight and much divided, growing to a small, single-stemmed (or sparingly branched at base) tree 2-5 m tall with the somewhat crooked main trunk reaching about 10 cm dbh; crown rather dense and spreading (2-5 m across), with age occupying about 20-30% of the total plant height.

Distribution and habitat. *Acacia inceana* subsp. *conformis* (Morawa south-east to Hines Hill and E to Boorabbin; often common in places where it occurs) is highly salt-tolerant and occur in alkaline dark red-brown, coarse clay-sand overlying yellow-brown coarse clay-sand or sandy loam at margins of salt pans or salt lakes; subsp. *latifolia* (Wubin area; uncommon in places where it occurs) is likely to have similar habitat characteristics; subsp. *inceana* (Kalgoorlie region; often common in places where it occurs) is possibly less salt tolerant (but needs checking).

Variation. *Acacia inceana* comprises three subspecies, subsp. *conformis*, subsp. *inceana* and subsp. *latifolia*.

Affinities. Closely related to *A. enervia* (see above) and not far from *A. lineolata* (not included in this report).

Biology. No definitive information available but this species is likely to be long lived (perhaps 30-50 years) and relatively slow-growing. It is unlikely to sucker; its coppicing/pollarding ability is unknown. Although the pods are numerous, they are scattered over the plants (not occurring in bunches) and it is therefore time-consuming collecting them by hand (the most efficient way of collecting seed in quantity is to manually shake or thresh branches and collect the pods and seeds on a ground sheet).

Wood. Heartwood dark-coloured.

General Uses. Subspecies *conformis* in particular has high potential for use in regenerating (soil stabilisation) of saline sites, and watercourses leading into them. Under natural conditions it forms large, dense populations around the margins of salt lakes and salt pans in many areas. Also, in places it develops large regrowth populations along road verges.

SEARCH relevance. Low to medium priority. While this species produces a reasonable amount of woody biomass, the trunks and branches or mature plants are somewhat crooked, also, it has dark-coloured heartwood and is likely to rather slow growing. Nevertheless, subsp. *conformis* and subsp. *latifolia* at least could well find a place in the SEARCH program on account of their salt tolerance.

Seed collections (provenance name in quotes) and vouchers

<u>subsp. latifolia</u>

Not sampled.

subsp. conformis

"Black Road", E of Kalannie, 30º 22' 10"S, 117º 24' 46"E, 25 Nov. 1999, B.R. Maslin 7949 (green pods), seed subsequently collected from this population by J. Carslake on 10 Dec. 1999.

"Warren Road", E of Kalannie, 10 Dec. 1999, J. Carslake (seed collected; no voucher taken).

"Lake O'Grady", at southern end of the lake, 10 Dec. 1999, J. Carslake (seed collected; no voucher taken).

Acacia inophloia

WA Herbarium taxon ID: **3385**

Habit. Shrub or small tree 2 - 4 m high (reaching about 6 m under cultivation in Kings Park), branching near the base, the trunks generally straight (5-7 cm dbh: few measurements made). Bark reddish, stringy and shaggy on trunks, ± 'Minni-Ritchi' on upper branches.

Distribution and habitat. Restricted to north and east of Kondinin; a single collection from Moora needs confirmation that the locality is correct. Normally grows in sandy loam or clay, often (?always) in association with granite outcrops.

Variation. Invariate.

Affinities. Seemingly related to *A. ephedroides* (which occurs around granite rocks mostly in the Darling Range south-east of Perth). May not be too far removed (taxonomically) from *A. fauntleroyi* (see above). Anecdotal field evidence suggests that *A. inophloia* may hybridise with *A. lasiocalyx* (see below) but needs confirmation.

Biology. Probably slow growing and long lived (perhaps 50+ years). Unlikely to sucker; coppicing/pollarding ability unknown.

Wood. Hard; heartwood grey-brown.

General Uses. Unknown.

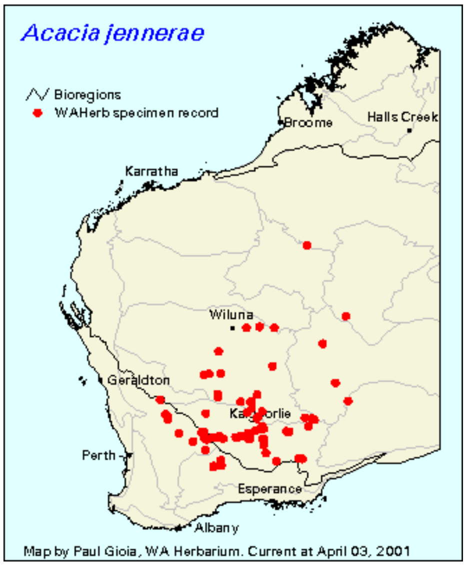
SEARCH relevance. Low to medium priority. Although *A. inophloia* shows a good growth form and produces a reasonable amount of woody biomass it is probably slow-growing and it has dark coloured heartwood, thus would seem unsuited for use in MDF production. Furthermore, it is geographically restricted and (under natural conditions at least) has a narrow ecological tolerance.

Seed collection (provenance name in quotes) and voucher

"Pederah", 7.5 km W of Pederah (SW of Hyden), 32º 34' 35"S, 118º 36' 17"E, 30 June 2000, B.R. Maslin 7988 (omitted to take herbarium voucher) and 4 Dec. 2000, B.R. Maslin 8214 (seed voucher).

Acacia jennerae (Coonavittra Wattle)

WA Herbarium taxon ID: **3393**



Habit. Obconic shrub or small tree often with an "Mallee-like" growth form, 1.5-4 (-6) m tall, often suckering to form clonal thickets, sometimes single-stemmed but more commonly the trunk dividing at ground level into 2 to many, straight, rather slender main stems, the crowns dense, rounded and 1-3(-5) m across.

Distribution and habitat. *Acacia jennerae* has a scattered distribution in southern arid and semi-arid areas of Australia extending from near Kalannie eastwards through Northern Territory and South Australia to western New South Wales and south-western Queensland. It is not common in the wheatbelt being known from only a few sites in the region of Kalannie. Grows on acid to neutral sands and loams, commonly in dune swales or along drainage lines, including the margins of salt lakes.

Variation. This species shows limited morphological variation.

Affinities. A member of the *A. microbotrya* group (Maslin 1995) and closely related to *A. microbotrya* itself (see below). It is not far removed from the very variable *A. brumalis* (not included in this report: see note under *A. microbotrya*).

Biology. *Acacia jennerae* is an adaptable, moderately-fast growing species which is reasonably fire and drought tolerant. In Tucson, Arizona, U.S.A., this species was unaffected by temperatures as low as -8.3°C and was assessed as being well-suited to hot, dry climates (Johnson 1996). It has strong coppicing and root-suckering ability and this can lead to the formation of dense clonal thickets; it may be possible to rejuvenate over-mature stands by inducing coppicing and/or root-suckering. During good seasons pods are produced in quantity and are easily harvested by hand or shaking; large pendulous bunches. At full maturity the pods can be easily harvested by hand or by shaking/threshing techniques; the large seeds are easily extracted from the pods (although mechanical threshing is required for efficient seed extraction if pods are harvested before attaining full maturity).

Wood. Wood air dry density: 862 kg/m^3, based on 13 samples tested (G. Pronk, pers. comm.). Probably has a reasonably pale coloured heartwood similar to *A. microbotrya* (needs confirming).

General Uses. *Acacia jennerae* has potential as a source of fuelwood in developing countries (Thomson et al. 1994). Its suckering habit and salt tolerance suggest it would be useful for soil stabilisation in some saline areas. With age the plants attain a height and form suitable for use as a visual screen and in shelterbelt plantings as a low windbreak and for providing shade for stock and wildlife. *Acacia jennerae* is one of the promising species suggested by Maslin *et al.* (1998) for trialing as a source of seed for human food.

SEARCH relevance. Medium priority. Similar growth and biological characteristics to *A. microbotrya* except that it does not appear to produce as much woody biomass and I suspect that it has a (slightly) greater propensity to root sucker. It is reported to coppice which is a desirable characteristic for SEARCH. Under natural conditions, *A. jennerae* grows in drier climates than does *A. microbotrya* and it may also be more salt tolerant.

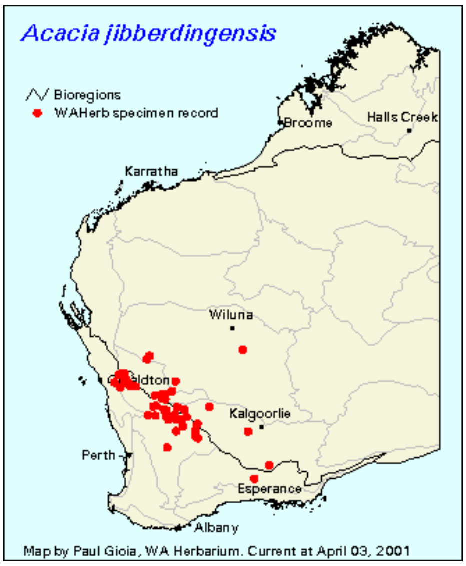
Herbarium vouchers (no seed collected)

About 35 km N of Kalgoorlie on road to Menzie, 30º 21' 06"S, 121º 18' 23"E, 25 June 2000, B.R. Maslin 7971 (in flower).

Karolin Rock, 18 km W of Bullfinch on road to Mukinbudin, 30º 58' 57"S, 118º 55' 15"E, 24 June 2000, B.R. Maslin 7967 (in flower).

Acacia jibberdingensis (Jibberding Wattle)

WA Herbarium taxon ID: **3395**



Habit. Shrub or small trees commonly (1.5-) 2-4 m tall, can reach 7 m tall in favourable situations, single-stemmed to 1.5 m or sparingly dividing just above ground level; stems to 15 cm dbh (to 25 cm at ground level) and, along with the main branches, can be rather crooked; crowns typically dense and spreading (to 2-3 (-6) m across). Plants are sometimes rather spindly when growing within dense scrub.

Distribution and habitat. Occurs from Mullewa and Jingemarra Station south-east to Peak Charles National Park. There is an outlying population at Kathleen Valley (about 350 km east of Jingemarra Station). Grows in association with granite rocks in hard, light brown sandy loam.

Variation. Invariate.

Affinities. Appears to be most closely allied to *A. acuminata* (see above). Sometimes confused with *A. longiphyllodinea* (not included in this report) but the two species are not closely related.

Biology. Appears to be moderately fast-growing (but would need substantiation in trial situations); I guess that it would not be overly long-lived (perhaps not exceeding about 25 years). Unlikely to sucker; coppicing/pollarding ability unknown; according to Elliot and Jones (1982) it can be grown from cuttings. The following account is taken from McDowall (1997) and is based on observations of plants in cultivation in Melbourne: “Light tip pruning needs to be done frequently when the plant is young and especially towards the end of the flowering season before new shoot growth has begun, as shoot regeneration does not occur readily from the old wood. For this reason, attempts to shape the tree by hard pruning once it has become too large for its situation can result in a bare leggy base with flowering restricted mostly to the upper branches. Heavy pruning after new shoot growth has begun can kill the tree.” Pods (when produced) tend to occur in great profusion and easy to collect by hand with threshing technique (it is possible that pod set in this species, like in *A. acuminata*, is variable: in some years pods fail to develop or crops are light).

Wood. Wood characteristics unknown but could be similar to Jam (*A. acuminata*).

General Uses. Has potential for use in revegetation programs, especially those involving granite rocks. Its growth form is suited to providing windbreaks, visual screens, and shade and shelter for both stock and wildlife.

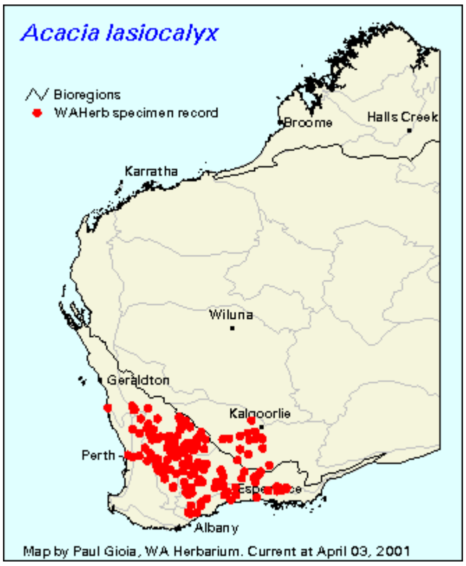
SEARCH relevance. Medium priority. Mature plants produce a reasonable amount of woody biomass although the form of the plants is often not overly good (stems can become somewhat crooked or the habit rather spindly); its probable dark heartwood would preclude its use in MDF production. However, it may be worth incorporating *A. jibberdingensis* into SEARCH trials, especially if the reported moderately fast growth rates are accurate; although in nature it is fairly habitat-specific it has been successfully grown (for ornamental purposes) in many places across southern Australia, and may therefore prove to be quite adaptable. It is regrettable that I was unable to procure seed during 1999/2000 field survey.

Herbarium vouchers (no seed collected)

About 23 km S of Norseman, on E side of Dundas Rock, 32º 23' 41"S, 121º 46' 19"E, 26 June 2000, B.R. Maslin 7973.

Acacia lasiocalyx

WA Herbarium taxon ID: **3408**



Map by Paul Gioia, WA Herbarium. Current at April 03, 2001

Habit. Spreading shrub or tree commonly 2-5 m and 2-6 m wide (perhaps reaching wider, but needs confirming) with dbh commonly 13-15 cm; however, around the base of granite rocks it normally grows as an erect tree and can reach 10-15 m tall, here the trunks are straight to sub-straight, single-stemmed or sparingly divided at the base (maximum dbh is 30-50 cm).

Distribution and habitat. Widely distributed from near Eneabba east to near Kalgoorlie and south to near Bremer Bay and Mt Heywood (north-east of Esperance). Grows in sand, gravelly sand, loamy sand, clayey sand and loam, normally associated with granite hills or outcrops (it commonly forms dense populations around the base of wheatbelt granite rocks).

Variation. When plants grow close (as they often do around the base of granite rocks) they tend to have an erect habit. Anecdotal evidence suggests that plants growing away from granite outcrops are smaller, more spreading and have less straight trunks than those associated with granite.

Affinities. Most closely related to *A. conniana* (see above); also close to *A. longiphyllodinea* (a generally smaller plant not included in this survey). It may have a superficial resemblance to *A. yorkrakinensis* subsp. *acrita* (not included in this survey on account of its great susceptibility to Gall Rust infection). Anecdotal field evidence suggests that *A. lasiocalyx* may hybridise with *A. inophloia* (see above) but needs confirmation.

Biology. Little definitive information is available for this species. However, it looks as though it may have a moderately fast growth rate and a medium life-span (perhaps 20-40 years). It is unlikely to sucker and its coppicing/pollarding ability is unknown. Quite large numbers of pods are produced on the plants and these are easily collected by hand (threshing/shaking) although the height of the plants often makes them difficult to reach. The phyllodes of *A. lasiocalyx* contain relatively high concentrations of cyanogenic glucoside; however, they do not appear to possess an endogenous enzyme that is needed to hydrolyse this into hydrogen cyanide (Maslin *et al.* 1987); there are no reported cases of stock losses involving this species.

Wood. Heartwood yellowish (young branches) or pale brown.

General Uses. Its growth form is suited to providing windbreaks and visual screens, as well as shade and shelter for both stock and wildlife. Plants with straight, undivided trunks may be worth examining as a potential source of small poles and other timber products.

SEARCH relevance. Medium to high priority. *Acacia lasiocalyx* is perhaps the largest species encountered in this survey. Plants from around the base of granite rocks generally have excellent form (often with +/- straight, undivided or sparingly branched trunks) and lots of woody biomass (unexpectedly the wood is pale-coloured). This species appears to have a reasonably fast growth rate, however, this judgement made on the basis of plants growing around the base of granite rocks where water would not be limiting (they may not do so will in trial situations with less water). The form of the species appears to deteriorate at the southern end of its range (e.g. Mt Ridley); *A. conniana* would be more suited for growing in these southerly regions.

Acacia lasiocalyx and *A. conniana* are the only plurinerved species encountered in this survey that had pale-coloured heartwood (other plurinerved species such as *A. acuminata*, *A. inceana*, etc. have very dark-coloured heartwood); it is likely that if tested the wood of *A. lasiocalyx* and *A. conniana* will show significantly different physical/chemical properties from other pale-wooded species (such as *A. saligna*, *A. microbotrya*, etc.), all of which had uninerved phyllodes.

Seed collections (provenance name in quotes) and vouchers

"Mt Stirling", Glenluce Road, 1.4 km N of Munyard Road, E of Mount Stirling, about 25 km S of Kellerberrin, 31° 50' 56 "S, 117° 38' 03"E, 8 Dec. 2000, D.J. Cooper 18 (seed voucher); a flowering collection also made from this same population (23 June 2000, B.R. Maslin 7961).

"Welbungin", 5.7 km E of Welbungin Siding on road to Mukinbudin, 30° 50' 52"S, 118° 02' 40"E, 26 Nov. 1999, B.R. Maslin 7953 (immature pods), seeds subsequently collected from this population by J. Carslake on 11 Dec. 1999.

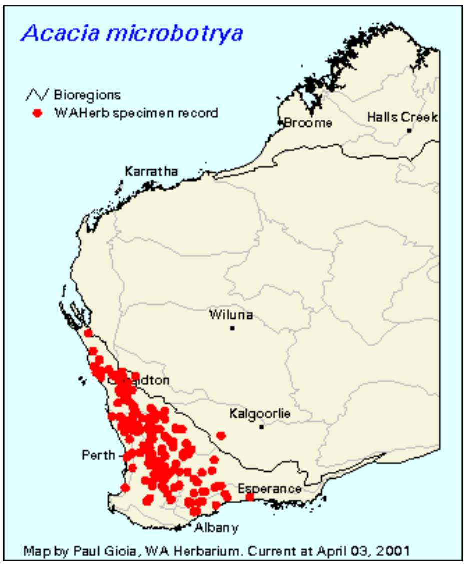
"Muntadgin", 10 km N of Muntadgin (on Brissenden Road, 9.5 km E of Merredin - Narembeen Road), 31° 43' 03"S, 118° 29' 56"E, 4 Dec. 2000, B.R. Maslin 8213 (seed voucher).

"Pederah", about 25 km due SW of Hyden (on Pederah Road West), 32° 34' 36"S, 118° 36' 31"E, 4 Dec. 2000, B.R. Maslin 8215 (seed voucher).

Mount Ridley (NE side), NE of Esperance, 33° 17' 25"S, 122° 07' 28"E, 27 June 2000, B.R. Maslin 7978 (flowering specimen).

Acacia microbotrya (Manna Wattle)

WA Herbarium taxon ID: **3442**



Note. As currently defined *A. microbotrya* is a variable species and is currently under revision (expected to be completed towards the end of 2001). The information presented below applies to the species in its broad sense; future studies are likely to show that more than one species will be encompassed by the information presented here. Where possible I have noted to what variant of *A. microbotrya* each piece of information refers.

Habit. Bushy, tall shrub or small tree commonly 2-4 m tall (Dandaragan variant are trees to 7 m tall), often forming dense clonal clumps by root suckers; dividing at ground level into 2-4 main trunks (6-9 cm in diameter at breast height) or with a single trunk (about 11 cm diameter at ground level) to about 1 m before branching, crowns on oldest plants occupying 20-30% of the total plant height.

Distribution and habitat. Widespread and common in the wheatbelt region where it extends from the Murchison River south to near Katanning, with scattered occurrences around Ongerup and Lake King (see also under **Variation** below). *Acacia microbotrya sens. lat.* occurs on a variety of soil types including texture contrast soils derived from laterite, sands and sandy loams surrounding granite rock outcrops or clay loams near rivers and drainage lines. It is probably slightly to moderately salt tolerant.

Variation. Current indications are that there are at least three separate entities encompassed by what is generally called *A. microbotrya*. (1) Typical *A. microbotrya* occurs in areas south of about the latitude of Moora; these plants have cream to pale yellow heads, green phyllode and develop into small, robust trees to about 4 m tall. (2) North of Moora the plants have light golden heads, often shorter and more bluish phyllodes, and are commonly slightly smaller in stature than their southern counterparts; these northern plants probably correspond to what has been described as *A. microbotrya var. borealis*. (3) In the Dandaragan - Badgingarrra area there exists a particularly robust form; these plants reach about 7 m in height, they have narrower pods than the other two forms and have (I think) light golden heads. Taxonomic and genetic work is currently in progress that is attempting to elucidate the patterns of relationships between these entities.

Affinities. *Acacia microbotrya* along with 43 relatives Australia-wide (mainly in southern temperate and semi-arid areas) comprise the *A. microbotrya* group (see Maslin 1995 for discussion). The members of this group included in this report *are A. aestivalis, A. jennerae* and *A. steedmanii*. Other tall members of the group not included in this report include *A. amblyophylla, A. brumalis* and *A. harveyi*. Most of these relatives tend to produce generally less woody biomass than *A. microbotrya* but an investigation of them may be warranted if an interest in *A. microbotrya* is developed because some possess interesting characteristics. For example, *A. brumalis* (north-central wheatbelt) appears to be less prone to suckering than *A. microbotrya* while *A. amblyophylla* (an aggressive suckerer restricted to the Shark Bay district) grows on sandy, calcareous soils close to the ocean.

Biology. This species is hardy, drought- and frost-tolerant, and fast-growing; it probably has a life span of about 20-30 years (Gardner 1957). *Acacia microbotrya var. microbotrya* in southern areas is reported by Newbey (1982) to be susceptible to infection by woolly caterpillars, but these can be controlled and the trees will recover. Suckering is common in plants of *A. microbotrya*, however, it is not known yet if it occurs in the same frequency in each of the three variants noted above. I would expect this species to coppice. Natural stands of *A. microbotrya* normally produce heavy pod crops; the seeds are large, easily collected, and are easily separated from the pods by manual threshing methods.

General Uses. The species is reported to be useful as a low windbreak and shelter plant and is also a source of honey or pollen (Elliot and Jones 1982; Simmons 1981). Tree forms are sometimes used for amenity planting in wheatbelt towns of the south-west of Western Australia; this species flowers earlier in the season than most other W.A. acacias. According to Hussey (pers. comm.) the phyllodes of *A. microbotrya* are nutritious but the plants do not withstand grazing. *Acacia microbotrya* is used in direct seeding programs for regeneration and shelter belt plantings in the northern wheatbelt region of Western Australia (P. Ryan, pers. comm.). In the early days the bark of *A. microbotrya* was often used in home tanning and as a source of “manna gum” for export (Gardner 1957). The question of commercial potential from gum of this species is sometimes raised; my impression is that, apart from the difficulties (and cost) of collection, this gum is not of a particularly high quality. This matter would need to be explored more thoroughly before dismissing it as a commercial potential (interaction with David Seigler is relevant here). The seeds and gum have been used as food items by Australian Aborigines (Meagher 1974). *Acacia microbotrya* is one of the promising species suggested by Maslin et al. (1998) for trialing as a source of seed for human food. I have heard unconfirmed reports that this species is being advocated by Phil Bellamy as being suitable for growing by wheatbelt farmers for potential commercial returns from gum, wood and seed! This species is currently being trialed for its potential as a Sandalwood host plant.

Wood. No specific details but I think this species has fairly pale coloured heartwood and yellow sap wood.

SEARCH relevance. Medium to high priority. Plants of this species are fast growing, fairly ecologically adaptable (although having a preference for loam soils). It is widespread in the wheatbelt (although absent from south-eastern areas, east of Ravensthorpe) and is reasonably well known and used in regeneration and nature conservation projects. It produces a reasonable amount of woody biomass; I suspect that the wood is pale coloured and if so might be suited to MDF production. The plants vary somewhat with regard to how robust and straight the main trunks and branches are: further information on this matter should appear in the forthcoming review of the species that I am currently conducting. Plants from the Dandaragan-Badgingarra area have good form and are particularly robust - SEARCH should keep an eye on this entity. The question of the associated commercial benefits that might be derived from gum or seed (for human consumption) from *A. microbotrya sens. lat*. needs further investigation. Sale of provenance seed could be a useful spin-off advantage from growing this species. Should *A. microbotrya* prove useful to SEARCH then we should look more closely at its close relatives that are noted under **Affinities** above; also, there are quite a few +/- arborescent members of the *A. microbotrya* group that occur outside W.A. (some of these could have relevance to the project).

Seed collections (provenance name in quotes) and vouchers

<u>var. borealis</u>

"Three Springs", 2.5 km N of Three Springs on Midlands Road to Mingenew, 29º 31' 11"S, 115º 44' 20"E, 22 Nov. 1999, B.R. Maslin 7929 (seed voucher, seed slightly immature; mature seed recollected from this population by J. Carslake on 8 Dec. 1999).

"Arrino", 18.5 km N of Three Springs on Midlands Road to Mingenew, 22 Nov. 1999, B.R. Maslin (seed slightly immature; no voucher taken).

"Yandanooka", 38.7 km N of Three Springs on Midlands Road to Mingenew, 22 Nov. 1999, B.R. Maslin (seed collected; no voucher taken).

"Kalannie", Xantippe cricket pitch, 12 km due NW of Kalannie, 30º 16' 30"S, 117º 01' 45"E, 10 Dec. 1999, J. Carslake (seed collected; no voucher taken).

<u>var. microbotrya</u>

"Muntadgin", about 8 km due NNW of Muntadgin, on Brissenden Road, 8 km E of Narembeen Road, 31º 43' 03"S, 118º 29' 59"E, 26 Nov. 1999, B.R. Maslin 7957 (seed slightly immature), mature seed subsequently collected from this population by J. Carslake on 11 Dec. 1999.

"Corrigin", Kunjin reserve, 10 km west of Corrigin on the corner of Kunjin South Road and Corrigin-Brookton Road, W. Edgecombe (seed collected, no voucher taken.

"Three Springs", 29º 35'S, 115º 35'E, Australian Tree Seed Centre seed lot number 17643.

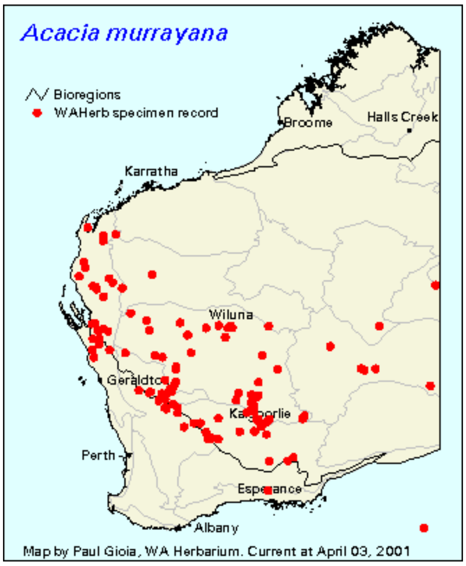
"Barbalin Rock", 30º 58'S, 118º 58'E, Australian Tree Seed Centre seed lot number 17649.

<u>Dandaragan - Badgingarra variant</u>

13.5 km from Dandaragan on road to Badgingarra (11.5 km N of the Dandaragan - Moora road), 30º 35' 02"S, 115º 38' 22"E, 28 Nov. 2000, B.R. Maslin 8206D (seed voucher). Subsequent seed collections by (1) J. Carslake from Coalara Rd, 300 meters from the T junction with North West Rd and (2) W. Edgecombe from Coalara road and Namban West Rd.

Acacia murrayana (Colony Wattle, Murray's Wattle, and more)

WA Herbarium taxon ID: **3452**



Habit. Large shrub or tree 2-6 (-8) m, single- or multi-stemmed from the base, main stems straight or sometimes rather crooked and with dbh to 15 cm (few measurements made therefore exact range not known), the crown bushy and often wide-spreading 3-8 m across, commonly suckering to form clonal thickets.

Distribution and habitat. Widely distributed in the arid and semi-arid zones (100-500 mm annual rainfall) of Australia where it extends from the central-west coast of W.A. eastwards through all mainland states except Victoria. Over its extensive range *A. murrayana* occurs predominantly on deep red sands but it may also occur on clay loams. It favours well-drained sites with access to run-on water such as the base of dunes, road verges and stream levees. It is tolerant of alkaline soils according to Elliot and Jones (1982) but results from glasshouse trials suggest that it is relatively salt-sensitive (Aswathappa *et al*. 1987). Further details on its ecology are given in Doran and Turnbull (1997).

Variation. There is marked variation in phyllode size and colour between plants from different areas and future studies may show the need to recognise new taxa to accommodate at least the two main phyllode forms (i.e. plants with narrow, green phyllodes are common in Queensland; elsewhere phyllodes are normally wider and pruinose). According to Maslin *et al*. (1998) provenance variation in economic characters is also likely to be great, given the extensive natural distribution and occurrence on different soil types of this species.

Affinities. *Acacia murrayana*, together with four close relatives (*A. gelasina*, *A. pachyacra*, *A. praelongata* and *A. subrigida*) comprise the informal "*Acacia murrayana* group" (see Maslin 1995 for discussion); only *A. murrayana* itself is included in this report. This species is not far removed taxonomically from *A. victoriae* (see below).

Biology. *Acacia murrayana* is an adaptable, fast-growing but short-lived (10-25 years) and according to Latz (1995) is highly fire-tolerant and drought-adapted (when above-ground parts are killed by fire and severe drought coppice shoots quickly appear from the roots). Because of its root-suckering ability, especially in disturbed sites such as road verges, this species has the potential of becoming weedy. *Acacia murrayana* produces heavy pod crops during favourable seasons; however, in south western Queensland at least parrots are reported to remove much of the seed prior to maturity. The pods may be rapidly harvested by shaking/threshing. Plants can be pruned to one main stem which would facilitate mechanical harvesting. Phyllodes are rarely consumed by stock (dry matter digestibility of foliage was assessed by Vercoe (1989) as being below maintenance levels) but pods are sought after.

Wood. Air dry density is 603 kg/m^3, based on 10 samples tested (G. Pronk, pers. comm.). Listed as highly suitable for the production of fuelwood and charcoal by Thomson *et al.* (1994).

General Uses. This species has potential for use in revegetation within at least parts of the northern wheatbelt. It is well-suited for providing windbreaks, visual screens and shade and shelter for stock and wildlife. Because it commonly suckers it has good potential for providing soil stabilisation. *Acacia murrayana* is one of the most promising species suggested by Maslin *et al.* (1998) for trialing in southern Australia as a source of seed for human food. Central Australian aborigines are reported to have consumed the gum exudate found in plants of this species (gum production not great though).

Silviculture. *Acacia murrayana* is an adaptable species that should be able to be successfully grown on a wide range of well-drained soils (acid to alkaline sands, loams and texture-contrast types) in low rainfall areas (<500-600 mm yr^{-1}) across southern Australia; waterlogged sites should be avoided, but supplementary watering/irrigation can be expected to enhance longevity and fruiting in very low rainfall areas (< 250-300 mm yr^{-1}). Planted specimens grow quickly during wetter years (>390 mm yr^{-1}), but plant health rapidly declines during dry periods (<150 mm yr^{-1}). Declining stands can be regenerated either by coppicing and/or shallow ploughing to stimulate root-suckering. It responds to pruning after flowering according to Elliot and Jones (1982).

SEARCH relevance. Medium to high priority. *Acacia murrayana* has a number of desirable features, including good growth form, fast growth rate, an ability of coppice and to produce quite reasonable amounts of woody biomass. Seed production for food could be a minor secondary product from this species (but see note under *A. victoriae* below). These features are not dissimilar to its relative, *A. victoriae* but unlike that species *A. murryana* is not a thorny plant. For SEARCH its main drawback may be its relatively low salt tolerance and its propensity to grow on light and medium textured soils; also, it is not know if its wood has desirable characteristics for MDF production. The propensity of *A. murrayana* to sucker may or may not be advantageous, it depends whether or not this attribute is required for the system in which it is placed. It is likely that this species would do best in the northern wheatbelt (I doubt that it would survive well south of the Great Eastern Highway).

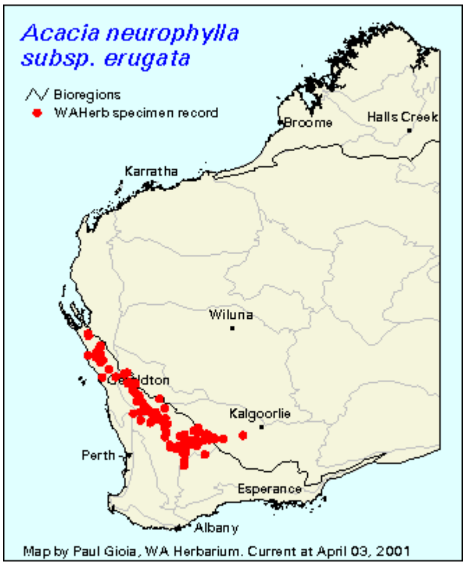
Seed collections (provenance name in quotes) and vouchers

"Mt Magnet",19 km S of Mount Magnet on Great Northern Highway to Paynes Find, 28º 13' 25"S, 117º 51' 42"E, 24 Nov. 1999, B.R. Maslin 7942 (seed voucher).

"Paynes Find", about 57 km SW of Paynes Find on Great Northern Highway to Wubin, 29º 28' 10"S, 117º 11' 48"E, 24 Nov. 1999, B.R. Maslin (seed collected, from two populations about 1 km apart; no vouchers taken).

"Mullewa", 79.7 km E of Mullewa on road to Mt Magnet, 9 Dec. 1999, J.Carslake (seed collected; no voucher taken).

Acacia neurophylla subsp. *erugata* (Broad-leaf Wodjil)



WA Herbarium taxon ID: **15290**

Habit. Spreading shrub (1-) 2-4 (-5) m tall and 2-5 m wide, multi-stemmed from base.

Distribution and habitat. Occurs from Cooloomia (about 90 km north of Kalbarri) south-east Kondinin and Bulla Bulling near Coolgardie). Commonly forms dense roadside populations in the places where it occurs. Grows mainly in yellow sand and laterite

Variation. Subsp. *erugata* is rather invariate. However, the species *A. neurophylla* comprises two subspecies, subsp. *neurophylla* and subsp. *erugata*.

Affinities. Related to the rare species *A. incongesta* (not included in this report and which is restricted to granite soils in the Peak Charles National Park).

Biology. Little known about this hardy, relatively fast growing subspecies. It is likely have a life span of around 10+ years and reproduces from seed (sucker regrowth unlikely).

General Uses. *Acacia neurophylla* subsp. *erugata* is a hardy, primary coloniser that is well-suited to revegetation work, particularly gravelly sites. Because of its low-spreading habit and dense crown this subspecies is ideal for revegetating disused gravel pits and the plants would provide a good wildlife refuge.

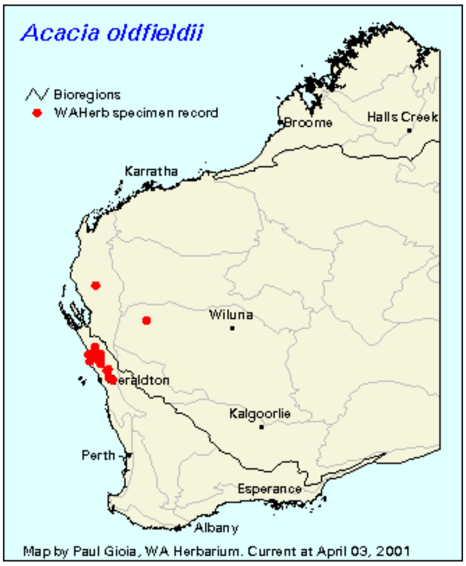
SEARCH relevance. Low priority on account of insufficient woody biomass and probable dark heart wood. However, subsp. *erugata* would be useful as a fill-in shrub for situations where a hardy, fast-growing plant is required for cover and soil stabilisation (particularly in light-textured, lateritic or gravelly soils). It is quite possible that subsp. *neurophylla* would perform a similar function.

Herbarium voucher (no seed bulk collected)

subsp. erugata

1 km S of Yuna township on road to Tenindewa, 28º 19' 48"S, 115º 00' 30"E, 23 Nov. 1999, B.R. Maslin 7932.

Acacia oldfieldii (Oldfield's Wattle)



WA Herbarium taxon ID: **3466**

Habit. Multi-stemmed, spreading shrub or small tree 2-4 m tall, rarely with a bole to about 1 m; main branches somewhat crooked (less straight than in *A. acuminata*).

Distribution and habitat. Restricted to a small area flanking the Murchison River near Ajana (two populations known). Grows on deep yellow sand or on shallow sand over sandstone (pH 5.5-6).

Variation. Invariate.

Affinities. Allied to *A. acuminata* but genetic evidence suggests that the relationship is not as close as the morphological data would suggest. Seemingly also close to *A. drepanophylla* (common on shallow sand over limestone in the Billabong-Overlander area), a species not assessed for this project.

Biology. Probably similar to *A. acuminata*.

General Uses. Little known.

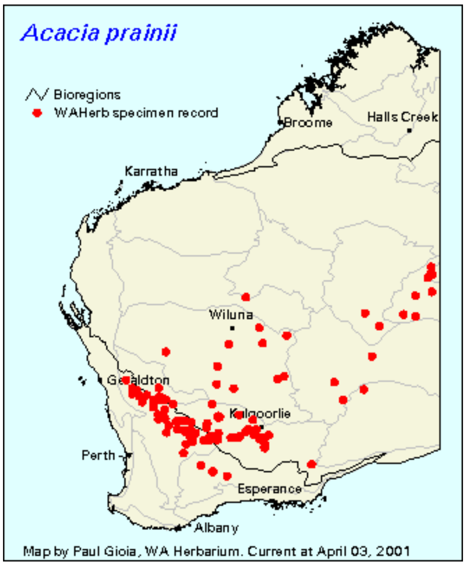
SEARCH relevance. The spreading growth form, somewhat crooked branches, relatively low woody biomass and probable dark heartwood would tend to make this species unsuited for extensive use by SEARCH. Its main benefit (apart from its potential Sandalwood host) could be as a “companion” to *A. acuminata*, for growing on sites too sandy to support Jam. However, if its natural occurrence can be taken as a guide, it may not be suited to many places other than the northern wheatbelt region.

Seed collections and vouchers

Seed and vouchers were collected from populations of this species as part of the *A. acuminata* project (see Maslin *et al*. 1999) and could be available to SEARCH via Jon Brand.

Acacia prainii (Prain's Wattle)

WA Herbarium taxon ID: **3495**



Habit. Dense, spreading, shrub (1-) 1.5-3 (-5) m tall and 1.5-4 (-5) m wide, either obconic with sub-rounded crowns occupying about 60% of the total plant height, or rounded with the crowns extending to the ground, branching at or just above ground level into a number of erect to ascending stems; main stems and branches rather straight (4-6 cm dbh).

Distribution and habitat. Widely distributed in arid and semi-arid areas of southern Australia, extending into the northern and central wheatbelt around Morawa and Holt Rock; it ranges eastwards to Lake Amadeus in southern Northern Territory and Lake Everard in South Australia. Over its range *A. prainii* grows in sand , sandy clay and brown calcareous earths and around Kalannie at least tolerates slightly to moderately saline soils.

Variation. *Acacia prainii* exhibits considerable variation in phyllode shape and size and future studies may show that infraspecific taxa should be recognised. In the wheatbelt region of south-west Western Australia the phyllodes are flat and frequently 2-5 cm long (this is the "typical" form of *A. prainii*), but further east in the Arid Zone they may reach 11 cm (this form includes the type of *A. prolifera*, which is regarded as a synonym of *A. prainii*). Some specimens from around Coolgardie and Widgiemooltha in the goldfields region of Western Australian have very thin, quadrangular phyllodes less than 1 mm wide; these plants were described as *A. prainii* var. *linearis*, however, this name is currently not formally used.

Affinities. A member of the "*Acacia prainii* group" (see Maslin 1995 for discussion), three members of which are included in this report, namely, *A. anthochaera*, *A. hemiteles* and *A. prainii*. *Acacia prainii* is perhaps most closely related to *A. hemiteles.*

Biology. A hardy species with a moderate to moderately fast growth rate; I imagine that it would have a life-span of around 20-30 years. Its coppicing ability is unknown, and it has not been recorded to root sucker under natural conditions. Pod crops are normally reliable and when they occur the pods are normally produced in large numbers and held terminally, therefore, are very accessible for harvesting (shaking/threshing technique); the medium-sized to large seeds are easily separated from the pods.

Wood. Characteristics unknown.

General Uses. *Acacia prainii* has good potential for revegetation in the northern and central wheatbelt on account of its large growth form, moderately fast growth rate and its occurrence on a wide range of soil types (including those that are slightly to moderately saline). This species would be useful for salinity and erosion control, visual screens, windbreaks and shelter belt planting. *Acacia prainii* is one of the lesser-known species suggested by Maslin *et al.* (1998) for trialing as a source of seed for human food.

SEARCH relevance. Medium priority. The relevance of this species is similar to that given above for *A. anthochaera*, however, *A. prainii* is not quite so good on account of the form of the plant (i.e. not quite so much wood relative to foliage, and the individual stems thinner and more numerously branched). As with *A. anthochaera* the wood characteristics of A. prainii are unknown.

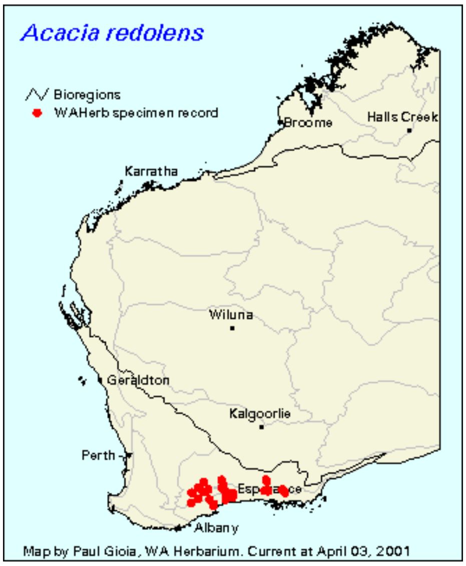
Herbarium vouchers (no seed collected)

Black Road, E of Kalannie, 30º 24' 40"S, 117º 23' 50"E, 25 Nov. 1999, B.R. Maslin 7950.

Note: Other populations of this species were located but mature seed not collected from them, namely: Rollison Road, 0.2 km No f Kalannie - Koorda road, and Dandanning Road, S of Mukinbudin.

Acacia redolens

WA Herbarium taxon ID: **3511**



Habit. Low-domed shrub 2-3 tall and spreading to 2-7 m across; stems and main branches rather twisted, the largest reaching 5-8 cm diameter; crown rather dense and foliage vanilla-scented.

Distribution and habitat. Most common in the Ongerup - Ravensthorpe area where it forms rather dense roadside populations in places; also found near Newdegate and Pingrup. Grows in often sub-saline alkaline loam, clay or clay loam; frequently occurs around margins of salt lakes.

Variation. Plants from around Pingrup have unusually narrow phyllodes and further study is needed to ascertain whether or not these are *A.* affin. *redolens* which is described below.

Affinities. Seemingly most closely related to *A. trineura* (an eastern Australian species). Also related to *A.* affin. *redolens* (see below)

Biology. This species is probably reasonably fast-growing; it would live for at least 10-15 years. Reproduction is likely to be from seed (unlikely to sucker) but coppicing ability is unknown. Pods occur in great profusion on plants and are easy to collect by hand or by simple threshing techniques.

General Uses. *Acacia redolens* was introduced to the U.S.A. in the early sixties where it was used in soil erosion programs, in landscaping of median strips on highways, and in the reclamation of dredged soils containing sand, sodium salt, sea shells and clay; it was reported to grow exceptionally well on the coast under extreme conditions without any wind burn damage. *Acacia redolens* would appear to have good potential for landscape amelioration (erosion and salinity) in W.A.

SEARCH relevance. *Acacia redolens* would be a useful supplementary species for situations where ground cover in saline sites is required. Locating natural stands and collecting seed would be easy. Compared with most other species included in this report *A. redolens* does not produce a large quantity of easily harvested wood product. Investigation of the chemical composition of the vanilla scent found in the foliage may possibly prove useful.

Seed collections (provenance name in quotes) and vouchers

"Newdegate", 1.5 km S of Newdegate (at entrance to Country Club) on Magenta Road to Lake Magenta, 33° 06' 13"S, 11° 01' 50"E, 12 Dec. 1999, J. Carslake (seed collected; vouchered by B.R. Maslin 7959 taken from this same population on 27 Nov. 1999).

"East Ravensthorpe", 1.6 km E of Ravensthorpe, 33° 34' 27"S, 120° 04' 00"E, 7 Dec. 2000, D.J. Cooper 15 (seed voucher).

"West Ravensthorpe", 7.9 km from Ravensthorpe heading N on Armadale-Ravensthorpe Road from South Coast Highway, 33° 30' 53"S, 119° 58' 43"E, 7 Dec. 2000, D.J. Cooper 17 (seed voucher).

Acacia affin. *redolens*

WA Herbarium taxon ID: **3511** (part of)

Habit. Small tree 4-7 m high, may reach 10 m in good sites; dividing at 0.5-1.8 m above ground level into 2-3 main stems (9-20 cm dbh); stems and main branches sub-straight; crown bushy. Bark thin.

Distribution and habitat. Plants definitely referable to this taxon occur in a few scattered localities from near Scaddan eastwards for about 40 km (to near Mt Burdett). This species is not very common in the places where it occurs. Further study would be required to ascertain the full geographic range (it could possible extend west to the Fitzgerald River). Grows in waterlogged clay-loam over clay or in grey sand over clay adjacent to waterlogged depression. I suspect that it would be able to tolerate at least low to moderate salinity.

Variation. Seem relatively invariate.

Affinities. Until now this taxon had been confused with *A. redolens* with which is has a superficial resemblance in phyllodes, flowers and pods (but a very different growth form, and does not have vanilla-scented foliage). Taxonomic work would be needed to properly separate the two taxa. In habit it resembles some forms of *A. cyclops* (with which it is sometimes sympatric) but it is unlikely that the two species are taxonomically closely related. *Acacia* affin. *redolens* most probably represents a new species.

Biology. Probably relatively long-lived (20+ years). Growth rate unknown. No evidence of suckering. Coppicing/pollarding unknown (probably unlikely). Pod crops were fair but can be difficult to collect on account of height of plants.

Wood. Wood relatively hard; quite a lot of pale yellow sapwood relative and a relative small amount of light brown or pale grey-brown heartwood.

General Uses. None recorded.

SEARCH relevance. Medium priority. This species could be a useful inclusion for SEARCH on account of its growth form and the fact that it produces a reasonable amount of woody biomass (wood generally pale coloured). Also, its preference for water-logged clays could be a useful attribute (this is not a common habitat for an *Acacia*) and it is one of the relatively few larger acacias that are found in south coastal areas. I have ranked it as medium priority because other species such as *A. cyclops* that have similar characteristics may well perform better.

Seed collections (provenance name in quotes) and vouchers

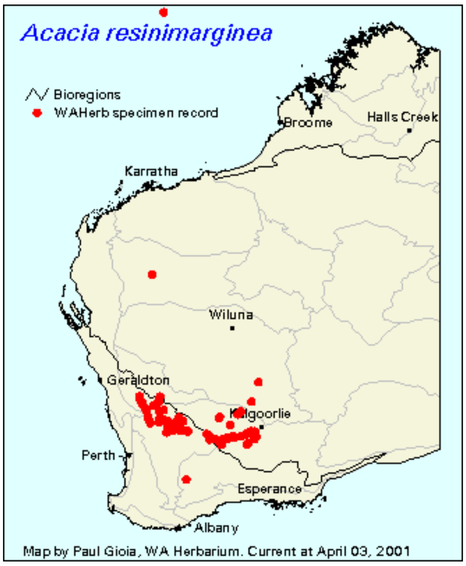
"Scaddan", 2 km S of Scaddan on Coolgardie-Esperance Highway, 33º 27' 20"S, 121º 43' 50"E, 27 June 2000, B.R. Maslin 7975 (in flower) and 5 Dec. 2000, B.R. Maslin 8217 (seed voucher: seed collected by D.J. Cooper and J. Carslake 6 Dec. 2000).

"Mt Ney", NE of Esperance, Burdett Road, 4 km W of Backmans Road, 33º 31' 53"S, 122º 18' 05"E, 27 June 2000, B.R. Maslin 7980 and 5 Dec. 2000, B.R. Maslin 8218 (seed voucher: seed collected by D.J. Cooper and J. Carslake 6 Dec. 2000).

Wittenoom Road, 1 km S of Burdett Road, 33º 26' 05"S, 122º 10' 38"E, 27 June 2000, B.R. Maslin 7979 (flowering specimen).

Acacia resinimarginea (Old Man Wodjil)

WA Herbarium taxon ID: **3513**



Habit. Obconic tree 4-7 m high, single-stemmed or 2-5 branched near base; trunks fairly straight, generally erect, and reaching 20 cm dbh, crowns dense, rounded to sub-rounded, spreading yet narrow (2-4 m across) and occupying about 30% of the total plant height (40-50% in young plants).

Distribution and habitat. Common from Perenjori south-east to near Kambalda; it also occurs inland to Leonora. This species often forms pure stands in the places where it occurs with the plants typically grow close together and form dense, often monotypic, populations.

Variation. Invariate.

Affinities. Allied to the relatively uncommon species *A. jamesiana* (Arid Zone) and *A. ampliata* (northern wheatbelt and Arid Zone) which are similar in habit to *A. resinimarginea*.

Biology. Likely to be long-lived (probably 50+ years). Suckering very unlikely; coppicing/pollarding ability unknown. Pods occur in great profusion and are easy to collect by hand using threshing/shaking techniques; the seeds are very small. Phyllodes contain low concentrations of cyanogenic glucoside but this is unlikely to be problematic in utilisation of this species. In places it appears that this species may be a natural host for Sandalwood (*Santalum spicatum*).

Wood. Characteristics unknown but heartwood likely to be dark-coloured.

General Uses. *Acacia resinimarginea* is an excellent species for revegetation of Wodjil sands. Its arborescent growth form and its dense, spreading, porous crowns make this species ideally suited for use as a windbreak and visual screen, as well as for providing good shade and shelter for stock; it is well-suited for soil stabilisation and under natural conditions it often forms dense, monotypic stands on deep yellow or gravelly sandy soils. The straight, unbranched trunks render this species suitable for poles and other wood products such as fence posts, subject to plants of suitable size being found.

SEARCH relevance. Medium priority. The only reason why this species is not rated more highly is because its heartwood is likely to be very dark coloured and that its growth rate is unknown (may be rather slow). *Acacia resinimarginea* has an excellent growth form, it has robust, essentially straight and sparingly branched trunks and produces a good quantity of woody biomass. The species would be a very good for use on deep Wodjil sands or gravelly yellow sands in the northern and central wheatbelt. It is unlikely to be salt tolerant. If it were decided to use this species in the SEARCH program it would be advisable that we take a closer look at its relatives, particularly *A. ampliata*, for possible inclusion also. Other Wodjil species include *A. neurophylla* (see above), *A. stereophylla* (see below) and *A. yorkrakinensis* (not included in this report on account of its great susceptibility to Gall Rust infection.).

Seed collections (provenance name in quotes) and vouchers

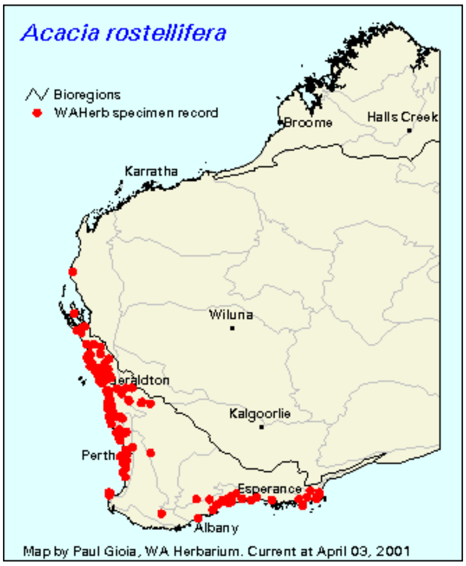
"Kalannie", Kulja Central Road, 4.5 km S of Warren Road (E of Kalannie), 13º 16' 03"S, 117º 20' 15"E, 25 Nov. 1999, B.R. Maslin 7948 (seeds immature), mature seed subsequently collected from this population by J. Carslake 10 Dec. 1999.

"Mt Gibson", 5.6 km S of Rabbit Proof Fence on Great Northern Highway, between Wubin and Paynes Find, 29º 34' 53"S, 117º 09' 10"E, 24 Nov. 1999, B.R. Maslin (seed collected; no voucher taken).

Note: Population (plants with immature pods) also located at 0.7 km W of Welbungin, W. of Mukinbudin, but mature seed not collected; a little seed subsequently collected from this population by J. Carslake.

Acacia rostellifera

WA Herbarium taxon ID: **3525**



Habit. Dense shrub or tree commonly 2-5 m tall, usually clonal. A "typical" plant has main stems 5-10 cm dbh; the largest plant observed during this survey measured 6-7 m tall and 10 m across, it branched near ground level into about 4 trunks, each 15-20 cm dbh (main trunk about 60 cm diam at ground level). When growing within dense clonal thickets the plants are often pretty spindly with stems about 2-3 cm dbh.

Distribution and habitat. Occurs in coastal areas from Shark Bay south to Cape Naturaliste and then from Bremer Bay east to Israelite Bay; around Geraldton it extends inland through Northampton to near Yuna and south to Latham. Normally very common in the places where it occurs and it usually forms dense, monotypic, clonal thickets. Grows most commonly in porous coastal sand; along road verges inland from Geraldton it may occur on granitic rocky sand.

Variation. A narrow phyllode variant occurs on yellow sandy soil from north of the Murchison River near Ajana to Shark Bay.

Affinities. A member of the *A. bivenosa* group (see Chapman and Maslin 1992) and particularly closely related to the widespread Arid Zone species, *A. ligulata.*

Biology. A vigorous plant probably having a fast to moderately fast growth rate; it is probably moderately long-lived (about 20 years I suspect). *Acacia rostellifera* appears to normally have an aggressively suckering habit; its coppicing/pollarding ability is unknown (but could well be present since its close relative *A. ligulata* is said to have high coppicing ability, see Thomson *et al.* 1994). Presumably because it commonly reproduces vegetatively pods tend to be infrequent but when present they often occur scattered over the plants and the seed can therefore be a little tedious to collect.

Wood. Pale coloured throughout (scarcely any dark heartwood developed), however, only one plant sampled.

General Uses. Well-suited to sand dune stabilisation.

SEARCH relevance. Medium/high priority. If requiring a +/- fast growing, aggressively suckering plant for light-textured soils then *A. rostellifera* would appear to be a suitable candidate. It produces pretty good woody biomass (although if the plants grow too close together then they may not bulk up much: this is a silvicultural problem) and preliminary indications are that the wood is reasonably soft and pale coloured (testing for MDF suitability is recommended). Locating and collecting seed could prove troublesome.

If *A. rostellifera* proves relevant to the SEARCH program then it is recommended that other species from this group be examined also. Although most of these taxa occur in the Arid Zone a few occur naturally in the south-west province (e.g. *A. cupularis*: south coast, *A. telmica*: waterlogged heavy soil near Eneabba and *A. xanthina*: coastal limestone from Perth – Geraldton). *Acacia tysonii* (see below) only just reaches the wheatbelt. *Acacia ligulata* is the most widespread species in the group (all States in the Arid Zone) although

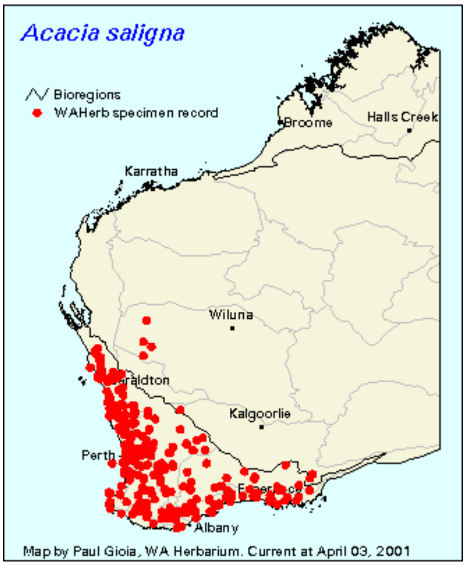
A. sclerosperma is common in the north-west of W.A.: both these species just reach the perimeter of the northern wheatbelt. *Acacia ampliceps* (Pilbara, Kimberley and N.T.) is an extremely salt tolerant member of the group; in habit at least this species bears a striking resemblance to *A. saligna. Acacia salicina* (central and eastern Australia) grow to substantial trees.

Seed collections (provenance name in quotes) and vouchers

4.5 km towards Nanson from North West Coastal Highway turn-off at Northampton, 28º 23' 10"S, 114º 40' 47"E, 23 Nov. 1999, B.R. Maslin 7930 (seed immature; mature seed subsequently collected from this plant by J. Carslake).

Eastern outskirts of Esperance on highway to Albany, 33º 50' 20"S, 121º 52' 56"E, 29 June 2000, B.R. Maslin 7985 (plants sterile).

Acacia saligna (Golden Wreath Wattle, Orange Wattle)



WA Herbarium taxon ID: **3527**

Note. There is a large body of literature concerning this species and it is not intended that I summarise all this information here. See Fox (1995) and Doran & Turnbull (1997) for extensive treatments of this species.

Habit. Shrub or tree 2-6(-10) m tall, either single- or multi-stemmed, mature trunks 20–40 cm dbh, crown bushy and spreading 2-6(-12) m across, sometimes forming thickets due to root suckering (not sure if all forms of this species sucker), the ultimate branchlets often more or less pendulous. Very variable in growth form, for example, plants from the Swan Coastal Plain are robust small trees but between Gingin and Geraldton the plants are smaller and more spindly, an apparently rare prostrate form is reported to occur in the Jurien Bay district.

Distribution and habitat. Widespread and often locally abundant in south-west Western Australia where it extends from near Kalbarri south-east to near Mount Ragged; there are outlying populations about 200 km east-north-east of Kalbarri on Meka, Murgoo and Jingemarra Stations. The species is naturalised (and often weedy) in temperate and sub-tropical eastern Australia and also around the Mediterranean Sea, in South Africa and in California. *Acacia saligna* has a broad edaphic range, including alkaline and moderately saline soils. In W.A. *A. saligna* is an adaptable species that is best developed on often calcareous sandy soils of the Swan Coastal Plain from Gingin to Busselton. Further inland, in the wheatbelt region, it is less common and is often confined to watercourses or to soil aprons surrounding granite outcrops. It occurs along saline drainage systems such as the human-induced salt-affected, upper catchment of the Avon River (e.g. east of Brookton) and the naturally saline Sanford River (north-east of Kalbarri). Details of the ecology of *A. saligna* is provided in Fox (1995).

Variation. *Acacia saligna* is a very polymorphic species, particularly in regard to phyllode morphology and growth form. Much research is needed to understand and document this variation; a RIRDC grant application has been submitted to explore this.

Affinities. At present it is not possible to ascertain with certainty the close relatives of *A. saligna*. There are, however, some indications that the species may not be too far removed taxonomically from certain members of the *A. bivenosa* group (see Chapman and Maslin 1992 for revision of this group) or to *A. blakelyi* and *A. scirpifolia* (see above). In the past *A. pycnantha* (native to eastern Australia but a weed in parts of the W.A. wheatbelt) was commonly thought to be related to *A. saligna*; however, it is probable that they are not particularly close.

Biology. A hardy, fast-growing species which, according to Fox (1995) is somewhat frost tender -see Fox (1995) for further details on growth characteristics. It's life span is about 10-20 years. The species readily suckers (it has been reported to me that there are non-suckering forms but I have not specifically examined this issue); at least some forms of the species will coppice if cut at ground level and resprout from the base following fire. A range of insect pests are reported by Van den Berg (1980a, 1980b and 1980c) from native

Western Australian populations of *A. saligna*; the purpose of these studies was to establish the importance of natural enemies with a view to biological control of *A. saligna* (and *A. cyclops*) in South Africa. This species is also susceptible to infection by gall rust. See Fox (1995) for further details on the biology of this species. Nakos (1977) found that the ability of *A. saligna* to fix nitrogen was greatly reduced by drought, waterlogging, shading or defoliation. This species has the capacity to become weedy outside its natural habitat: see Stirton 1978, Milton & Siegfried 1981 and Whibley & Symon 1992). In southern Australia *A. saligna* sets moderately heavy seed crops in most years; in cultivation this species sets profuse seed crops from about 6 years of age (Goor and Barney 1968). The mature pods can be rapidly harvested manually by shaking/threshing, and the seeds readily detach from the mature pods. According to Fox (1995) perhaps 80% of seed produced may be predated on the plants. For further details on seed production (and dispersal) see Fox (1995).

Wood. The wood is described by Fahn (1959) as diffuse-porous with growth rings absent; anatomical details of wood structure are summarised by Fox (1995). Air dry density: 525 kg/m^3, based on 1 sample tested (G. Pronk, pers. comm.).

Propagation. *Acacia saligna* can be propagated from seed or cuttings (Elliot and Jones 1982). The seed requires a boiling or hot water treatment to break dormancy (see Fox 1995 for details of seed viability and germination techniques). Raising seedlings in the nursery and field establishment presents few problems, however, protection of newly established plantations from grazing animals is essential. Although it may be grown under light-moderate shade, plants prefer full sun and seed production will be maximised under such conditions. Direct seeding (750 g pre-treated seed /ha) has been used to establish plantations on better quality, well-cultivated soils in Cyprus (Michaelides 1979). In south-west Western Australia forage plantations of *A. saligna* have been established by mechanised direct seeding and more recently from bare rooted cuttings. The plants respond well to light pruning and may coppice strongly, but are rather short-lived, typically 10-20 years. At least some forms of the species regrow vigorously when pollarded at about 50 cm above ground level. It may be possible to rejuvenate declining stands by coppicing and/or shallow ploughing to induce root-suckering; Michaelides (1979) has recommended a short rotation of 5-10 years duration, with regeneration by coppicing. According to Hass (1993) irrigation can double height growth over the first 17 months from planting. *Acacia saligna* plants may be damaged by a wide range of insect pests and diseases (see above). Broad-scale cultivation of *A. saligna* in southern Australia may be expected to result in a build-up of one or more of these diseases. Such anticipated problems may be minimised by establishing mixed and/or dispersed small-scale plantings, and by maintaining plants in a healthy condition, e.g. by planting at wide spacings on more difficult sites. Further details of growth performance of this species in pot and field trials is summarised in Fox (1995).

Uses

Revegetation. Because *A. saligna* is very variable in its growth form and displays a wide range of ecological tolerance it has excellent potential for use in salinity and soil erosion control, as a windbreak, visual screen and for shade and shelter for both stock and wildlife. Indeed, it is already commonly used for these purposes in south-west Western Australia and elsewhere (see Fox 1995) where it is employed in direct seeding programs for regeneration and salinity control (P. Ryan, pers. comm.); Wilcox *et al*. (1996) recommend its us for a variety of soil types in the Midlands and northern wheatbelt regions, Clarke (1998) regards it as being suited to revegetating drainage lines in these areas and Lefroy *et al*. (1991) recommends it use for “Grevillea” country (i.e. upland sandplain areas characterised by deep yellow, neutral to acidic sand over deep yellow sandy clay) in the central wheatbelt region.

Fodder. This species would appear to have fairly good potential as a fodder plant. Previous reports suggest that while the protein content of its phyllodes is high, varying from 14-19 %, it has low digestibility; however, this matter was the subject of a MSc project by Delwyn Howard. According to Lefroy *et al.* (1992) the advantage of using *A. saligna* is that it is easily established at relatively low cost, but a disadvantage is that the plants have to be cut regularly to make the foliage available to the animals; this study suggests that A. saligna is most effective as a fodder when used in combination with other plants such as Tagasaste (*Chamaecytisus palmensis*) and/or perennial grasses. Overseas *A. saligna* is highly valued as a stock fodder (El-Lakany 1987). For example, over 200 000 ha have been planted in north Africa as food for sheep and goats (Crompton 1991); however, the response of animals to grazing *A. saligna* is variable, depending upon breed. For example, based on work in South Africa, it appears that some breeds of sheep have a greater ability to digest *A. saligna* than others, possibly due to differences in gut flora (Lefroy, pers. comm.). Also, under trial conditions in Cyprus goats lost weight when fed on *A. saligna* only (Fox 1995). Crushed seeds of this species have been fed to a concentration of 95% total ration to sheep without ill effects, but results with poultry were not encouraging (Anon. 1955).

Wood. The wood may be used for fuelwood or charcoal, and has even been successfully converted into particle board in Tunisia (El-Lakany 1987). Annual wood production (assessed over bark) varies between 1.5 - 10 m^3/ha (Michaelides 1979). According to Sale (1948: cited in Fox 1995) a firewood harvest can be taken from dune plantings of this species at 10-15 years. It is likely that many other species of *Acacia* would produce a better-quality fuelwood than *A. saligna*.

Horticulture and amenity plantings. Widely cultivated (both within Australia and abroad) as an ornamental for use in park plantings, gardens and on farms.

*Seed for human food***.** *Acacia saligna* is one of the promising species suggested by Maslin *et al.* (1998) for trialing in southern Australia as a source of seed for human food.

Tannin products. Acacia saligna was at one time the principal source of tan bark in south-west Western Australia, with a yield of nearly 30% tannins (Maiden 1889). It was also previously a major source of tannin in South Africa before being replaced by superior tanbarks (of *A. mearnsii*) (Boucher and Stirton 1980).

Gum. Physiological stress or mechanical damage to the bark may induce copious gum flows: the acid-stable gum may have use in certain foodstuffs (Michaelides 1979). An analysis of the gum has been provided by Charlson *et al.* (1955) and Kaplan and Stephen (1967, cited in Anderson and Bell 1976).

Dye. The phyllodes of *A. saligna* can be used to dye wool to a lemon yellow colour using an alum mordant (Martin 1974).

SEARCH relevance. High priority. *Acacia saligna* is probably the most promising of all south-west W.A. acacias included in this report. It is a fast growing, hardy and adaptable species which (some forms at least) produces a good quantity of woody biomass with wood characters seemingly well-suited to MDF (and presumably) energy production. There could also be secondary product spin-off benefits (such as fodder) from using this species; additional to this is the benefit derived from its use in landscape amelioration programs. *Acacia saligna* has had a long history of multipurpose utilisation, both within Australia and abroad, and indeed, is probably the most extensively used W.A. species of *Acacia*. It is widespread and common in the south-west and is currently used in the region for revegetation and in a few agroforestry programs. *Acacia saligna* is therefore quite well "known" to a number of people, some of whom are very enthusiastic about its potential for lowering water tables and as a fodder plant (it is probably true to say, however, that some of this enthusiasm is based on anecdotal evidence). However, ahead of any extended/extensive use of this species it is essential to develop a better understanding its variation patterns; also, it is particularly important to understand its weed potential (although *A. saligna* is a serious weed in some places abroad, to my knowledge it is not a problem here in W.A.). Apart from the benefits that might come to W.A. farmers from a more extensive use of *A. saligna* the possible benefits of exporting knowledge (and verified/improved seed) of the species to overseas users should not be overlooked or underestimated. Indeed, with this in mind it might be worth considering if any benefits would be derived by SEARCH from developing "collaborations" with groups abroad who are currently using this species.

Seed collections (provenance name in quotes) and vouchers

"Pink Lake", 8.1 km SW on Pink Lake Drive, 6.1 km from Nicolson Road and 3.9 km from Helms Road, Esperance, 33° 51' 02"S, 121° 47' 08"E, 6 Dec. 2000, D.J. Cooper 14 (seed voucher).

"Wagin", 6.5 km S of Wagin on Great Southern Highway (c. 100 m N of Parkeyerring Lake crossing), 33° 21' 48"S, 117° 21' 20"E, 27 Nov. 1999, B.R. Maslin 7960 (seeds immature); mature seed subsequently collected from this population by J. Carslake 21 Dec. 1999.

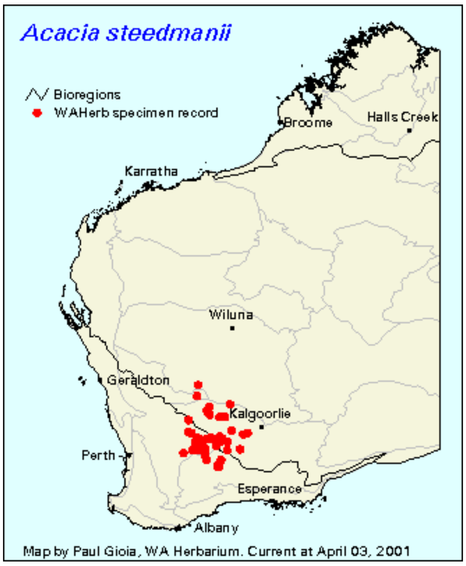
"Muntadgin", about 8 km due NNW of Muntadgin, on Brissenden Road, 8 km E of Narembeen Road, 31º 43' 03"S, 118º 29' 59"E, 11 Dec. 1999, J. Carslake (seed collected; voucher not taken).

"Arthur River", 7.5 km west of Arthur River along Coalfields Rd, 500 meters from the T junction with Clarke Rd, 21 Dec. 1999, D.J. Cooper (seed collected; voucher not taken).

"Gingin", Brand Highway 7.5 km S of Gingin, between Creighton Rd(North) and Nambung Road(South), 21 Dec. 1999, J. Carslake (seed collected; voucher not taken).

Mount Ridley (NE side), NE of Esperance, 33º 17' 25"S, 122º 07' 28"E, 27 June 2000, B.R. Maslin 7977 (flowering specimen).

Acacia steedmanii (Steedman's Wattle)



WA Herbarium taxon ID: **3555**

Habit. Spreading, single- or multi-stemmed, rather openly branched shrub or small tree 2-4 m tall.

Distribution and habitat. Central wheatbelt and adjacent semi-arid regions from Pigeon Rocks south to Bruce Rock and east to Bulla Bulling, with an outlier near Forrestonia. Grows in sand, sandy loam, loam, rocky loam and gravelly clay, frequently on or near granite rocks but also on lateritic gravelly rises and sand-plains.

Variation. Invariate.

Affinities. A member of the *A. microbotrya* group with its closest relative, *A. validinervia*, occurring in the Arid Zone.

Biology. Little definitive information known. However, it is likely to be rather fast growing and short-lived. Some evidence of root suckering but probably does not sucker aggressively. Coppicing ability unknown.

General Uses. Nothing special.

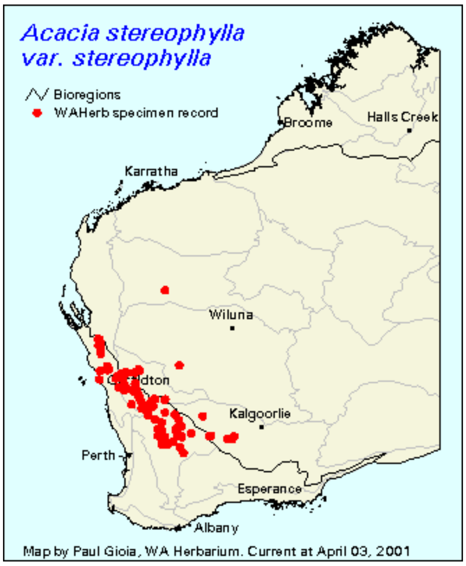
SEARCH relevance. Low priority, particularly on account of little woody biomass. Its wood characteristics, however, are likely to be similar to those of *A. microbotrya*.

Herbarium voucher (mature seed not collected)

17.5 km E of Mukinbudin on road to Bullfinch (at intersection of Davis Road), 30º 58' 20"S, 118º 22' 23"E, 26 Nov. 1999, B.R. Maslin 7954.

Acacia stereophylla var. *stereophylla*

WA Herbarium taxon ID: **15294**



Habit. Shrub or small tree (1-) 2-4 (-6) m tall with crowns 2-6 m wide, young plants multi-stemmed with dense, rounded crowns occupying 80-90% of the total plant height, mature plants either single-stemmed (branching at about 1 m above ground level) or multi-stemmed from ground level, the crown confined to the upper half of the plant; stems 4-8 cm dbh (few plant measured).

Distribution and habitat. Extends from Nerren Nerren Station south-east to Tammin and Boorabbin and is often common in the places where it occurs. Grows on sand, gravelly sand and loam; often found as a component of Wodjil communities.

Variation. *Acacia stereophylla* comprises two varieties, var. *stereophylla* and var. *cylindrata*, but only the typical variety was assessed for this project.

Affinities. Related to *A. sibina* which predominates in arid areas outside the wheatbelt (thus, not assessed for this project).

Biology. Reproduces from seed (suckering very unlikely); coppicing and pollarding ability unknown. Growth rate is probably rather slow. The small papery pods are numerous on the plants and are easily collected by hand, however, they do not dehisce readily upon collection and it can be tedious removing the seeds.

Wood. Characteristics unknown but likely to have a dark-coloured heartwood.

General Uses. *Acacia stereophylla* var. *stereophylla* is a hardy species that is suitable for revegetation, particularly on sandy sites with surface gravel. It is well-suited for soil stabilisation in disused gravel pits and for inclusion in shelterbelt plantings on light-textured soils.

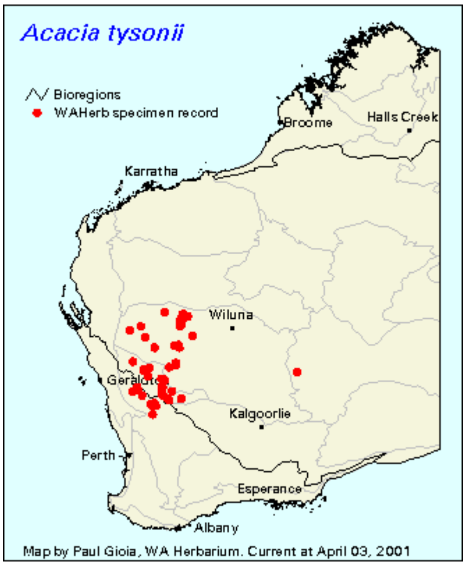
SEARCH relevance. Low priority on account of its relative low woody biomass (heartwood is probably dark-coloured like *A. acuminata* but this has not been checked) and likely slow growth rate. It could be kept in mind as a supplementary species for light textured gravelly sands in the northern and central wheatbelt.

Voucher specimen (bulk seed not collected)

"Yuna", 1 km S of Yuna township on road to Tenindewa, 28º 19' 48"S, 115º 00' 30"E, 23 Nov. 1999, B.R. Maslin 7931.

Acacia tysonii (Tyson's Wattle)

WA Herbarium taxon ID: **3586**



Habit. Compact, bushy shrub 1.5-3 m tall, maturing to small, rounded or sub-gnarled tree 4-6 m tall, single-stemmed or 2- to many-branched at ground level (trunks to about 15 cm diam. at ground level but few plants measured), crowns 1.5-4 m (or perhaps more, but data not available) across.

Distribution and habitat. Occurs from Gascoyne Junction and Peak Hill south to Morawa and Jibberding; possibly also at Lake Auld. Not common in the wheatbelt. Grows in sand, loam and clay and is usually associated with calcrete or limestone; near Kalannie it grows in hard grey-brown sandy loam around edge of a Samphire lake.

Variation. A small phyllode form occurs at Lake Auld but the species is otherwise relatively invariate.

Affinities. A member of the *A. bivenosa* group (see Chapman and Maslin 1992). *Acacia rostellifera* (see above) is the only other member of this group included in this report.

Biology. Little is know about this species. It probably has a reasonably fast growth rate and moderately long-lived (perhaps around 20+ years); its suckering, coppicing and pollarding ability is unknown. The pods and seeds are large and collection by hand is easy.

Wood. Characteristics unknown.

General Uses. Unknown.

SEARCH relevance. Low priority but could be worth considering as a ground cover for moderately saline sites, especially in the northern wheatbelt. Woody biomass is low to moderate (wood characteristics unknown) but very little is known about this uncommon, predominantly Arid Zone species. If *A. rostellifera* is adopted by SEARCH (see above) then it may be worth considering the potential of *A. tysonii*.

Seed collection (provenance name in quotes) and voucher

"Yalgoo", 102 km E of Mullewa on the road to Yalgoo, 28º 21' 35"S, 116º 31' 30"E, 23 Nov. 1999, B.R. Maslin 7941 (seed voucher).

Acacia veronica (Veronica's Wattle)

WA Herbarium taxon ID: **12675**

Note. Although *A. veronica* is included in this report it was not specifically examined in the field as part of this study.

Habit. An aromatic (phyllodes smell of Friars Balsam), erect, shapely shrub or tree usually 3–10 m high; trunk to at least 10 cm dbh (few measurements recorded).

Distribution and habitat. Endemic in the Stirling Range National Park, about. 80 km north of Albany. Sometimes abundant in the places where it occurs. Grows along watercourses in gullies at base of mountains; also found at summit of some high peaks (in sheltered sites).

Variation. Invariate except plants from higher altitudes have short phyllodes (6–8 cm long) and may be only 1.5 m high.

Affinities. The species seems not to be closely related to any other in W.A. except possibly *A. spongolitica* (Fitzgerald River, not included in this report). It seems to have some affinities with the eastern Australian species +/- arborescent species *A. baeuerlenii, A. subporosa*, *A. cognata* and *A. tessellata*. *Acacia veronica* sometimes superficially resembles *A. cyclops* (see above) but the relationship is not close.

Biology. Little definitive information known. It may have a life span of around 20-30 years and appears to have a reasonably fast growth rate. Its coppicing ability is unknown and it probably does not sucker. This species produces large quantities of pods which are easy to collect by hand.

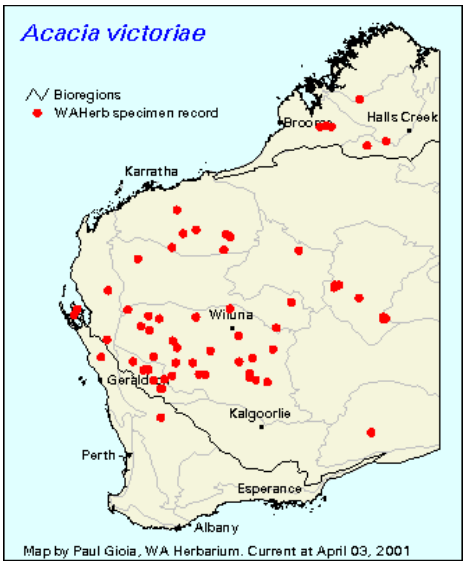
Wood. Unknown.

General uses. Unknown.

SEARCH relevance. Medium priority. This species has a number of desirable characteristics, namely, it reaches tall stature, has good form, has probably a reasonably fast growth rate (under temperate conditions at least) and produces a good amount of woody biomass. However, I am not sure that it would do well in the semiarid wheatbelt region (may be too dry for it); also, its wood characteristics are unknown. *Acacia veronica* could nevertheless be worth trying; it is in a taxonomic group quite different from all other species included in this report; it my therefore be expected to have quite different biological/ecological characteristics.

Acacia victoriae (Elegant Wattle, Bramble Wattle, and more)

WA Herbarium taxon ID: **3595**



Habit. Spreading, often straggly shrub or small tree 1.5-5 (-6) m tall, apparently reaching 9 m tall (but I have never seen it attain this height in W.A.), crowns to 6-7 m across; main stems commonly about 6 cm dbh but reaching 12-14(-18) cm (but few plants measured though), often with spiny stipules or remnants of twiggy branchlets persisting on the stems (making collection uncomfortable at times), young plants quite prickly; readily root suckering and sometimes forming thickets.

Distribution and habitat. Widespread in arid and sub-tropical areas of all mainland States of Australia except Victoria (where it is confined to the extreme north-west of that State). Over its extensive range *A. victoriae* occurs in a variety of habitats but is commonly found in clay or loam on alluvial flats (subsp. *arida* occurs on sand). Tolerant of lime, saline and clay soils (Simmons 1987). Details of its ecology are given in Turnbull (1986) and Fowler and Fox (1995).

Variation. In W.A. *A. victoriae* is relatively invariate, however, across its entire geographic range the species is quite polymorphic, especially in phyllode shape and size. The taxonomic status of a hairy variant, described as *A. victoriae* subsp. *arida*, requires further investigation: this variant occurs in a somewhat restricted geographic area in southern Northern Territory, northern South Australia, western New South Wales and south-west Queensland.

Affinities. This species along with nine close relatives comprise the "*A. victoriae* group" whose centre of diversity is located in W.A. (see Maslin 1992 for discussion). *Acacia victoriae* is not far removed taxonomically from *A. murrayana* (see above).

Biology. An adaptable, fast-growing, relatively short-lived species (10-15 years) which is fire-tolerant (when young) and moderately frost tolerant but is killed by severe drought. It readily coppices and is known to sucker (Thomson 1992). Pods are produced in great profusion and are easily collected by hand (shaking/threshing); the pods may be shed unopened or may open on the plant with the seeds still attached by the funicle. Arboretum plants may be susceptible to root rot (Fowler and Fox 1995). In some areas plant numbers may increase markedly during a succession of wet seasons and the species can become a nuisance, especially around watering points.

Wood. Air dry density: 804 kg/m^3, based on 7 samples tested (G. Pronk, pers. comm.).

General Uses. *Acacia victoriae* is a fast growing, salt tolerant species that is often used in land reclamation and mine site rehabilitation work in arid areas of Western Australia, particularly the goldfields region. Listed as highly suitable for the production of fuel wood and charcoal by Thomson *et al.* (1994). Its suckering ability enhances its utility for soil stabilisation purposes. *Acacia victoriae* is a useful fodder plant for arid and semi-arid areas but, according to Petherham and Kok (1983) it can be killed by severe browsing (recovers well after light grazing though). According to Mitchell and Wilcox (1994) animals readily eat the flowers and browse the foliage of this species during dry periods; the crude protein content is about 12% and digestibility 48%. *Acacia victoriae* is the main species of *Acacia* seed used in the “bush tucker” industry at present. The seeds of this species have good nutritional characteristics and they were commonly used as a food by aborigines (see Maslin *et al.* 1998 for more details). Further information on the utilisation of *A. victoriae* is provided in Hall *et al.* (1981), Turnbull (1986) and Thomson (1992).

SEARCH relevance. Medium priority. *Acacia victoriae* has a number of desirable features, including fast growth rate, salt tolerance, an ability of coppice and to produce reasonable amounts of woody biomass. Seed production for human food could be a minor secondary product from this species (although there is an established market for *A. victoriae* seed there are issues relating to wild harvest vs. on-farm production that would come into play if large-scale production occurred). These features are not dissimilar to its relative, *A. murrayana* (which is less salt tolerant but which probably produces more woody biomass). For SEARCH the main drawbacks of *A. victoriae* could be its spiny/thorny nature (particularly on young plants although even stems of mature plants can have persistent small spiny stipules); also, it is not know if its wood has desirable characteristics for MDF production. Its propensity to sucker may or may not be advantageous, it depends whether or not this attribute is required for the system in which it is placed. It is likely that this species would do best in the northern wheatbelt (I doubt that it would survive well south of the Great Eastern Highway).

Seed collections (provenance name in quotes) and vouchers

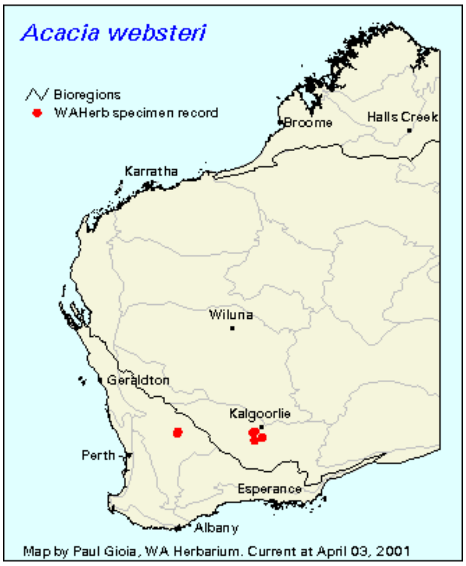
"Gabyon", 96.5 km E of Mullewa on the road to Yalgoo, 28º 21' 50"S, 116º 28' 15"E, 23 Nov. 1999, B.R. Maslin 7940 (seed immature); mature seed subsequently collected from this population by J. Carslake on 9 Dec. 1999.

"Wolla Wolla" 96.5 km E of Mullewa on the road to Yalgoo, 9 Dec. 1999, J. Carslake (seed collected; no voucher taken).

"Yalgoo", 107 km E of Mullewa on the road to Yalgoo, 10 Dec. 1999, J. Carslake (seed collected; no voucher taken).

Note: Populations of this species were found at two other localities but seed not collected, namely, 122.7 km E of Mullewa, and 4.9 km E of Mt Magnet.

Acacia websteri (Webster's Wattle)



WA Herbarium taxon ID: **3600**

Habit. Obconic tree or tall shrub mostly 3-5 m high and dividing just above ground level into rather straight, sparingly divided main stems with dbh 9-13 cm, well-developed plants can reach 6-7 m high with dbh to 18 cm; crowns bushy.

Distribution and habitat. Known only from the Bencubbin and Coolgardie - Kambalda areas. Locally abundant in suitable habitats just south of Coolgardie. Grows in red loam or clay-loam along diffuse drainage lines or in shallow depressions.

Variation. Invariate.

Affinities. Most closely allied to *A. symonii* (Arid Zone of W.A. and S.A.; not included in this report).

Biology. Probably slow growing and long lived (perhaps 50+ years). Unlikely to sucker; coppicing/pollarding ability unknown. Pods few and scattered over plants, making collection difficult.

Wood. Hard; heartwood dark brown.

General Uses. Unknown.

SEARCH relevance. Low priority. Although this species has good form and produces a reasonable amount of woody biomass it is probably slow growing, also its dark coloured heartwood would make it unsuited to MDF production. Furthermore, in nature it has a limited ecological range and its main area of occurrence is outside the wheatbelt. Under cultivation it is possible that this species would behave similar to Jam (*A. acuminata*), although it may require more water to do well.

Herbarium voucher (seed not collected)

7.5 km S of Southern Cross on road to Queen Victoria Rock, 31° 00' 41"S, 121° 06' 51"E, 25 June 2000, B.R. Maslin 7970.

References

Anderson, D.M.W. and Bell, P.C. (1976). Partial structural studies of four *Acacia* gum exudates of the series Phyllodinieae. *Phytochemistry* 15: 301-303.

Anon. (1955). *Acacia cyanophylla* as a forage species. Report of Forestry Department of Cyprus 1954 (66).

Aswathappa, N., Marcar, N.E. and Thomson, L.A.J. (1987). Salt tolerance of Australian tropical and sub-tropical acacias. In: Turnbull, J.W. (ed.) *Australian Acacias in developing Countries.* ACIAR Proceedings No. 16, pp. 70-73.

Ayensu, E.S. *et al.* (1980). *Firewood Crops. Shrub and Tree Species for Energy Production.* (National Academy of Sciences: Washington.)

Barrett, D.R. (1995). Review of the ecological characteristics of *Acacia acuminata* Benth. *Mulga Research Centre Journal* 12: 31-38.

Bootle, K.R. (1983). *Wood in Australia. Types, properties and uses*. (McGraw-Hill Book Company: Sydney.)

Boucher, C. and Stirton, C.H. (1980). Port Jackson - *Acacia saligna*. In: Stirton, C.H. (ed) *Plant Invaders: Beautiful, but dangerous,* pp. 60-63. (The Department of Nature and Environmental Conservation of the Cape Provincial Administration: Cape Town: Republic of South Africa.)

Chapman, A.R. and Maslin, B.R. (1992). *Acacia* Miscellany 5. A review of the *A. bivenosa* group (Leguminosae: Mimosoideae: Section Phyllodineae). *Nuytsia* 8: 249-283.

Charlson, A.J., Nunn, J.R. and Stephen, A.M. (1955). The composition of *Acacia cyanophylla* gum. *Journal Chemical Society* 269-273 (University of Cape Town.)

Clarke, M. (c. 1998). The West Morawa Catchment revegetation report. (Internal AgWA report compiled by A. Cox)

Craig, G.F., Bell, D.T. and Atkins, C.A. (1990). Response to salt and waterlogging stress of ten taxa of *Acacia* selected from naturally saline areas of Western Australia. *Austral. J. Bot.* 38: 619-630.

Craig, G.F., Bell, D.T. and Atkins, C.A. (1991). Nutritional characteristics of selected species of *Acacia* growing in naturally saline areas of Western Australia. *Austral. J. Exper. Agric.* 31: 341-345.

Crompton, H. (1991). NFTA Highlight No. *Acacia saligna* - for dryland fodder and soil stabilisation. (Nitrogen Fixing Tree Association: Hawaii.)

Doran, J. and Turnbull, J. (1997). *Australian trees and shrubs: species for land rehabilitation and farm planting in the tropics*. ACIAR Monograph No. 24. p.384. (Australian Centre for International Agricultural Research: Canberra.)

El-Lakany, M.H. (1987). Use of Australian acacias in north Africa. In: Turnbull, J.W.(ed) *Australian Acacias in Developing Countries*, pp. 116-117. (ACIAR Proceedings No. 16: Canberra.)

Elliot, W.R. and Jones, D.L. (1982). *Encyclopaedia of Australian Plants suitable for cultivation.* vol. 2. (Lothian Publishing Company).

Fahn, A. (1959). Xylem structure and annual rhythm of development in trees and shrubs of the desert. 111. *Eucalyptus camaldulensis and Acacia cyanophylla. Bulletin Research Council of Israel* 7D: 122-131.

Fowler, K.M. and Fox, J.E.D. (1995). Review of the ecological characteristics of *Acacia victoriae* Benth. *Mulga Research Centre Journal* 12: 65–71.

Fox, J.E.D. (1985). Ecological notes on *Acacia* species: Acacia cyclops. *Mulga Research Centre Journal* 8: 59-68.

Fox, J.E.D. (1995). A review of the ecological characteristics of *Acacia saligna* (Labill.) H. Wendl. *Mulga Research Centre Journal* 12: 39-56.

Gardner, C.A. (1957). The Manna Wattle (*Acacia microbotrya* Benth.). *The Journal of Agriculture of Western Australia* 6(3): 325-327.

Gill, M. (1979). Three weeks in south-west W.A., August 1979. (Unpublished report: Maslin library.)

Gill, M. (1985). *Acacia cyclops* G. Don (Leguminosae – Mimosoideae) in Australia: Distribution and Dispersal. *J. Roy. Soc. W. Austral*. 67(2): 59-65.

Goor, A.Y. and Barney, C.W. (1968). *Forest tree planting in arid zones*. (Ronald Press: New York.)

Hall, N., Turnbull, J.W. and Martensz, P.N. (1981). *Acacia victoriae* Benth. CSIRO Forest Research, Australian Acacias No. 14 (Information leaflet).

Johnson, M.B. (1996). Species of Interest: *Acacia jennerae* - a Eucalyptus mimic. In: ARIDUS, Vol. 8, No.2. Bulletin of the Desert Legume (Program of the Boyce Thompson South-western Arboretum and the University of Arizona.)

Langkamp, P. and Plaisted, M. (1987). Perspectives on the Use of Native Plant Seed in the Australian Mining Industry. In P. Langkamp (ed) *Germination of Australian Native Plant Seed*, pp. 107-114. (Inkata Press: Sydney.)

Latz, P.K. (1995) *Bushfires and bushtucker: Aborigines and plants in central Australia*. (IAD Press: Alice Springs.)

Lefroy, E.C., Hobbs, R.J. and Atkins, L.J. (1991). *Revegetation guide to the central Wheatbelt*. (Agriculture W.A.: Western Australia.)

Macar, N., Crawford, D., Leppert, P., Jovanovic T., Floyd, R. and Farrow, R. (1995). *Trees for Saltland: a guide to selecting native species for Australia.* (CSIRO, Division of Forestry: Australia.)

Maiden, J.H. (1889). *The useful native plants of Australia.* (Technological Museum of New South Wales: Sydney.)

Martin, V. (1974). Dyemaking with Australian flora. (Rigby: Australia.)

Maslin, B.R. (1990). *Acacia* Miscellany 4. Three new Western Australian species with affinities to *A. wilhelmiana* (Leguminosae: Mimosoideae: section Plurinerves) from Western Australia. *Nuytsia* 7(2): 221-228.

Maslin, B.R. (1992). *Acacia* Miscellany 6. A review of *Acacia victoriae* and related species (Leguminosae: Mimosoideae: Section Phyllodineae). *Nuytsia* 8: 285-309.

Maslin, B.R. (1995). *Acacia* miscellany 14. Taxonomy of some Western Australian "Uninerves-Racemosae" species (Leguminosae: Mimosoideae: section Phyllodineae). *Nuytsia* 10(2): 181-203.

Maslin, B.R., Conn, E.E. and Dunn, J.E. (1987). Cyanogenic Australian species of *Acacia*: A preliminary account of their toxic potential. pp. 107-111. In: Turnbull, J.W. (ed.) *Australian Acacias in Developing Countries*. Proceedings of an international workshop held at the Forestry Training Centre, Gympie, Qld, Australia, 4-7 August 1986.

Maslin, B.R., Thomson, L.A.J., McDonald, M.W. and Hamilton-Brown, S. (1998). Edible Wattle Seeds of Southern Australia. A review of species for semi-arid regions of southern Australia. (CSIRO, Forestry and Forest Products, Australian Tree Seed Centre: Canberra.)

Maslin, B.R., Byrne, M., Coates, D., Broadhurst, L., Coleman, H. and Macdonald, B. (1999). The *Acacia acuminata* (Jam) group: an analysis of variation to aid Sandalwood (*Santalum spicatum*) plantation research. (Internal CALM Report.)

McDowall, M.A. (1997). Some useful acacias flowering in Autumn. SGAP Acacia Study Group Newsletter 78: 6.

Meagher, S. (1974). The food resources of the Aborigines of the south-west of Western Australia. *Records of the Western Australian Museum* 3 (1):14–65.

Michaelides, E.D. (1979). Mini-monograph on *Acacia cyanophylla*. Invited paper to technical consultation on fast-growing plantation broadleaved trees for mediterranean and temperate zones held in Lisbon, Portugal 16-20 October. FO: FGB-79-6/1. (FAO: Rome.)

Milton, S.J. and Siegfried, W.R. (1981). Above ground biomass of Australian acacias in the southern Cape, South Africa. *Journal of South African Botany* 47: 701-716.

Mitchell, A.A. and Wilcox, D.G. (1994). *Arid shrubland plants of Western Australia*. ed. 2 (University of Western Australia Press in association with the Department of Agriculture, Western Australia: Perth.)

Nakos, G. (1977). Acetylene reduction (N2 fixation) by nodules of *Acacia cyanophylla. Soil Biology and Biochemistry* 9: 131-133.

Newbey, K.R. (1982). Growing Trees on Western Australian Wheatbelt Farms. (Farm Management Foundation of Australia).

Petheram, R.J. and Kok, B. (1983). Plants of the Kimberley region of Western Australia. (University of Western Australia Press for Rangeland Management Branch, Department of Agriculture, Western Australia: Perth.)

Roughley, R.J. (1987). *Acacia* and their root-nodule bacteria. In J.W. Turnbull (ed.) *Australian Acacias in developing countries. Proceedings of an international workshop held at the Forestry Training Centre, Gympie, Queensland, Australia, 4-7 August 1986.* Australian Centre for International Agricultural Research Proceedings No. 16, pages 45-49.

Rusbridge, S., Bradley, G. and Bradley, G. (1996). *Plant identification handbook for land rehabilitation in the goldfields of Western Australia*. (Goldfields Land Rehabilitation Group: Kalgoorlie.)

Simmons, M.H. (1981). Acacias of Australia. (Nelson: Melbourne.)

Simmons, M.H. (1987). Growing Acacias (Kangaroo Press.)

Stirton, C.H. (1978). *Plant Invaders: Beautiful, But Dangerous*. (The Department of Nature and Environmental Conservation of the Cape Provincial Administration: Cape Town.)

Thomson, L.A.J. (1992). Australia's subtropical dry-zone *Acacia* species with human food potential. In House, A.P.N. and Harwood, C.E. (eds), *Australian Dry-Zone Acacias for Human Food*, pp. 37–53. (Australian Tree Seed Centre, CSIRO Division of Forestry: Canberra.)

Thomson, L.A.J., Turnbull, J.W. & Maslin, B.R. (1994). The utilization of Australian species of *Acacia*, with particular reference to those of the subtropical dry zone. J. Arid Environments 27: 279-295.

Turnbull, J.W. (ed.) (1986). *Multipurpose Australian trees and shrubs. Lesser-known species for fuelwood and agroforestry*. (Australian Centre for International Agricultural Research: Canberra.)

Van den Berg, M.A. (1980a). Natural enemies of *Acacia cyclops* A. Cunn. ex G. Don and A. saligna (Labill.) Wendl. in Western Australia. I. Lepidoptera. *Phytophlactica* 12: 165-167.

Van den Berg, M.A. (1980b). Natural enemies of *Acacia cyclops* A. Cunn. ex G. Don and A. saligna (Labill.) Wendl. in Western Australia. II. Coleoptera. *Phytophlactica* 12: 169-171.

Van den Berg, M.A. (1980c). Natural enemies of *Acacia cyclops* A. Cunn. ex G. Don and A. saligna (Labill.) Wendl. in Western Australia. III. Hemiptera. *Phytophlactica* 12: 223-226.

Vercoe, T.K. (1989). Fodder value of selected Australian tree and shrub species. Pages 95-100 in Borland, D.J. (ed.) *Trees for the tropics*. ACIAR Monograph No. 10.

Whibley, D.J.E. and D.E. Symon (1992). *Acacias of South Australia*. (South Australian Government Printer: Adelaide.)

Wilcox, D.G., Lefroy, E.C., Stoneman, T.C., Schoknecht, N.R. and Griffin, E.A. (1996). *Trees and shrubs for the Midlands and Northern Wheatbelt*. (Agriculture Western Australia: Western Australia.)

Search Report

Appendix 11

Wood coring data – all cores

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Acacia acuminata	JC	Dumbleyung - Lloyd	4	12	100%	67	7.6		8.2		1077		
Acacia aestivalis	Trip 9	Big Springs Road	2	12	100%	37	4.2	5.2	3.8	1243	918	26%	35%
Acacia aestivalis	Trip 9	Big Springs Road	3	12	100%	43	4.9	5.9	4.3	1213	892	26%	36%
Acacia aestivalis	Trip 9	Big Springs Road	4	12	100%	33	3.7	4.7	3.6	1259	975	23%	29%
Acacia aestivalis	Trip 9	Big Springs Road	5	12	100%	34	3.8	4.7	3.4	1222	895	27%	37%
Acacia aestivalis	Trip 9	Big Springs Road	6	12	100%	34	3.8	4.9	3.6	1274	923	28%	38%
Acacia aestivalis	Trip 9	Big Springs Road	1h	12	100%	36	4.1	4.8	3.5	1179	847	28%	39%
Acacia aestivalis	Trip 9	Big Springs Road	1l	12	100%	47	5.3	6.3	4.5	1185	841	29%	41%
Acacia aestivalis	Trip 9	Big Springs Road	1m	12	100%	38	4.3	5.2	3.7	1210	854	29%	42%
Acacia aestivalis	Trip 9	Squires Home	2	12	100%	33	3.7	5.1	3.5	1366	943	31%	45%
Acacia aestivalis	Trip 9	Squires Home	3	12	100%	34	3.8	5.4	3.8	1404	991	29%	42%
Acacia aestivalis	Trip 9	Squires Home	4	12	100%	33	3.7	5.0	3.6	1340	957	29%	40%
Acacia aestivalis	Trip 9	Squires Home	5	12	100%	45	5.1	6.9	5.0	1356	990	27%	37%
Acacia aestivalis	Trip 9	Squires Home	6	12	100%	32	3.6	5.0	3.6	1382	989	28%	40%
Acacia aestivalis	Trip 9	Squires Home	1h	12	100%	37	4.2	5.4	4.0	1290	965	25%	34%
Acacia aestivalis	Trip 9	Squires Home	1l	12	100%	42	4.8	6.4	4.8	1347	1002	26%	34%
Acacia aestivalis	Trip 9	Squires Home	1m	12	100%	39	4.4	5.7	4.3	1292	977	24%	32%
Acacia aff. redolens	JC	Burdett	1	12	100%	101	11.4		8.5		741		
Acacia aff. redolens	JC	Burdett	2	12	100%	57	6.4		5.2		805		
Acacia aff. redolens	JC	Burdett	3	12	100%	78	8.8		7.0		797		
Acacia aff. redolens	JC	Scaddan	1	12	100%	50	5.7		4.1		732		
Acacia aff. redolens	JC	Scaddan	2	12	100%	~	~		~		~		
Acacia aff. redolens	JC	Scaddan	3	12	100%	92	10.4		8.7		835		
Acacia aneura subsp. (?)	JC	Mullewa - Critch	30	12	100%	76	8.6		8.2		952		
Acacia anthochaera	JC	Kalannie - roadside	18	12	100%	77	8.7		9.1		1050		
Acacia anthochaera	Trip 9	Grants	1	12	100%	30	3.4	4.9	3.7	1444	1099	24%	31%
Acacia anthochaera	Trip 9	Grants	2	12	100%	23	2.6	3.7	2.7	1422	1030	28%	38%
Acacia anthochaera	Trip 9	Grants	3	12	100%	23	2.6	3.6	2.6	1384	1007	27%	37%
Acacia b (?)	JC	Badgingarra - Raffin	1	12	?	47	5.3		4.7		875		
Acacia b (?)	JC	Badgingarra - Raffin	2	12	100%	61	6.9		6.2		896		
Acacia beauverdiana	Trip 9	Squires windbreak	1	12	100%	31	3.5	4.3	3.6	1226	1021	17%	20%
Acacia beauverdiana	Trip 9	Squires windbreak	2	12	100%	64	7.2	9.2	7.8	1271	1080	15%	18%
Acacia beauverdiana	Trip 9	Squires windbreak	3	12	100%	36	4.1	5.1	4.3	1253	1061	15%	18%
Acacia blakelyi	Trip 7	Brand 13	1	12	100%	50	5.7	5.5	3.4	973	596	39%	63%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Acacia blakelyi	Trip 7	Brand 13	2	12	100%	44	5.0	5.6	3.5	1125	703	38%	60%
Acacia blakelyi	Trip 7	Brand 13	3	12	100%	43	4.9	5.1	3.1	1049	644	39%	63%
Acacia blakelyi	Trip 9	North Road	2	12	100%	29	3.3	4.0	2.3	1220	689	44%	77%
Acacia blakelyi	Trip 9	North Road	3	12	100%	34	3.8	4.5	2.6	1170	666	43%	76%
Acacia blakelyi	Trip 9	North Road	4	12	100%	26	2.9	3.5	2.3	1190	789	34%	51%
Acacia blakelyi	Trip 9	North Road	5	12	100%	28	3.2	3.5	2.3	1105	714	35%	55%
Acacia blakelyi	Trip 9	North Road	6	12	100%	32	3.6	3.9	2.5	1078	682	37%	58%
Acacia blakelyi	Trip 9	North Road	1h	12	100%	30	3.4	3.7	2.3	1091	672	38%	62%
Acacia blakelyi	Trip 9	North Road	1l	12	100%	43	4.9	5.8	3.6	1193	732	39%	63%
Acacia blakelyi	Trip 9	North Road	1m	12	100%	37	4.2	4.8	3.1	1147	746	35%	54%
Acacia blakelyi	Trip 9	Port Gregory Road	2	12	100%	45	5.1	5.7	3.7	1120	723	35%	55%
Acacia blakelyi	Trip 9	Port Gregory Road	3	12	100%	34	3.8	4.1	2.5	1066	648	39%	65%
Acacia blakelyi	Trip 9	Port Gregory Road	4	12	100%	39	4.4	4.6	2.9	1043	657	37%	59%
Acacia blakelyi	Trip 9	Port Gregory Road	5	12	100%	31	3.5	3.5	2.3	998	656	34%	52%
Acacia blakelyi	Trip 9	Port Gregory Road	6	12	100%	31	3.5	4.2	2.7	1198	764	36%	57%
Acacia blakelyi	Trip 9	Port Gregory Road	1h	12	100%	30	3.4	3.0	1.9	884	551	38%	60%
Acacia blakelyi	Trip 9	Port Gregory Road	1l	12	100%	45	5.1	5.4	3.5	1061	678	36%	57%
Acacia blakelyi	Trip 9	Port Gregory Road	1m	12	100%	38	4.3	4.1	2.8	954	640	33%	49%
Acacia brumalis	JC	Kalannie - Hudson	9	12	100%	77	8.7		7.7		884		
Acacia brumalis	JC	Kalannie - Hudson	10	12	100%	63	7.1		6.3		881		
Acacia brumalis	Trip 9	Hudsons	2	12	100%	46	5.2	6.2	4.3	1192	830	30%	44%
Acacia brumalis	Trip 9	Hudsons	3	12	100%	47	5.3	6.5	4.9	1223	918	25%	33%
Acacia brumalis	Trip 9	Hudsons	4	12	100%	46	5.2	5.9	4.3	1134	819	28%	38%
Acacia brumalis	Trip 9	Hudsons	5	12	100%	44	5.0	5.6	4.0	1125	800	29%	41%
Acacia brumalis	Trip 9	Hudsons	6	12	100%	36	4.1	5.0	3.6	1228	889	28%	38%
Acacia brumalis	Trip 9	Hudsons	1h	12	100%	38	4.3	4.9	3.7	1140	852	25%	34%
Acacia brumalis	Trip 9	Hudsons	1l	12	100%	55	6.2	7.1	5.3	1141	858	25%	33%
Acacia brumalis	Trip 9	Hudsons	1m	12	100%	43	4.9	5.7	4.2	1172	857	27%	37%
Acacia burkittii	Trip 9	Tenendiwa	1	12	100%	41	4.6	6.6	4.9	1423	1055	26%	35%
Acacia burkittii	Trip 9	Tenendiwa	2	12	100%	35	4.0	5.5	3.9	1389	978	30%	42%
Acacia burkittii	Trip 9	Tenendiwa	3	12	100%	62	7.0	9.7	6.9	1383	984	29%	41%
Acacia citrinoviridis	JC	Mullewa - Critch	31	12	100%	67	7.6		8.3		1094		
Acacia conniana	JC	?	1	12	100%	52	5.9		4.3		723		
Acacia conniana	JC	?	2	12	100%	65	7.4		5.8		782		

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Acacia conniana	JC	?	3	12	100%	65	7.4		5.8		784		
Acacia coolgardiensis	JC	Kalannie - Hudson	7	12	100%	81	9.2		9.3		1013		
Acacia coolgardiensis subsp. effusa	Trip 9	Grants	1	12	100%	24	2.7	3.7	2.6	1363	962	29%	42%
Acacia coolgardiensis subsp. effusa	Trip 9	Grants	2	12	100%	37	4.2	5.5	4.3	1314	1030	22%	28%
Acacia coolgardiensis subsp. effusa	Trip 9	Grants	3	12	100%	26	2.9	4.1	3.3	1394	1105	21%	26%
Acacia coolgardiensis subsp. latior	Trip 9	Irwin North	1	12	100%	35	4.0	5.5	4.6	1389	1157	17%	20%
Acacia coolgardiensis subsp. latior	Trip 9	Irwin North	2	12	100%	26	2.9	4.2	3.4	1428	1153	19%	24%
Acacia coolgardiensis subsp. latior	Trip 9	Irwin North	3	12	100%	34	3.8	5.2	4.4	1352	1139	16%	19%
Acacia cyclops	JC	?	1	12	100%	52	5.9		4.8		808		
Acacia cyclops	JC	?	2	12	100%	80	9.0		7.1		780		
Acacia cyclops	JC	Tagon Beach	1	12	100%	114	12.9		10.2		794		
Acacia cyclops	JC	Tagon Beach	2	12	100%	112	12.7		10.5		826		
Acacia enervia	Trip 9	Odea	1	12	100%	31	3.5	5.1	3.9	1455	1124	23%	29%
Acacia enervia	Trip 9	Odea	2	12	100%	33	3.7	5.4	4.2	1447	1125	22%	29%
Acacia enervia	Trip 9	Odea	3	12	100%	22	2.5	3.8	3.1	1527	1226	20%	25%
Acacia eremaea	Trip 9	Kalannie East	1	12	100%	29	3.3	4.6	3.4	1403	1034	26%	36%
Acacia eremaea	Trip 9	Kalannie East	2	12	100%	28	3.2	4.4	3.5	1389	1112	20%	25%
Acacia eremaea	Trip 9	Kalannie East	3	12	100%	26	2.9	4.1	3.3	1394	1122	20%	24%
Acacia fauntleroyi	Trip 9	Barbalin Rock	2	12	100%	35	4.0	4.4	3.5	1112	877	21%	27%
Acacia fauntleroyi	Trip 9	Barbalin Rock	3	12	100%	33	3.7	4.7	3.6	1259	962	24%	31%
Acacia fauntleroyi	Trip 9	Barbalin Rock	4	12	100%	27	3.1	3.6	2.7	1179	894	24%	32%
Acacia fauntleroyi	Trip 9	Barbalin Rock	5	12	100%	42	4.8	5.1	4.2	1074	876	18%	23%
Acacia fauntleroyi	Trip 9	Barbalin Rock	6	12	100%	38	4.3	5.1	3.9	1187	914	23%	30%
Acacia fauntleroyi	Trip 9	Barbalin Rock	1h	12	100%	33	3.7	4.5	3.6	1206	962	20%	25%
Acacia fauntleroyi	Trip 9	Barbalin Rock	1l	12	100%	39	4.4	5.5	4.4	1247	986	21%	26%
Acacia fauntleroyi	Trip 9	Barbalin Rock	1m	12	100%	35	4.0	4.8	3.9	1213	983	19%	23%
Acacia inceana subsp. conformis	Trip 9	Black Road II	1	12	100%	28	3.2	4.6	3.6	1453	1134	22%	28%
Acacia inceana subsp. conformis	Trip 9	Black Road II	2	12	100%	25	2.8	4.1	3.5	1450	1231	15%	18%
Acacia inceana subsp. conformis	Trip 9	Black Road II	3	12	100%	22	2.5	3.7	2.8	1487	1105	26%	35%
Acacia jennerae	Trip 9	Grants	2	12	100%	26	2.9	3.8	2.8	1292	952	26%	36%
Acacia jennerae	Trip 9	Grants	3	12	100%	26	2.9	4.1	2.9	1394	979	30%	42%
Acacia jennerae	Trip 9	Grants	4	12	100%	21	2.4	3.1	2.2	1305	918	30%	42%
Acacia jennerae	Trip 9	Grants	5	12	100%	47	5.3	7.2	5.4	1355	1022	25%	33%
Acacia jennerae	Trip 9	Grants	6	12	100%	40	4.5	5.6	4.0	1238	886	28%	40%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Acacia jennerae	Trip 9	Grants	1h	12	100%	31	3.5	4.3	3.2	1226	901	27%	36%
Acacia jennerae	Trip 9	Grants	1l	12	100%	35	4.0	5.3	3.7	1339	945	29%	42%
Acacia jennerae	Trip 9	Grants	1m	12	100%	31	3.5	4.3	3.2	1226	901	27%	36%
Acacia jibberdingensis	Trip 9	Squires Granite	2	12	100%	27	3.1	3.3	2.2	1081	734	32%	47%
Acacia jibberdingensis	Trip 9	Squires Granite	3	12	100%	34	3.8	3.9	2.8	1014	728	28%	39%
Acacia jibberdingensis	Trip 9	Squires Granite	4	12	100%	25	2.8	3.7	2.5	1309	898	31%	46%
Acacia jibberdingensis	Trip 9	Squires Granite	5	12	100%	23	2.6	2.9	1.8	1115	704	37%	58%
Acacia jibberdingensis	Trip 9	Squires Granite	6	12	100%	28	3.2	4.1	2.6	1295	821	37%	58%
Acacia jibberdingensis	Trip 9	Squires Granite	1h	12	100%	31	3.5	3.8	2.5	1084	719	34%	51%
Acacia jibberdingensis	Trip 9	Squires Granite	1l	12	100%	42	4.8	5.7	3.7	1200	783	35%	53%
Acacia jibberdingensis	Trip 9	Squires Granite	1m	12	100%	39	4.4	5.0	3.4	1134	760	33%	49%
Acacia lasiocalyx	JC	Dumbleyung - Lloyd	1	12	100%	117	13.2		7.9		593		
Acacia lasiocalyx	JC	Quairading	1	12	100%	96	10.9		7.3		668		
Acacia lasiocalyx	JC	Quairading	2	12	100%	~	~		~		~		
Acacia lasiocalyx	JC	Quairading	3	12	100%	77	8.7		5.3		611		
Acacia lasiocalyx	Trip 5	The Rocks	2	12	100%	49	5.5	6.6	4.8	1191	870	27%	37%
Acacia lasiocalyx	Trip 5	The Rocks	3	12	100%	77	8.7	10.0	7.5	1148	861	25%	33%
Acacia lasiocalyx	Trip 5	The Rocks	4	12	100%	40	4.5	5.3	4.1	1172	900	23%	30%
Acacia lasiocalyx	Trip 5	The Rocks	5	12	100%	61	6.9	7.5	5.4	1087	780	28%	39%
Acacia lasiocalyx	Trip 5	The Rocks	6	12	100%	41	4.6	5.1	3.8	1100	828	25%	33%
Acacia lasiocalyx	Trip 5	The Rocks	1h	12	100%	41	4.6	5.5	4.2	1186	912	23%	30%
Acacia lasiocalyx	Trip 5	The Rocks	1l	12	100%	84	9.5	10.7	8.1	1126	852	24%	32%
Acacia lasiocalyx	Trip 5	The Rocks	1m	12	100%	54	6.1	7.1	5.4	1163	879	24%	32%
Acacia lasiocalyx	Trip 6	Copping Road	1	12	100%	38	4.3	5.1	3.4	1187	798	33%	49%
Acacia lasiocalyx	Trip 6	Copping Road	2	12	100%	41	4.6	5.1	3.7	1100	794	28%	39%
Acacia lasiocalyx	Trip 6	Copping Road	4	12	100%	50	5.7	6.6	4.8	1167	854	27%	37%
Acacia lasiocalyx	Trip 6	Copping Road	5	12	100%	56	6.3	5.4	3.9	853	616	28%	38%
Acacia lasiocalyx	Trip 6	Copping Road	6	12	100%	97	11.0	10.7	7.7	975	705	28%	38%
Acacia lasiocalyx	Trip 6	Copping Road	3h	12	100%	36	4.1	3.7	2.7	909	668	26%	36%
Acacia lasiocalyx	Trip 6	Copping Road	3l	12	100%	76	8.6	8.9	6.6	1035	773	25%	34%
Acacia lasiocalyx	Trip 6	Copping Road	3m	12	100%	45	5.1	5.2	3.8	1022	749	27%	36%
Acacia lasiocalyx	Trip 9	Shire boundary	2	12	100%	36	4.1	4.8	3.2	1179	776	34%	52%
Acacia lasiocalyx	Trip 9	Shire boundary	3	12	100%	41	4.6	5.3	3.8	1143	809	29%	41%
Acacia lasiocalyx	Trip 9	Shire boundary	4	12	100%	41	4.6	4.7	3.4	1014	725	29%	40%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Acacia lasiocalyx	Trip 9	Shire boundary	5	12	100%	41	4.6	5.5	3.4	1186	731	38%	62%
Acacia lasiocalyx	Trip 9	Shire boundary	6	12	100%	36	4.1	5.2	3.2	1277	796	38%	60%
Acacia lasiocalyx	Trip 9	Shire boundary	1h	12	100%	32	3.6	3.7	2.5	1022	677	34%	51%
Acacia lasiocalyx	Trip 9	Shire boundary	1l	12	100%	47	5.3	5.3	3.6	997	681	32%	46%
Acacia lasiocalyx	Trip 9	Shire boundary	1m	12	100%	40	4.5	4.4	3.1	973	681	30%	43%
Acacia microbotrya var. borealis	JC	Dumbleyung - Lloyd	2	12	100%	70	7.9		6.8		853		
Acacia microbotrya var. borealis	JC	Dumbleyung - Lloyd	3	12	51%	27	3.0		2.7		911		
Acacia microbotrya var. borealis	Trip 9	Wattoning West Road	1	12	100%	33	3.7	4.9	3.5	1313	946	28%	39%
Acacia microbotrya var. borealis	Trip 9	Wattoning West Road	2	12	100%	39	4.4	4.6	3.3	1043	757	27%	38%
Acacia microbotrya var. borealis	Trip 9	Wattoning West Road	3	12	100%	39	4.4	5.9	4.0	1338	898	33%	49%
Acacia microbotrya var. microbotrya	JC	Kellerberrin - Scott	1	12	100%	54	6.1		5.0		817		
Acacia microbotrya var. microbotrya	JC	Kellerberrin - Scott	2	12	100%	63	7.1		6.7		933		
Acacia microbotrya var. microbotrya	JC	Kellerberrin - Scott	3	12	100%	65	7.4		6.1		828		
Acacia microbotrya var. microbotrya	JC	Kellerberrin - Scott	4	12	100%	47	5.3		4.4		832		
Acacia microbotrya var. microbotrya	JC	Kellerberrin - Scott	7	12	51%	63	7.1		6.1		853		
Acacia microbotrya var. microbotrya	JC	Muntadgin	1	12	?	85	9.6		9.1		949		
Acacia microbotrya var. microbotrya	JC	Muntadgin	2	12	100%	66	7.5		7.2		959		
Acacia microbotrya var. microbotrya	JC	Muntadgin	3	12	100%	101	11.4		10.8		943		
Acacia microbotrya var. microbotrya	JC	Narrogin - Ag. school	1	12	100%	85	9.6		7.7		808		
Acacia microbotrya var. microbotrya	JC	Narrogin - Ag. school	2	12	100%	78	8.8		7.0		795		
Acacia microbotrya var. microbotrya	JC	Narrogin - Ag. school	3	12	100%	94	10.6		8.4		790		
Acacia microbotrya var. microbotrya	Trip 4	Doley's	1	12	100%	60	6.8	7.3	4.4	1076	654	39%	64%
Acacia microbotrya var. microbotrya	Trip 4	Doley's	2	12	100%	66	7.5	9.7	5.2	1299	699	46%	86%
Acacia microbotrya var. microbotrya	Trip 4	Doley's	3	12	100%	76	8.6	10.8	5.7	1256	661	47%	90%
Acacia microbotrya var. microbotrya	Trip 6	McCabe	2	12	100%	38	4.3	5.5	3.8	1280	884	31%	45%
Acacia microbotrya var. microbotrya	Trip 6	McCabe	3	12	100%	38	4.3	5.7	3.2	1326	752	43%	76%
Acacia microbotrya var. microbotrya	Trip 6	McCabe	4	12	100%	52	5.9	6.9	4.7	1173	796	32%	47%
Acacia microbotrya var. microbotrya	Trip 6	McCabe	5	12	100%	37	4.2	5.3	3.4	1267	817	35%	55%
Acacia microbotrya var. microbotrya	Trip 6	McCabe	6	12	100%	39	4.4	5.5	4.0	1247	898	28%	39%
Acacia microbotrya var. microbotrya	Trip 6	McCabe	1h	12	100%	38	4.3	5.2	3.5	1210	807	33%	50%
Acacia microbotrya var. microbotrya	Trip 6	McCabe	1l	12	100%	64	7.2	9.2	6.5	1271	904	29%	41%
Acacia microbotrya var. microbotrya	Trip 6	McCabe	1m	12	100%	49	5.5	6.2	4.2	1119	765	32%	46%
Acacia microbotrya var. microbotrya	Trip 6	Ongerup sand pit	2	12	100%	41	4.6	5.9	4.1	1272	886	30%	44%
Acacia microbotrya var. microbotrya	Trip 6	Ongerup sand pit	3	12	100%	43	4.9	6.1	4.4	1254	901	28%	39%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Acacia microbotrya var. microbotrya	Trip 6	Ongerup sand pit	4	12	100%	36	4.1	5.0	3.3	1228	811	34%	52%
Acacia microbotrya var. microbotrya	Trip 6	Ongerup sand pit	5	12	100%	33	3.7	5.0	3.3	1340	884	34%	52%
Acacia microbotrya var. microbotrya	Trip 6	Ongerup sand pit	6	12	100%	39	4.4	5.7	3.9	1292	889	31%	45%
Acacia microbotrya var. microbotrya	Trip 6	Ongerup sand pit	1h	12	100%	48	5.4	6.1	4.3	1124	798	29%	41%
Acacia microbotrya var. microbotrya	Trip 6	Ongerup sand pit	1l	12	100%	71	8.0	9.8	6.8	1220	841	31%	45%
Acacia microbotrya var. microbotrya	Trip 6	Ongerup sand pit	1m	12	100%	52	5.9	6.9	4.8	1173	814	31%	44%
Acacia murrayana	JC	Kalannie - Hudson	1	12	100%	78	8.8		5.6		639		
Acacia murrayana	JC	Kalannie - Hudson	2	12	100%	80	9.0		6.1		679		
Acacia murrayana	JC	Kalannie - Hudson	3	12	100%	93	10.5		6.6		628		
Acacia murrayana	Trip 9	Hudsons	2	12	100%	60	6.8	8.0	5.0	1179	731	38%	61%
Acacia murrayana	Trip 9	Hudsons	3	12	100%	52	5.9	6.4	3.1	1088	522	52%	108%
Acacia murrayana	Trip 9	Hudsons	4	12	100%	41	4.6	4.9	2.8	1057	612	42%	73%
Acacia murrayana	Trip 9	Hudsons	5	12	100%	48	5.4	5.7	3.1	1050	578	45%	82%
Acacia murrayana	Trip 9	Hudsons	6	12	100%	63	7.1	7.8	4.7	1095	658	40%	66%
Acacia murrayana	Trip 9	Hudsons	1h	12	100%	42	4.8	5.0	3.0	1053	638	39%	65%
Acacia murrayana	Trip 9	Hudsons	1l	12	100%	63	7.1	8.0	4.8	1123	667	41%	68%
Acacia murrayana	Trip 9	Hudsons	1m	12	100%	50	5.7	6.5	3.9	1149	688	40%	67%
Acacia murrayana	Trip 9	Stephens III	1	12	100%	32	3.6	4.5	2.5	1243	702	44%	77%
Acacia murrayana	Trip 9	Stephens III	2	12	100%	60	6.8	8.2	4.8	1208	707	41%	71%
Acacia murrayana	Trip 9	Stephens III	3	12	100%	54	6.1	7.1	4.2	1163	691	41%	68%
Acacia murrayana	Trip 9	Wattoning Road West	2	12	100%	36	4.1	4.7	2.5	1154	616	47%	87%
Acacia murrayana	Trip 9	Wattoning Road West	3	12	100%	33	3.7	4.5	2.5	1206	673	44%	79%
Acacia murrayana	Trip 9	Wattoning Road West	4	12	100%	32	3.6	4.8	3.1	1326	843	36%	57%
Acacia murrayana	Trip 9	Wattoning Road West	5	12	100%	36	4.1	5.3	3.2	1302	791	39%	65%
Acacia murrayana	Trip 9	Wattoning Road West	6	12	100%	40	4.5	5.8	3.4	1282	745	42%	72%
Acacia murrayana	Trip 9	Wattoning Road West	1h	12	100%	34	3.8	5.3	3.3	1378	850	38%	62%
Acacia murrayana	Trip 9	Wattoning Road West	1l	12	100%	50	5.7	7.6	4.6	1344	813	39%	65%
Acacia murrayana	Trip 9	Wattoning Road West	1m	12	100%	38	4.3	5.6	3.2	1303	742	43%	76%
Acacia neurophylla subsp. erugata	Trip 9	Squires Shed	1	12	100%	35	4.0	4.2	3.5	1061	882	17%	20%
Acacia neurophylla subsp. erugata	Trip 9	Squires Shed	2	12	100%	22	2.5	2.9	2.4	1166	973	17%	20%
Acacia neurophylla subsp. erugata	Trip 9	Squires Shed	3	12	100%	21	2.4	2.7	2.3	1137	977	14%	16%
Acacia obtecta	Trip 9	Grants	2	12	100%	34	3.8	5.3	3.7	1378	973	29%	42%
Acacia obtecta	Trip 9	Grants	3	12	100%	38	4.3	5.8	3.7	1350	870	36%	55%
Acacia obtecta	Trip 9	Grants	4	12	100%	45	5.1	6.5	4.6	1277	900	30%	42%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Acacia obtecta	Trip 9	Grants	5	12	100%	40	4.5	6.3	4.2	1393	931	33%	50%
Acacia obtecta	Trip 9	Grants	6	12	100%	48	5.4	7.1	5.0	1308	914	30%	43%
Acacia obtecta	Trip 9	Grants	1h	12	100%	46	5.2	6.8	4.5	1307	873	33%	50%
Acacia obtecta	Trip 9	Grants	1l	12	100%	54	6.1	8.4	5.7	1375	935	32%	47%
Acacia obtecta	Trip 9	Grants	1m	12	100%	49	5.5	7.2	4.9	1299	888	32%	46%
Acacia prainii	JC	Kalannie - Polinson	13	12	100%	48	5.4		5.7		1043		
Acacia prainii	Trip 9	Grants	1	12	100%	33	3.7	5.2	3.8	1393	1018	27%	37%
Acacia prainii	Trip 9	Grants	2	12	100%	32	3.6	4.8	3.4	1326	942	29%	41%
Acacia prainii	Trip 9	Grants	3	12	100%	29	3.3	4.6	3.4	1403	1040	26%	35%
Acacia pruinocarpa	JC	Mullewa - Critch	32	12	50%	50	5.7		3.5		614		
Acacia redolens	DH	Ian Walsh, Cranbrook	1	12	100%	78	8.8	10.2	7.2	1156	814	30%	42%
Acacia redolens	DH	Ian Walsh, Cranbrook	2	12	100%	70	7.9	9.3	6.8	1175	855	27%	37%
Acacia redolens	DH	Ian Walsh, Cranbrook	3	12	100%	69	7.8	8.7	6.3	1115	802	28%	39%
Acacia redolens	DH	Ian Walsh, Cranbrook	3	12	100%	42	4.8	5.8	3.9	1221	817	33%	49%
Acacia redolens	DH	Ian Walsh, Cranbrook	3	12	100%	52	5.9	7.0	4.8	1190	821	31%	45%
Acacia resinimarginea	JC	Kalannie - Hudson	8	12	100%	107	12.1		13.0		1075		
Acacia resinimarginea	JC	Kalannie - Rolinson	11	12	100%	49	5.5		5.2		946		
Acacia resinimarginea	JC	Kalannie - Rolinson	12	12	100%	71	8.0		8.3		1027		
Acacia rostellifera	JC	Mullewa - Critch	26	12	100%	70	7.9		7.1		892		
Acacia rostellifera	JC	Mullewa - Critch	27	12	100%	101	11.4		10.7		934		
Acacia rostellifera	JC	Mullewa - Critch	28	12	100%	80	9.0		7.7		851		
Acacia rostellifera	JC	Mullewa - Critch	29	12	100%	55	6.2		5.9		948		
Acacia rostellifera	JC	Northampton - roadside	38	12	100%	118	13.3		9.7		729		
Acacia rostellifera	JC	Northampton - roadside	39	12	100%	69	7.8		7.2		920		
Acacia rostellifera	JC	Northampton - roadside	40	12	100%	71	8.0		6.7		829		
Acacia rostellifera	JC	Perth (North) - Rocks Beach	1	12	100%	111	12.6		9.3		739		
Acacia rostellifera	JC	Perth (North) - Rocks Beach	2	12	100%	55	6.2		4.5		727		
Acacia rostellifera	JC	Perth (North) - Rocks Beach	3	12	?	51	5.8		4.3		742		
Acacia rostellifera	Trip 7	8km Dam	1	12	100%	42	4.8	6.1	4.0	1284	838	35%	53%
Acacia rostellifera	Trip 7	8km Dam	2	12	100%	47	5.3	6.5	4.2	1223	783	36%	56%
Acacia rostellifera	Trip 7	8km Dam	3	12	100%	50	5.7	7.4	5.2	1309	920	30%	42%
Acacia saligna	JC	Beverley - Ainsley	1	12	100%	138	15.6	16.3	9.0	1042	575	45%	81%
Acacia saligna	JC	Beverley - Ainsley	2	12	100%	81	9.2	10.5	5.9	1151	648	44%	77%
Acacia saligna	JC	Beverley - Ainsley	3	12	100%	146	16.5	16.0	9.1	968	551	43%	76%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Acacia saligna	JC	Dongara - Grieves	20	12	100%	74	8.4		4.7		557		
Acacia saligna	JC	Dongara - Grieves	21	12	100%	106	12.0		6.6		551		
Acacia saligna	JC	Dongara - Grieves	22	12	100%	99	11.2		6.1		547		
Acacia saligna	JC	Kalannie - Hudson	4	12	100%	97	11.0		7.6		694		
Acacia saligna	JC	Kalannie - Hudson	5	12	100%	96	10.9		7.8		717		
Acacia saligna	JC	Kalannie - Hudson	6	12	100%	104	11.8		8.3		707		
Acacia saligna	JC	Narrogin - Ag. school	5	12	100%	51	5.8		3.3		577		
Acacia saligna	JC	Narrogin - Ag. school	6	12	100%	79	8.9		5.4		601		
Acacia saligna	JC	Narrogin - Ag. school	7	12	49%	30	3.4		1.9		560		
Acacia saligna	JC	Wickepin - Mullan	1	12	100%	116	13.1		9.4		714		
Acacia saligna	JC	Wickepin - Mullan	2	12	100%	92	10.4		7.6		730		
Acacia saligna	JC	Wickepin - Mullan	3	12	100%	112	12.7		9.3		735		
Acacia saligna	JC	Wickepin - Mullan	4	12	100%	89	10.1		6.4		635		
Acacia saligna	Trip 4	Arrowsmith River	1	12	100%	77	8.7	8.0	5.0	919	575	37%	60%
Acacia saligna	Trip 4	Arrowsmith River	2	12	100%	95	10.7	11.2	6.4	1042	594	43%	76%
Acacia saligna	Trip 4	Arrowsmith River	3	12	100%	54	6.1	6.5	3.5	1064	575	46%	85%
Acacia saligna	Trip 4	Doley's	1	12	100%	75	8.5	8.7	5.2	1026	618	40%	66%
Acacia saligna	Trip 4	Doley's	2	12	100%	72	8.1	7.8	4.6	958	567	41%	69%
Acacia saligna	Trip 4	Doley's	3	12	100%	51	5.8	7.2	3.6	1248	615	51%	103%
Acacia saligna	Trip 6	Frankland River	2	12	100%	52	5.9	6.0	3.2	1020	542	47%	88%
Acacia saligna	Trip 6	Frankland River	3	12	100%	31	3.5	3.3	2.0	941	570	39%	65%
Acacia saligna	Trip 6	Frankland River	4	12	100%	40	4.5	4.0	2.1	884	469	47%	89%
Acacia saligna	Trip 6	Frankland River	5	12	100%	50	5.7	5.5	2.9	971	508	48%	91%
Acacia saligna	Trip 6	Frankland River	6	12	100%	55	6.2	5.6	3.3	900	535	41%	68%
Acacia saligna	Trip 6	Frankland River	1h	12	100%	35	4.0	3.5	2.1	884	541	39%	64%
Acacia saligna	Trip 6	Frankland River	1l	12	100%	47	5.3	5.0	3.1	941	576	39%	63%
Acacia saligna	Trip 6	Frankland River	1m	12	100%	38	4.3	3.8	2.4	884	547	38%	62%
Acacia saligna	Trip 6	McCabe	1	12	100%	53	6.0	6.4	4.1	1068	689	35%	55%
Acacia saligna	Trip 6	McCabe	2	12	100%	60	6.8	7.0	4.2	1032	613	41%	68%
Acacia saligna	Trip 6	McCabe	3	12	100%	52	5.9	5.6	3.2	952	541	43%	76%
Acacia saligna	Trip 6	McCabe	4	12	100%	45	5.1	4.5	2.8	884	556	37%	59%
Acacia saligna	Trip 6	McCabe	5	12	100%	45	5.1	4.8	3.0	943	580	39%	63%
Acacia saligna	Trip 6	McCabe	6h	12	100%	39	4.4	4.4	2.6	998	585	41%	71%
Acacia saligna	Trip 6	McCabe	6l	12	100%	121	13.7	12.7	8.0	928	585	37%	59%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Acacia saligna	Trip 6	McCabe	6m	12	100%	73	8.3	7.6	4.7	921	568	38%	62%
Acacia scirpifolia	Trip 7	Mount Adams Road	1	12	100%	42	4.8	4.9	3.3	1032	686	33%	50%
Acacia scirpifolia	Trip 7	Mount Adams Road	2	12	100%	48	5.4	5.3	3.6	976	669	32%	46%
Acacia scirpifolia	Trip 7	Mount Adams Road	3	12	100%	43	4.9	4.8	3.4	987	689	30%	43%
Acacia scirpifolia	Trip 9	Bishops Gully	2	12	100%	27	3.1	3.3	2.3	1081	743	31%	45%
Acacia scirpifolia	Trip 9	Bishops Gully	3	12	100%	26	2.9	3.1	2.1	1054	704	33%	50%
Acacia scirpifolia	Trip 9	Bishops Gully	4	12	100%	33	3.7	3.9	2.7	1045	710	32%	47%
Acacia scirpifolia	Trip 9	Bishops Gully	5	12	100%	45	5.1	5.4	3.7	1061	725	32%	46%
Acacia scirpifolia	Trip 9	Bishops Gully	6	12	100%	47	5.3	5.5	3.6	1035	681	34%	52%
Acacia scirpifolia	Trip 9	Bishops Gully	1h	12	100%	33	3.7	4.0	2.7	1072	713	34%	50%
Acacia scirpifolia	Trip 9	Bishops Gully	1l	12	100%	51	5.8	6.2	4.1	1075	707	34%	52%
Acacia scirpifolia	Trip 9	Bishops Gully	1m	12	100%	44	5.0	5.5	3.7	1105	733	34%	51%
Acacia scirpifolia	Trip 9	Yallabathara	2	12	100%	44	5.0	5.6	3.4	1125	685	39%	64%
Acacia scirpifolia	Trip 9	Yallabathara	3	12	100%	31	3.5	3.6	2.6	1027	747	27%	37%
Acacia scirpifolia	Trip 9	Yallabathara	4	12	100%	52	5.9	6.1	3.6	1037	612	41%	69%
Acacia scirpifolia	Trip 9	Yallabathara	5	12	100%	57	6.4	6.2	4.1	962	628	35%	53%
Acacia scirpifolia	Trip 9	Yallabathara	6	12	100%	42	4.8	4.8	2.9	1011	608	40%	66%
Acacia scirpifolia	Trip 9	Yallabathara	1h	12	100%	27	3.1	3.1	2.0	1015	665	35%	53%
Acacia scirpifolia	Trip 9	Yallabathara	1l	12	100%	45	5.1	5.9	3.6	1159	709	39%	63%
Acacia scirpifolia	Trip 9	Yallabathara	1m	12	100%	42	4.8	5.0	3.1	1053	655	38%	61%
Acacia sclerosperma	JC	Mullewa - Critch	33	12	100%	49	5.5		5.6		1009		
Acacia sclerosperma	JC	Mullewa - Critch	34	12	100%	62	7.0		6.7		960		
Acacia sclerosperma	JC	Mullewa - Critch	35	12	100%	57	6.4		6.2		959		
Acacia steedmanii	Trip 9	Davis Road	2	12	100%	32	3.6	4.0	2.9	1105	810	27%	37%
Acacia steedmanii	Trip 9	Davis Road	3	12	100%	34	3.8	4.1	3.1	1066	801	25%	33%
Acacia steedmanii	Trip 9	Davis Road	4	12	100%	33	3.7	4.2	2.8	1125	748	34%	51%
Acacia steedmanii	Trip 9	Davis Road	5	12	100%	33	3.7	4.7	3.5	1259	924	27%	36%
Acacia steedmanii	Trip 9	Davis Road	6	12	100%	32	3.6	4.7	3.0	1299	834	36%	56%
Acacia steedmanii	Trip 9	Davis Road	1h	12	100%	40	4.5	5.3	3.8	1172	840	28%	39%
Acacia steedmanii	Trip 9	Davis Road	1l	12	100%	45	5.1	6.2	4.4	1218	870	29%	40%
Acacia steedmanii	Trip 9	Davis Road	1m	12	100%	47	5.3	6.0	4.4	1129	833	26%	35%
Acacia stereophylla var. stereophylla	Trip 9	Maya	1	12	100%	27	3.1	3.9	3.2	1277	1048	18%	22%
Acacia stereophylla var. stereophylla	Trip 9	Maya	2	12	100%	47	5.3	6.7	5.2	1260	969	23%	30%
Acacia stereophylla var. stereophylla	Trip 9	Maya	3	12	100%	30	3.4	4.4	3.7	1297	1088	16%	19%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Acacia bartleana Maslin (ms)	JC	Badgingarra - roadside	1	12	100%	84	9.5		7.6		795		
Acacia bartleana Maslin (ms)	JC	Badgingarra - roadside	2	12	100%	106	12.0		9.0		752		
Acacia bartleana Maslin (ms)	JC	Badgingarra - roadside	3	12	100%	77	8.7		7.7		880		
Acacia bartleana Maslin (ms)	JC	Badgingarra - roadside	4	12	100%	72	8.1		7.2		881		
Acacia bartleana Maslin (ms)	JC	Dumbleyung - Temby	1	12	46%	39	4.4		3.8		859		
Acacia bartleana Maslin (ms)	JC	Dumbleyung - Temby	2	12	51%	52	5.9		4.5		772		
Acacia bartleana Maslin (ms)	JC	Wally's collection	1	12 x 15.5	100%	124	23.1		21.4		926		
Acacia bartleana Maslin (ms)	Trip 7	Coomberdale West	1	12	100%	64	7.2	8.8	5.2	1216	723	41%	68%
Acacia bartleana Maslin (ms)	Trip 7	Coomberdale West	2	12	100%	60	6.8	7.8	4.9	1149	718	38%	60%
Acacia bartleana Maslin (ms)	Trip 7	Coomberdale West	3	12	100%	56	6.3	7.2	5.4	1137	845	26%	35%
Acacia tysonii	Trip 9	Morawa South	2	12	100%	46	5.2	7.1	5.3	1365	1023	25%	33%
Acacia tysonii	Trip 9	Morawa South	3	12	100%	31	3.5	4.8	3.5	1369	1001	27%	37%
Acacia tysonii	Trip 9	Morawa South	4	12	100%	31	3.5	5.0	3.5	1426	993	30%	44%
Acacia tysonii	Trip 9	Morawa South	5	12	100%	20	2.3	3.1	2.2	1371	981	28%	40%
Acacia tysonii	Trip 9	Morawa South	6	12	100%	36	4.1	5.5	3.8	1351	931	31%	45%
Acacia tysonii	Trip 9	Morawa South	1h	12	100%	22	2.5	3.3	2.5	1326	985	26%	35%
Acacia tysonii	Trip 9	Morawa South	1l	12	100%	43	4.9	6.7	4.8	1378	989	28%	39%
Acacia tysonii	Trip 9	Morawa South	1m	12	100%	34	3.8	5.1	3.7	1326	967	27%	37%
Acacia victoriae	JC	Kellerberrin - Scott	5	12	100%	44	5.0		4.4		890		
Acacia victoriae	JC	Kellerberrin - Scott	6	12	100%	79	8.9		6.6		739		
Actinostrobus acuminatus	Trip 4	Drill Track E	1	12	100%	62	7.0	7.7	4.6	1098	657	40%	67%
Actinostrobus acuminatus	Trip 4	Drill Track E	2	12	100%	76	8.6	8.2	5.5	954	636	33%	50%
Actinostrobus acuminatus	Trip 4	Drill Track E	3	12	100%	86	9.7	10.0	6.7	1028	689	33%	49%
Actinostrobus arenarius	Trip 4	Mt Adams Road	1	12	100%	77	8.7	8.4	5.9	965	681	29%	42%
Actinostrobus arenarius	Trip 4	Mt Adams Road	2	12	100%	51	5.8	5.2	3.8	902	666	26%	35%
Actinostrobus arenarius	Trip 4	Mt Adams Road	3	12	100%	58	6.6	6.7	4.7	1021	720	30%	42%
Actinostrobus arenarius	Trip 7	Agaton	2	12	100%	47	5.3	5.4	3.6	1014	679	33%	49%
Actinostrobus arenarius	Trip 7	Agaton	3	12	100%	42	4.8	4.9	3.2	1032	680	34%	52%
Actinostrobus arenarius	Trip 7	Agaton	4	12	100%	41	4.6	4.7	3.4	1014	725	29%	40%
Actinostrobus arenarius	Trip 7	Agaton	5	12	100%	42	4.8	5.2	3.3	1095	691	37%	59%
Actinostrobus arenarius	Trip 7	Agaton	6	12	100%	53	6.0	4.4	3.2	734	536	27%	37%
Actinostrobus arenarius	Trip 7	Agaton	1h	12	100%	39	4.4	4.0	2.8	907	642	29%	41%
Actinostrobus arenarius	Trip 7	Agaton	1l	12	100%	44	5.0	4.7	3.3	944	655	31%	44%
Actinostrobus arenarius	Trip 7	Agaton	1m	12	100%	42	4.8	4.6	3.0	968	636	34%	52%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Actinostrobus arenarius	Trip 7	Wilcox 2	1	12	100%	44	5.0	5.3	3.2	1065	649	39%	64%
Actinostrobus arenarius	Trip 7	Wilcox 2	3	12	100%	49	5.5	6.0	3.6	1083	641	41%	69%
Actinostrobus arenarius	Trip 7	Wilcox 2	4	12	100%	41	4.6	5.1	3.1	1100	664	40%	66%
Actinostrobus arenarius	Trip 7	Wilcox 2	5	12	100%	53	6.0	5.6	3.9	934	646	31%	45%
Actinostrobus arenarius	Trip 7	Wilcox 2	6	12	100%	43	4.9	4.9	3.2	1008	648	36%	56%
Actinostrobus arenarius	Trip 7	Wilcox 2	2h	12	100%	39	4.4	5.0	2.7	1134	617	46%	84%
Actinostrobus arenarius	Trip 7	Wilcox 2	2l	12	100%	56	6.3	6.8	4.3	1074	674	37%	59%
Actinostrobus arenarius	Trip 7	Wilcox 2	2m	12	100%	62	7.0	8.0	5.0	1141	716	37%	59%
Actinostrobus pyramidalis	Trip 6	Winfield	1	12	100%	39	4.4	4.8	2.8	1088	635	42%	71%
Actinostrobus pyramidalis	Trip 6	Winfield	2	12	100%	44	5.0	5.2	3.1	1045	619	41%	69%
Actinostrobus pyramidalis	Trip 6	Winfield	3	12	100%	44	5.0	5.0	2.9	1005	585	42%	72%
Actinostrobus pyramidalis	Trip 8	Lake Muir Road	2	12	100%	28	3.2	3.6	2.1	1137	647	43%	76%
Actinostrobus pyramidalis	Trip 8	Lake Muir Road	3	12	100%	35	4.0	4.6	2.7	1162	669	42%	74%
Actinostrobus pyramidalis	Trip 8	Lake Muir Road	4	12	100%	25	2.8	3.5	1.9	1238	654	47%	89%
Actinostrobus pyramidalis	Trip 8	Lake Muir Road	5	12	100%	34	3.8	4.4	2.3	1144	590	48%	94%
Actinostrobus pyramidalis	Trip 8	Lake Muir Road	6	12	100%	29	3.3	4.1	2.3	1250	695	44%	80%
Actinostrobus pyramidalis	Trip 8	Lake Muir Road	1h	12	100%	32	3.6	4.4	2.2	1216	602	50%	102%
Actinostrobus pyramidalis	Trip 8	Lake Muir Road	1l	12	100%	34	3.8	4.7	2.4	1222	622	49%	97%
Actinostrobus pyramidalis	Trip 8	Lake Muir Road	1m	12	100%	32	3.6	4.3	2.2	1188	597	50%	99%
Actinostrobus pyramidalis	Trip 8	Unicup compt 3	2	12	100%	35	4.0	4.2	2.7	1061	669	37%	58%
Actinostrobus pyramidalis	Trip 8	Unicup compt 3	3	12	100%	42	4.8	5.3	3.2	1116	663	41%	68%
Actinostrobus pyramidalis	Trip 8	Unicup compt 3	4	12	100%	29	3.3	4.2	2.2	1281	680	47%	88%
Actinostrobus pyramidalis	Trip 8	Unicup compt 3	5	12	100%	30	3.4	3.7	2.2	1091	645	41%	69%
Actinostrobus pyramidalis	Trip 8	Unicup compt 3	6	12	100%	37	4.2	5.0	2.6	1195	612	49%	95%
Actinostrobus pyramidalis	Trip 8	Unicup compt 3	1h	12	100%	31	3.5	4.2	2.1	1206	593	51%	103%
Actinostrobus pyramidalis	Trip 8	Unicup compt 3	1l	12	100%	36	4.1	4.9	2.5	1203	602	50%	100%
Actinostrobus pyramidalis	Trip 8	Unicup compt 3	1m	12	100%	41	4.6	5.4	2.7	1165	591	49%	97%
Actinostrobus pyramidalis	Trip 9	Bolgart East Road	1	12	100%	35	4.0	3.9	2.7	985	687	30%	43%
Actinostrobus pyramidalis	Trip 9	Bolgart East Road	2	12	100%	33	3.7	4.4	2.6	1179	689	42%	71%
Actinostrobus pyramidalis	Trip 9	Bolgart East Road	3	12	100%	39	4.4	4.6	3.0	1043	673	35%	55%
Actinostrobus pyramidalis	Trip 9	Muchea	1	12	100%	45	5.1	5.9	3.3	1159	641	45%	81%
Actinostrobus pyramidalis	Trip 9	Muchea	2	12	100%	32	3.6	4.1	2.3	1133	630	44%	80%
Actinostrobus pyramidalis	Trip 9	Muchea	3	12	100%	36	4.1	4.6	2.7	1130	651	42%	74%
Adenanthos cygnorum	Trip 4	Yanchep North 2	1	12	100%	64	7.2	8.0	4.4	1105	601	46%	84%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Adenanthos cygnorum	Trip 4	Yanchep North 2	2	12	100%	64	7.2	8.6	4.3	1188	598	50%	99%
Adenanthos cygnorum	Trip 4	Yanchep North 2	3	12	100%	50	5.7	6.8	3.2	1203	571	53%	111%
Adenanthos cygnorum	Trip 7	Agaton	1	12	100%	40	4.5	5.5	2.8	1216	617	49%	97%
Adenanthos cygnorum	Trip 7	Agaton	2	12	100%	46	5.2	6.3	3.2	1211	611	50%	98%
Adenanthos cygnorum	Trip 7	Agaton	3	12	100%	30	3.4	4.1	2.2	1208	640	47%	89%
Adenanthos cygnorum	Trip 7	Agaton	4	12	100%	48	5.4	6.8	3.4	1253	626	50%	100%
Adenanthos cygnorum	Trip 7	Agaton	6	12	100%	49	5.5	6.5	3.2	1173	570	51%	106%
Adenanthos cygnorum	Trip 7	Agaton	5h	12	100%	40	4.5	5.1	2.7	1127	595	47%	90%
Adenanthos cygnorum	Trip 7	Agaton	5l	12	100%	75	8.5	9.8	4.9	1155	575	50%	101%
Adenanthos cygnorum	Trip 7	Agaton	5m	12	100%	43	4.9	5.6	2.9	1152	596	48%	93%
Adenanthos cygnorum	Trip 7	Moore River SF II	1	12	100%	44	5.0	6.2	2.8	1246	553	56%	125%
Adenanthos cygnorum	Trip 7	Moore River SF II	2	12	100%	48	5.4	6.8	3.1	1253	571	54%	119%
Adenanthos cygnorum	Trip 7	Moore River SF II	4	12	100%	38	4.3	5.4	2.5	1256	570	55%	120%
Adenanthos cygnorum	Trip 7	Moore River SF II	5	12	100%	37	4.2	5.0	2.5	1195	593	50%	102%
Adenanthos cygnorum	Trip 7	Moore River SF II	6	12	100%	42	4.8	5.8	2.9	1221	617	49%	98%
Adenanthos cygnorum	Trip 7	Moore River SF II	3h	12	100%	41	4.6	5.4	2.8	1165	610	48%	91%
Adenanthos cygnorum	Trip 7	Moore River SF II	3l	12	100%	57	6.4	7.7	3.9	1194	605	49%	97%
Adenanthos cygnorum	Trip 7	Moore River SF II	3m	12	100%	51	5.8	6.7	3.4	1162	586	50%	98%
Adenanthos sericeus	Trip 2	Quaranup	1	12	100%	65	7.4	9.0	4.0	1224	547	55%	124%
Adenanthos sericeus	Trip 2	Quaranup	2	12	100%	82	9.3	11.5	6.0	1240	645	48%	92%
Adenanthos sericeus	Trip 2	Quaranup	3	12	100%	96	10.9	13.0	6.3	1197	581	51%	106%
Adenanthos sericeus	Trip 8	Quaranup	2	12	100%	34	3.8	5.1	2.4	1326	629	53%	111%
Adenanthos sericeus	Trip 8	Quaranup	3	12	100%	56	6.3	7.9	3.1	1247	483	61%	158%
Adenanthos sericeus	Trip 8	Quaranup	4	12	100%	48	5.4	6.9	2.8	1271	514	60%	147%
Adenanthos sericeus	Trip 8	Quaranup	5	12	100%	44	5.0	6.4	2.9	1286	581	55%	121%
Adenanthos sericeus	Trip 8	Quaranup	6	12	100%	50	5.7	7.2	3.5	1273	621	51%	105%
Adenanthos sericeus	Trip 8	Quaranup	1h	12	100%	34	3.8	4.9	2.0	1274	528	59%	141%
Adenanthos sericeus	Trip 8	Quaranup	1l	12	100%	44	5.0	6.5	2.5	1306	510	61%	156%
Adenanthos sericeus	Trip 8	Quaranup	1m	12	100%	40	4.5	5.7	2.4	1260	524	58%	141%
Adenanthos sericeus	Trip 8	Silent Grove	2	12	100%	48	5.4	6.8	3.0	1253	549	56%	128%
Adenanthos sericeus	Trip 8	Silent Grove	3	12	100%	47	5.3	6.7	3.4	1260	630	50%	100%
Adenanthos sericeus	Trip 8	Silent Grove	4	12	100%	63	7.1	8.9	4.7	1249	658	47%	90%
Adenanthos sericeus	Trip 8	Silent Grove	5	12	100%	57	6.4	8.0	3.8	1241	588	53%	111%
Adenanthos sericeus	Trip 8	Silent Grove	6	12	100%	58	6.6	8.3	3.6	1265	543	57%	133%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Adenanthos sericeus	Trip 8	Silent Grove	1h	12	100%	47	5.3	6.8	3.1	1279	591	54%	117%
Adenanthos sericeus	Trip 8	Silent Grove	1l	12	100%	57	6.4	8.3	3.7	1288	569	56%	126%
Adenanthos sericeus	Trip 8	Silent Grove	1m	12	100%	49	5.5	7.1	3.2	1281	579	55%	121%
Adenanthos stictus	Trip 4	Marchagee Track	1	12	100%	42	4.8	5.8	2.9	1221	604	51%	102%
Adenanthos stictus	Trip 4	Marchagee Track	2	12	100%	46	5.2	6.1	2.9	1173	559	52%	110%
Adenanthos stictus	Trip 4	Marchagee Track	3	12	100%	52	5.9	7.0	3.3	1190	568	52%	110%
Adenanthos stictus	Trip 4	Marchagee Track	4	12	100%	56	6.3	7.7	4.0	1216	632	48%	93%
Adenanthos stictus	Trip 9	Marchagee	2	12	100%	26	2.9	3.7	1.6	1258	537	57%	134%
Adenanthos stictus	Trip 9	Marchagee	3	12	100%	29	3.3	4.1	1.5	1250	466	63%	168%
Adenanthos stictus	Trip 9	Marchagee	4	12	100%	40	4.5	5.9	2.6	1304	584	55%	123%
Adenanthos stictus	Trip 9	Marchagee	5	12	100%	25	2.8	3.6	1.6	1273	580	54%	120%
Adenanthos stictus	Trip 9	Marchagee	6	12	100%	39	4.4	5.4	2.6	1224	599	51%	105%
Adenanthos stictus	Trip 9	Marchagee	1h	12	100%	45	5.1	6.7	3.5	1316	696	47%	89%
Adenanthos stictus	Trip 9	Marchagee	1l	12	100%	52	5.9	7.6	3.7	1292	629	51%	105%
Adenanthos stictus	Trip 9	Marchagee	1m	12	100%	49	5.5	7.1	3.6	1281	641	50%	100%
Adenanthos stictus	Trip 9	Wilton	2	12	100%	41	4.6	5.8	2.6	1251	552	56%	127%
Adenanthos stictus	Trip 9	Wilton	3	12	100%	28	3.2	3.9	1.8	1232	562	54%	119%
Adenanthos stictus	Trip 9	Wilton	4	12	100%	33	3.7	4.6	2.1	1233	565	54%	118%
Adenanthos stictus	Trip 9	Wilton	5	12	100%	33	3.7	4.6	2.4	1233	632	49%	95%
Adenanthos stictus	Trip 9	Wilton	6	12	100%	26	2.9	3.8	1.9	1292	656	49%	97%
Adenanthos stictus	Trip 9	Wilton	1h	12	100%	32	3.6	4.5	2.3	1243	624	50%	99%
Adenanthos stictus	Trip 9	Wilton	1l	12	100%	41	4.6	5.9	3.0	1272	656	48%	94%
Adenanthos stictus	Trip 9	Wilton	1m	12	100%	37	4.2	5.1	2.7	1219	636	48%	92%
Agonis flexuosa	Trip 2	Rifle Range	1	12	100%	93	10.5	12.6	7.9	1198	746	38%	61%
Agonis flexuosa	Trip 2	Rifle Range	2	12	100%	101	11.4	14.1	9.6	1234	839	32%	47%
Agonis flexuosa	Trip 2	Rifle Range	3	12	100%	100	11.3	13.9	8.8	1229	774	37%	59%
Alectryon oleifolius	Trip 5	Kanowna Lakes	1	12	100%	40	4.5	6.4	4.9	1415	1083	23%	31%
Alectryon oleifolius	Trip 5	Kanowna Lakes	2	12	100%	25	2.8	3.9	2.8	1379	1001	27%	38%
Alectryon oleifolius	Trip 5	Kanowna Lakes	3	12	100%	34	3.8	5.2	3.6	1352	947	30%	43%
Allocasuarina acutivalvis	Trip 3	Cascades Road	1	12	100%	50	5.7	7.0	5.2	1238	925	25%	34%
Allocasuarina acutivalvis	Trip 3	Cascades Road	2	12	100%	54	6.1	7.6	5.8	1244	951	24%	31%
Allocasuarina acutivalvis	Trip 3	Cascades Road	3	12	100%	48	5.4	7.2	5.4	1326	1002	24%	32%
Allocasuarina acutivalvis	Trip 3	Forrestonia Pub	1	12	100%	64	7.2	9.4	7.4	1299	1020	21%	27%
Allocasuarina acutivalvis	Trip 3	Forrestonia Pub	2	12	100%	83	9.4	11.9	9.4	1268	999	21%	27%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Allocasuarina acutivalvis	Trip 3	Forrestonia Pub	3	12	100%	50	5.7	7.2	5.6	1273	990	22%	29%
Allocasuarina campestris	Trip 4	Yalgoo Road	1	12	100%	68	7.7	9.6	7.7	1248	1004	20%	24%
Allocasuarina campestris	Trip 4	Yalgoo Road	2	12	100%	68	7.7	9.6	7.6	1248	993	20%	26%
Allocasuarina campestris	Trip 4	Yalgoo Road	3	12	100%	60	6.8	7.9	6.3	1164	928	20%	25%
Allocasuarina dielsiana	Trip 5	Bullfinch	1	12	100%	56	6.3	8.3	5.7	1311	902	31%	45%
Allocasuarina dielsiana	Trip 5	Bullfinch	2	12	100%	60	6.8	9.3	6.5	1371	962	30%	42%
Allocasuarina dielsiana	Trip 5	Bullfinch	3	12	100%	59	6.7	9.0	6.6	1349	995	26%	36%
Allocasuarina huegeliana	JC	Narrogin - Ag. school	4	12	100%	103	11.6		8.6		734		
Allocasuarina huegeliana	Trip 1	Dryandra	1	12	50%	88	10.0	10.8	7.7	1085	778	28%	40%
Allocasuarina huegeliana	Trip 1	Dryandra	2	12	100%	118	13.3	13.7	9.7	1027	725	29%	42%
Allocasuarina huegeliana	Trip 1	Dryandra	3	12	100%	133	15.0	16.8	11.4	1117	756	32%	48%
Alyogyne hakeifolia	Trip 4	Horrocks Tip	1	12	100%	43	4.9	6.0	3.9	1234	808	35%	53%
Alyogyne hakeifolia	Trip 4	Horrocks Tip	2	12	100%	48	5.4	6.5	4.4	1197	814	32%	47%
Alyogyne hakeifolia	Trip 4	Horrocks Tip	3	12	100%	59	6.7	7.8	4.8	1169	713	39%	64%
Alyogyne huegelii	Trip 4	Indian Ocean Drive	1	12	100%	69	7.8	9.6	5.9	1230	752	39%	64%
Alyogyne huegelii	Trip 4	Indian Ocean Drive	2	12	100%	51	5.8	6.5	3.6	1127	615	45%	83%
Alyogyne huegelii	Trip 4	Indian Ocean Drive	3	12	100%	51	5.8	7.4	4.3	1283	742	42%	73%
Alyogyne huegelii	Trip 7	Brand Cutting	2	12	100%	49	5.5	6.6	3.6	1191	651	45%	83%
Alyogyne huegelii	Trip 7	Brand Cutting	3	12	100%	42	4.8	6.0	3.5	1263	737	42%	71%
Alyogyne huegelii	Trip 7	Brand Cutting	4	12	100%	51	5.8	6.9	3.8	1196	659	45%	82%
Alyogyne huegelii	Trip 7	Brand Cutting	5	12	100%	58	6.6	7.8	4.0	1189	605	49%	96%
Alyogyne huegelii	Trip 7	Brand Cutting	6	12	100%	38	4.3	5.4	3.2	1256	735	41%	71%
Alyogyne huegelii	Trip 7	Brand Cutting	1h	12	100%	45	5.1	6.3	4.1	1238	802	35%	54%
Alyogyne huegelii	Trip 7	Brand Cutting	1l	12	100%	50	5.7	7.0	4.6	1238	805	35%	54%
Alyogyne huegelii	Trip 7	Brand Cutting	1m	12	100%	46	5.2	6.6	4.2	1269	815	36%	56%
Alyogyne sp.	Trip 9	Mullewa	2	12	100%	33	3.7	4.6	2.6	1233	683	45%	80%
Alyogyne sp.	Trip 9	Mullewa	3	12	100%	29	3.3	4.0	2.1	1220	634	48%	92%
Alyogyne sp.	Trip 9	Mullewa	4	12	100%	51	5.8	7.1	3.9	1231	669	46%	84%
Alyogyne sp.	Trip 9	Mullewa	5	12	100%	45	5.1	6.3	3.4	1238	662	47%	87%
Alyogyne sp.	Trip 9	Mullewa	6	12	100%	40	4.5	5.8	3.3	1282	723	44%	77%
Alyogyne sp.	Trip 9	Mullewa	1h	12	100%	28	3.2	3.8	2.1	1200	657	45%	83%
Alyogyne sp.	Trip 9	Mullewa	1l	12	100%	48	5.4	6.7	3.6	1234	663	46%	86%
Alyogyne sp.	Trip 9	Mullewa	1m	12	100%	42	4.8	5.8	3.1	1221	655	46%	86%
Anthocercis littorea	Trip 4	Beekeeper Ridge	1	12	100%	57	6.4	5.8	3.1	900	478	47%	88%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Anthocercis littorea	Trip 4	Beekeeper Ridge	2	12	100%	50	5.7	5.1	2.6	902	456	49%	98%
Anthocercis littorea	Trip 4	Beekeeper Ridge	3	12	100%	45	5.1	4.6	1.9	904	379	58%	138%
Anthocercis littorea	Trip 7	Railway 45	2	12	100%	36	4.1	3.7	1.9	909	467	49%	95%
Anthocercis littorea	Trip 7	Railway 45	3	12	100%	44	5.0	4.6	2.5	924	496	46%	86%
Anthocercis littorea	Trip 7	Railway 45	4	12	100%	52	5.9	5.7	2.7	969	456	53%	113%
Anthocercis littorea	Trip 7	Railway 45	5	12	100%	49	5.5	4.8	2.6	866	475	45%	83%
Anthocercis littorea	Trip 7	Railway 45	6	12	100%	41	4.6	4.7	2.2	1014	474	53%	114%
Anthocercis littorea	Trip 7	Railway 45	1h	12	100%	28	3.2	2.9	1.5	916	467	49%	96%
Anthocercis littorea	Trip 7	Railway 45	1l	12	100%	48	5.4	5.0	2.4	921	438	52%	110%
Anthocercis littorea	Trip 7	Railway 45	1m	12	100%	45	5.1	4.7	2.3	923	442	52%	109%
Anthocercis littorea	Trip 7	Railway 48	2	12	100%	26	2.9	2.5	1.1	850	377	56%	125%
Anthocercis littorea	Trip 7	Railway 48	3	12	100%	38	4.3	4.1	2.1	954	482	50%	98%
Anthocercis littorea	Trip 7	Railway 48	4	12	100%	26	2.9	3.1	1.7	1054	582	45%	81%
Anthocercis littorea	Trip 7	Railway 48	5	12	100%	25	2.8	2.7	1.6	974	563	42%	73%
Anthocercis littorea	Trip 7	Railway 48	6	12	100%	26	2.9	3.0	1.6	1020	527	48%	94%
Anthocercis littorea	Trip 7	Railway 48	1h	12	100%	37	4.2	3.4	2.0	813	473	42%	72%
Anthocercis littorea	Trip 7	Railway 48	1l	12	100%	43	4.9	4.2	2.2	864	454	47%	90%
Anthocercis littorea	Trip 7	Railway 48	1m	12	100%	42	4.8	4.4	2.3	926	491	47%	89%
Astartea heteranthera	Trip 2	Bandicoot	1	12	100%	75	8.5	10.8	6.9	1273	816	36%	56%
Astartea heteranthera	Trip 2	Bandicoot	2	12	100%	74	8.4	10.9	6.8	1302	816	37%	60%
Astartea heteranthera	Trip 2	Bandicoot	3	12	100%	66	7.5	9.1	6.1	1219	812	33%	50%
Banksia attenuata	Trip 1	Beaufort Rubbish Dump	1	12	100%	85	9.6	10.9	6.7	1134	700	38%	62%
Banksia attenuata	Trip 1	Beaufort Rubbish Dump	2	12	100%	82	9.3	11.2	6.3	1208	681	44%	77%
Banksia attenuata	Trip 1	Beaufort Rubbish Dump	3	12	100%	79	8.9	10.0	5.9	1119	663	41%	69%
Banksia attenuata	Trip 6	Gordon River	1	12	100%	43	4.9	5.8	3.2	1193	666	44%	79%
Banksia attenuata	Trip 6	Gordon River	3	12	100%	58	6.6	7.9	4.6	1204	703	42%	71%
Banksia attenuata	Trip 6	Gordon River	4	12	100%	55	6.2	7.7	4.1	1238	651	47%	90%
Banksia attenuata	Trip 6	Gordon River	5	12	100%	43	4.9	6.2	3.5	1275	709	44%	80%
Banksia attenuata	Trip 6	Gordon River	6	12	100%	58	6.6	8.3	4.3	1265	654	48%	93%
Banksia attenuata	Trip 6	Gordon River	2h	12	100%	47	5.3	6.6	3.5	1242	657	47%	89%
Banksia attenuata	Trip 6	Gordon River	2l	12	100%	68	7.7	9.6	5.0	1248	645	48%	94%
Banksia attenuata	Trip 6	Gordon River	2m	12	100%	55	6.2	7.9	4.1	1270	656	48%	94%
Banksia attenuata	Trip 8	Kemerton	2	12	100%	35	4.0	5.4	3.1	1364	771	44%	77%
Banksia attenuata	Trip 8	Kemerton	3	12	100%	38	4.3	5.9	3.1	1373	721	47%	90%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Banksia attenuata	Trip 8	Kemerton	4	12	100%	40	4.5	6.3	3.6	1393	800	43%	74%
Banksia attenuata	Trip 8	Kemerton	5	12	100%	37	4.2	5.6	3.1	1338	738	45%	81%
Banksia attenuata	Trip 8	Kemerton	6	12	100%	41	4.6	6.2	3.3	1337	720	46%	86%
Banksia attenuata	Trip 8	Kemerton	1h	12	100%	35	4.0	5.2	2.7	1314	685	48%	92%
Banksia attenuata	Trip 8	Kemerton	1l	12	100%	42	4.8	6.4	3.4	1347	722	46%	87%
Banksia attenuata	Trip 8	Kemerton	1m	12	100%	40	4.5	6.0	3.1	1326	676	49%	96%
Banksia grandis	Trip 2	Brookton Highway	1	12	100%	67	7.6	8.7	4.9	1148	643	44%	79%
Banksia grandis	Trip 2	Brookton Highway	2	12	100%	89	10.1	11.8	6.4	1172	638	46%	84%
Banksia grandis	Trip 2	Brookton Highway	3	12	100%	103	11.6	12.4	7.9	1064	678	36%	57%
Banksia grandis	Trip 5	Power lines	1	12	100%	43	4.9	6.2	3.4	1275	703	45%	81%
Banksia grandis	Trip 5	Power lines	3	12	100%	45	5.1	6.2	3.3	1218	646	47%	88%
Banksia grandis	Trip 5	Power lines	4	12	100%	46	5.2	6.6	3.5	1269	669	47%	90%
Banksia grandis	Trip 5	Power lines	5	12	100%	47	5.3	6.7	3.7	1260	692	45%	82%
Banksia grandis	Trip 5	Power lines	6	12	100%	62	7.0	8.7	4.5	1241	647	48%	92%
Banksia grandis	Trip 5	Power lines	2h	12	100%	40	4.5	5.6	3.1	1238	681	45%	82%
Banksia grandis	Trip 5	Power lines	2l	12	100%	49	5.5	7.0	3.6	1263	644	49%	96%
Banksia grandis	Trip 5	Power lines	2m	12	100%	47	5.3	6.5	3.4	1223	640	48%	91%
Banksia grandis	Trip 6	Boundary Road	1	12	100%	73	8.3	10.4	5.8	1260	703	44%	79%
Banksia grandis	Trip 6	Boundary Road	2	12	100%	50	5.7	7.4	4.0	1309	711	46%	84%
Banksia grandis	Trip 6	Boundary Road	3	12	100%	66	7.5	9.8	5.1	1313	689	48%	91%
Banksia grandis	Trip 6	Boundary Road	4	12	100%	55	6.2	8.4	4.8	1350	767	43%	76%
Banksia grandis	Trip 6	Boundary Road	5	12	100%	39	4.4	6.2	3.4	1406	773	45%	82%
Banksia grandis	Trip 6	Boundary Road	6h	12	100%	45	5.1	6.5	3.2	1277	621	51%	106%
Banksia grandis	Trip 6	Boundary Road	6l	12	100%	62	7.0	9.0	4.3	1284	615	52%	109%
Banksia grandis	Trip 6	Boundary Road	6m	12	100%	51	5.8	7.3	3.5	1266	610	52%	107%
Banksia prionotes	Trip 2	Temple Farm	1	12	100%	88	10.0	11.4	6.6	1145	661	42%	73%
Banksia prionotes	Trip 2	Temple Farm	2	12	100%	87	9.8	11.3	6.7	1148	676	41%	70%
Banksia prionotes	Trip 2	Temple Farm	3	12	100%	76	8.6	9.5	5.6	1105	649	41%	70%
Banksia prionotes	Trip 7	Agaton	2	12	100%	44	5.0	5.8	3.2	1166	637	45%	83%
Banksia prionotes	Trip 7	Agaton	3	12	100%	51	5.8	7.1	3.4	1231	595	52%	107%
Banksia prionotes	Trip 7	Agaton	4	12	100%	44	5.0	5.8	3.1	1166	625	46%	86%
Banksia prionotes	Trip 7	Agaton	5	12	100%	47	5.3	6.0	3.2	1129	593	48%	90%
Banksia prionotes	Trip 7	Agaton	6	12	100%	43	4.9	5.7	3.2	1172	650	45%	80%
Banksia prionotes	Trip 7	Agaton	1h	12	100%	56	6.3	7.6	4.1	1200	649	46%	85%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Banksia prionotes	Trip 7	Agaton	1l	12	100%	65	7.4	8.8	4.5	1197	615	49%	95%
Banksia prionotes	Trip 7	Agaton	1m	12	100%	63	7.1	8.6	4.6	1207	646	47%	87%
Banksia prionotes	Trip 7	Yanchep pines	2	12	100%	75	8.5	10.3	5.5	1214	652	46%	86%
Banksia prionotes	Trip 7	Yanchep pines	3	12	100%	115	13.0	16.2	8.0	1246	614	51%	103%
Banksia prionotes	Trip 7	Yanchep pines	4	12	100%	69	7.8	9.6	5.6	1230	714	42%	72%
Banksia prionotes	Trip 7	Yanchep pines	5	12	100%	74	8.4	9.9	5.0	1183	593	50%	100%
Banksia prionotes	Trip 7	Yanchep pines	6	12	100%	85	9.6	11.4	6.4	1186	661	44%	80%
Banksia prionotes	Trip 7	Yanchep pines	1h	12	100%	40	4.5	5.8	2.9	1282	650	49%	97%
Banksia prionotes	Trip 7	Yanchep pines	1l	12	100%	62	7.0	8.6	4.2	1226	605	51%	103%
Banksia prionotes	Trip 7	Yanchep pines	1m	12	100%	60	6.8	8.6	4.1	1267	598	53%	112%
Brachychiton gregorii	Trip 5	Lake Deborah	1	12	100%	57	6.4	7.9	2.8	1225	437	64%	180%
Brachychiton gregorii	Trip 5	Lake Deborah	2	12	100%	111	12.6	15.1	5.3	1203	425	65%	183%
Brachychiton gregorii	Trip 5	Lake Deborah	3	12	100%	115	13.0	15.5	5.8	1192	448	62%	166%
Brachychiton gregorii	Trip 9	Masefield Road	2	12	100%	40	4.5	4.9	1.8	1083	398	63%	172%
Brachychiton gregorii	Trip 9	Masefield Road	3	12	100%	61	6.9	8.5	3.5	1232	504	59%	144%
Brachychiton gregorii	Trip 9	Masefield Road	4	12	100%	66	7.5	8.6	3.8	1152	505	56%	128%
Brachychiton gregorii	Trip 9	Masefield Road	5	12	100%	30	3.4	3.7	1.3	1091	377	65%	189%
Brachychiton gregorii	Trip 9	Masefield Road	6	12	100%	82	9.3	10.8	4.7	1165	506	57%	130%
Brachychiton gregorii	Trip 9	Masefield Road	1h	12	100%	54	6.1	7.4	3.0	1212	498	59%	143%
Brachychiton gregorii	Trip 9	Masefield Road	1l	12	100%	85	9.6	11.8	4.7	1227	493	60%	149%
Brachychiton gregorii	Trip 9	Masefield Road	1m	12	100%	70	7.9	9.4	3.8	1187	479	60%	148%
Bursaria occidentalis	JC	Mullewa - Critch	37	12	100%	95	10.7		6.6		617		
Bursaria occidentalis	Trip 4	#8 Tank	1	12	100%	53	6.0	7.6	5.0	1268	834	34%	52%
Bursaria occidentalis	Trip 4	#8 Tank	2	12	100%	76	8.6	10.2	6.3	1187	731	38%	62%
Bursaria occidentalis	Trip 4	#8 Tank	3	12	100%	55	6.2	7.4	4.5	1190	728	39%	63%
Bursaria occidentalis	Trip 9	Elachbutling Rock	2	12	100%	42	4.8	5.7	3.2	1200	674	44%	78%
Bursaria occidentalis	Trip 9	Elachbutling Rock	3	12	100%	39	4.4	5.7	3.1	1292	691	46%	87%
Bursaria occidentalis	Trip 9	Elachbutling Rock	4	12	100%	38	4.3	5.4	2.9	1256	682	46%	84%
Bursaria occidentalis	Trip 9	Elachbutling Rock	5	12	100%	32	3.6	4.6	2.6	1271	727	43%	75%
Bursaria occidentalis	Trip 9	Elachbutling Rock	6	12	100%	33	3.7	4.4	2.8	1179	740	37%	59%
Bursaria occidentalis	Trip 9	Elachbutling Rock	1h	12	100%	34	3.8	4.9	2.6	1274	676	47%	88%
Bursaria occidentalis	Trip 9	Elachbutling Rock	1l	12	100%	40	4.5	5.9	3.2	1304	701	46%	86%
Bursaria occidentalis	Trip 9	Elachbutling Rock	1m	12	100%	36	4.1	5.4	2.8	1326	675	49%	96%
Callistachys lanceolata	Trip 2	Rifle Range	1	12	100%	83	9.4	11.0	6.2	1172	663	43%	77%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Callistachys lanceolata	Trip 2	Rifle Range	2	12	100%	69	7.8	8.8	5.0	1128	634	44%	78%
Callistachys lanceolata	Trip 2	Rifle Range	3	12	100%	97	11.0	12.1	6.9	1103	626	43%	76%
Callistachys lanceolata	Trip 6	Boundary Road	2	12	100%	63	7.1	8.0	4.4	1123	615	45%	83%
Callistachys lanceolata	Trip 6	Boundary Road	3	12	100%	56	6.3	6.9	3.8	1089	606	44%	80%
Callistachys lanceolata	Trip 6	Boundary Road	4	12	100%	49	5.5	5.9	3.3	1065	597	44%	78%
Callistachys lanceolata	Trip 6	Boundary Road	5	12	100%	41	4.6	5.1	2.7	1100	576	48%	91%
Callistachys lanceolata	Trip 6	Boundary Road	6	12	100%	50	5.7	6.2	3.4	1096	599	45%	83%
Callistachys lanceolata	Trip 6	Boundary Road	1h	12	100%	49	5.5	5.9	3.2	1065	568	47%	87%
Callistachys lanceolata	Trip 6	Boundary Road	1l	12	100%	70	7.9	8.6	4.5	1086	565	48%	92%
Callistachys lanceolata	Trip 6	Boundary Road	1m	12	100%	57	6.4	6.8	3.7	1055	569	46%	85%
Callistachys lanceolata	Trip 6	Tone River	2	12	100%	43	4.9	5.2	2.8	1069	582	46%	84%
Callistachys lanceolata	Trip 6	Tone River	3	12	100%	52	5.9	6.2	3.3	1054	558	47%	89%
Callistachys lanceolata	Trip 6	Tone River	4	12	100%	48	5.4	5.7	3.2	1050	586	44%	79%
Callistachys lanceolata	Trip 6	Tone River	5	12	100%	54	6.1	6.8	3.5	1113	567	49%	97%
Callistachys lanceolata	Trip 6	Tone River	6	12	100%	53	6.0	6.2	3.2	1034	536	48%	93%
Callistachys lanceolata	Trip 6	Tone River	1h	12	100%	39	4.4	4.6	2.7	1043	601	42%	74%
Callistachys lanceolata	Trip 6	Tone River	1l	12	100%	59	6.7	7.3	4.2	1094	634	42%	73%
Callistachys lanceolata	Trip 6	Tone River	1m	12	100%	45	5.1	5.2	2.9	1022	578	43%	77%
Callistemon phoeniceus	Trip 2	Temple Farm	1	12	100%	86	9.7	12.6	9.2	1295	945	27%	37%
Callistemon phoeniceus	Trip 2	Temple Farm	2	12	100%	73	8.3	10.7	7.5	1296	910	30%	42%
Callistemon phoeniceus	Trip 2	Temple Farm	3	12	100%	61	6.9	8.6	5.8	1247	844	32%	48%
Callistemon phoeniceus	Trip 3	Daniell siding	1	12	100%	49	5.5	7.1	5.1	1281	911	29%	41%
Callistemon phoeniceus	Trip 3	Daniell siding	2	12	100%	46	5.2	7.1	5.0	1365	953	30%	43%
Callistemon phoeniceus	Trip 3	Daniell siding	3	12	100%	40	4.5	5.9	4.2	1304	931	29%	40%
Callitris canescens	Trip 3	Cascades Road III	1	12	100%	62	7.0	7.6	5.3	1084	757	30%	43%
Callitris canescens	Trip 3	Cascades Road III	2	12	100%	58	6.6	7.5	4.9	1143	744	35%	54%
Callitris canescens	Trip 3	Cascades Road III	3	12	100%	47	5.3	6.1	4.4	1148	822	28%	40%
Callitris glaucophylla	Trip 3	Norseman	1	12	100%	65	7.4	8.0	5.5	1088	752	31%	45%
Callitris glaucophylla	Trip 3	Norseman	2	12	50%	73	8.3	8.5	6.3	1030	759	26%	36%
Callitris glaucophylla	Trip 3	Norseman	3	12	100%	71	8.0	9.2	6.2	1146	776	32%	48%
Callitris glaucophylla	Trip 4	Lochada	1	12	100%	60	6.8	7.7	5.6	1135	822	28%	38%
Callitris glaucophylla	Trip 4	Lochada	2	12	100%	48	5.4	6.1	4.4	1124	812	28%	38%
Callitris glaucophylla	Trip 4	Lochada	3	12	100%	48	5.4	6.8	4.4	1253	812	35%	54%
Callitris glaucophylla	Trip 9	Barrier Fence South	1	12	100%	118	13.3	13.8	10.2	1034	764	26%	35%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Callitris glaucophylla	Trip 9	Barrier Fence South	2	12	100%	79	8.9	9.0	6.6	1007	738	27%	37%
Callitris glaucophylla	Trip 9	Barrier Fence South	3	12	100%	87	9.8	11.4	8.3	1159	839	28%	38%
Callitris tuberculata	Trip 3	Hyden Fence II	1	12	100%	100	11.3	12.8	8.7	1132	767	32%	48%
Callitris tuberculata	Trip 3	Hyden Fence II	2	12	100%	68	7.7	8.8	5.6	1144	729	36%	57%
Callitris tuberculata	Trip 3	Hyden Fence II	3	12	100%	94	10.6	11.8	7.7	1110	721	35%	54%
Calothamnus asper	Trip 6	Mt Burdett	1	12	100%	39	4.4	5.4	3.4	1224	778	36%	57%
Calothamnus asper	Trip 6	Mt Burdett	2	12	100%	31	3.5	4.2	2.7	1198	759	37%	58%
Calothamnus asper	Trip 6	Mt Burdett	3	12	100%	30	3.4	4.3	2.7	1267	802	37%	58%
Calothamnus tuberosus	Trip 3	Bromus	1	12	100%	76	8.6	11.2	6.9	1303	798	39%	63%
Calothamnus tuberosus	Trip 3	Bromus	2	12	100%	63	7.1	9.2	5.6	1291	792	39%	63%
Calothamnus tuberosus	Trip 3	Bromus	3	12	100%	77	8.7	11.4	7.1	1309	819	37%	60%
Calycopeplus paucifolius	Trip 4	Yalgoo Road	1	12	100%	34	3.8	4.1	3.4	1066	879	18%	21%
Calycopeplus paucifolius	Trip 4	Yalgoo Road	2	12	100%	55	6.2	6.5	5.3	1045	849	19%	23%
Calycopeplus paucifolius	Trip 4	Yalgoo Road	3	12	100%	40	4.5	4.5	3.6	995	802	19%	24%
Casuarina obesa	Trip 1	Beaufort River Flats	1	12	100%	113	12.8	15.0	10.1	1174	789	33%	49%
Casuarina obesa	Trip 1	Beaufort River Flats	2	12	50%	94	10.6	12.6	9.1	1185	859	28%	38%
Casuarina obesa	Trip 1	Beaufort River Flats	3	12	100%	122	13.8	14.6	8.9	1058	641	39%	65%
Casuarina obesa	Trip 1	Nepowie TAFT	1	12	100%	100	11.3	13.1	8.3	1158	729	37%	59%
Casuarina obesa	Trip 1	Nepowie TAFT	2	12	100%	98	11.1	13.2	8.6	1191	777	35%	53%
Casuarina obesa	Trip 1	Nepowie TAFT	3	12	100%	91	10.3	11.8	7.1	1147	693	40%	65%
Casuarina obesa	Trip 5	Gillett Road	2	12	100%	60	6.8	8.3	4.2	1223	616	50%	99%
Casuarina obesa	Trip 5	Gillett Road	3	12	100%	72	8.1	10.3	5.4	1265	658	48%	92%
Casuarina obesa	Trip 5	Gillett Road	4	12	100%	80	9.0	11.2	6.0	1238	663	46%	87%
Casuarina obesa	Trip 5	Gillett Road	5	12	100%	62	7.0	8.6	4.6	1226	657	46%	87%
Casuarina obesa	Trip 5	Gillett Road	6	12	100%	53	6.0	7.4	4.1	1235	677	45%	82%
Casuarina obesa	Trip 5	Gillett Road	1h	10	100%	106	8.3	10.5	5.1	1261	617	51%	104%
Casuarina obesa	Trip 5	Gillett Road	1l	12	100%	61	6.9	8.7	4.6	1261	660	48%	91%
Casuarina obesa	Trip 5	Gillett Road	1m	18	100%	95	22.9	27.3	13.6	1195	597	50%	100%
Casuarina obesa	Trip 8	Boothy	2	12	100%	58	6.6	8.4	4.8	1281	733	43%	75%
Casuarina obesa	Trip 8	Boothy	3	12	100%	66	7.5	9.3	4.9	1246	662	47%	88%
Casuarina obesa	Trip 8	Boothy	4	12	100%	62	7.0	8.8	5.0	1255	706	44%	78%
Casuarina obesa	Trip 8	Boothy	5	12	100%	53	6.0	7.7	4.4	1285	726	44%	77%
Casuarina obesa	Trip 8	Boothy	6	12	100%	57	6.4	8.2	4.8	1272	741	42%	72%
Casuarina obesa	Trip 8	Boothy	1h	12	100%	46	5.2	6.5	3.7	1249	702	44%	78%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Casuarina obesa	Trip 8	Boothy	1l	12	100%	56	6.3	8.5	4.7	1342	739	45%	82%
Casuarina obesa	Trip 8	Boothy	1m	12	100%	52	5.9	7.6	4.2	1292	711	45%	82%
Casuarina obesa	Trip 9	Watheroo	2	12	100%	38	4.3	5.7	3.4	1326	784	41%	69%
Casuarina obesa	Trip 9	Watheroo	3	12	100%	36	4.1	5.2	3.1	1277	754	41%	69%
Casuarina obesa	Trip 9	Watheroo	4	12	100%	34	3.8	4.8	2.9	1248	746	40%	67%
Casuarina obesa	Trip 9	Watheroo	5	12	100%	30	3.4	4.4	2.8	1297	811	38%	60%
Casuarina obesa	Trip 9	Watheroo	6	12	100%	34	3.8	4.9	3.0	1274	772	39%	65%
Casuarina obesa	Trip 9	Watheroo	1h	12	100%	30	3.4	4.4	2.3	1297	678	48%	91%
Casuarina obesa	Trip 9	Watheroo	1l	12	100%	46	5.2	6.5	3.8	1249	728	42%	72%
Casuarina obesa	Trip 9	Watheroo	1m	12	100%	33	3.7	4.9	2.6	1313	707	46%	86%
Chamaecytisus palmensis	JC	Dongara - Grieves	24	12	100%	107	12.1		8.8		730		
Chamelaucium uncinatum	Trip 4	Houston Avenue	1	12	100%	62	7.0	8.4	5.0	1198	709	41%	69%
Codonocarpus cotinifolius	JC	Kalannie - roadside	14	12	100%	48	5.4		3.0		556		
Codonocarpus cotinifolius	JC	Kalannie - roadside	15	12	100%	48	5.4		2.5		464		
Codonocarpus cotinifolius	JC	Kalannie - roadside	16	12	100%	76	8.6		4.5		520		
Codonocarpus cotinifolius	JC	Kalannie - roadside	17	12	100%	102	11.5		5.7		496		
Codonocarpus cotinifolius	Trip 3	Cronin Rock	1	12	100%	83	9.4	10.4	5.3	1108	559	50%	98%
Codonocarpus cotinifolius	Trip 3	Cronin Rock	2	12	100%	78	8.8	10.4	4.5	1179	507	57%	133%
Codonocarpus cotinifolius	Trip 3	Cronin Rock	3	12	100%	62	7.0	8.5	3.3	1212	466	62%	160%
Codonocarpus cotinifolius	Trip 4	Paddock 38	1	12	100%	79	8.9	10.9	3.5	1220	395	68%	209%
Codonocarpus cotinifolius	Trip 4	Paddock 38	2	12	100%	56	6.3	7.2	2.6	1137	409	64%	178%
Codonocarpus cotinifolius	Trip 4	Paddock 38	3	12	100%	66	7.5	8.8	3.4	1179	458	61%	157%
Codonocarpus cotinifolius	Trip 5	Benari	2	12	100%	42	4.8	5.4	1.4	1137	303	73%	275%
Codonocarpus cotinifolius	Trip 5	Benari	3	12	100%	41	4.6	5.4	1.7	1165	371	68%	214%
Codonocarpus cotinifolius	Trip 5	Benari	4	12	100%	45	5.1	5.6	1.6	1100	308	72%	257%
Codonocarpus cotinifolius	Trip 5	Benari	5	12	100%	40	4.5	5.4	1.4	1194	312	74%	283%
Codonocarpus cotinifolius	Trip 5	Benari	6	12	100%	31	3.5	4.1	1.2	1169	339	71%	245%
Codonocarpus cotinifolius	Trip 5	Benari	1h	12	100%	26	2.9	3.5	1.1	1190	381	68%	213%
Codonocarpus cotinifolius	Trip 5	Benari	1l	12	100%	62	7.0	8.1	2.5	1155	349	70%	231%
Codonocarpus cotinifolius	Trip 5	Benari	1m	12	100%	40	4.5	5.3	1.6	1172	351	70%	233%
Codonocarpus cotinifolius	Trip 5	Karalee	1	12	100%	30	3.4	3.5	1.2	1032	345	67%	199%
Codonocarpus cotinifolius	Trip 5	Karalee	2	12	100%	36	4.1	4.6	1.2	1130	297	74%	280%
Codonocarpus cotinifolius	Trip 5	Karalee	3	12	100%	37	4.2	4.8	1.3	1147	318	72%	261%
Codonocarpus cotinifolius	Trip 5	Karalee	4	12	100%	34	3.8	4.3	1.6	1118	406	64%	176%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Codonocarpus cotinifolius	Trip 5	Karalee	5	12	100%	36	4.1	4.8	1.4	1179	334	72%	253%
Codonocarpus cotinifolius	Trip 5	Karalee	6	12	100%	41	4.6	5.1	1.6	1100	347	68%	217%
Codonocarpus cotinifolius	Trip 9	Chiddarcooping	2	12	100%	56	6.3	7.3	2.1	1153	333	71%	246%
Codonocarpus cotinifolius	Trip 9	Chiddarcooping	3	12	100%	69	7.8	9.3	3.1	1192	399	67%	199%
Codonocarpus cotinifolius	Trip 9	Chiddarcooping	4	12	100%	41	4.6	5.5	1.7	1186	371	69%	220%
Codonocarpus cotinifolius	Trip 9	Chiddarcooping	5	12	100%	44	5.0	5.8	1.8	1166	358	69%	226%
Codonocarpus cotinifolius	Trip 9	Chiddarcooping	6	12	100%	38	4.3	5.2	1.9	1210	433	64%	180%
Codonocarpus cotinifolius	Trip 9	Chiddarcooping	1h	12	100%	61	6.9	8.3	2.9	1203	422	65%	185%
Codonocarpus cotinifolius	Trip 9	Chiddarcooping	1l	12	100%	73	8.3	9.9	3.2	1199	391	67%	207%
Codonocarpus cotinifolius	Trip 9	Chiddarcooping	1m	12	100%	70	7.9	9.6	3.1	1213	389	68%	212%
Conospermum triplinervium	Trip 6	Mosquito mecca	1	12	100%	49	5.5	7.1	3.0	1281	543	58%	136%
Conospermum triplinervium	Trip 6	Mosquito mecca	2	12	100%	42	4.8	6.3	2.7	1326	566	57%	134%
Conospermum triplinervium	Trip 6	Mosquito mecca	3	12	100%	60	6.8	8.7	3.6	1282	531	59%	142%
Conospermum triplinervium	Trip 8	Secret Harbour	1	12	100%	28	3.2	4.0	1.6	1263	518	59%	144%
Conospermum triplinervium	Trip 8	Secret Harbour	2	12	100%	40	4.5	5.7	2.6	1260	584	54%	116%
Conospermum triplinervium	Trip 8	Secret Harbour	3	12	100%	26	2.9	3.8	1.8	1292	609	53%	112%
Conospermum triplinervium	Trip 8	Syred	2	12	100%	40	4.5	5.6	2.1	1238	464	63%	167%
Conospermum triplinervium	Trip 8	Syred	3	12	100%	47	5.3	6.6	2.6	1242	491	60%	153%
Conospermum triplinervium	Trip 8	Syred	4	12	100%	49	5.5	6.4	2.8	1155	512	56%	125%
Conospermum triplinervium	Trip 8	Syred	5	12	100%	46	5.2	5.9	2.6	1134	494	56%	130%
Conospermum triplinervium	Trip 8	Syred	6	12	100%	45	5.1	6.3	2.8	1238	544	56%	127%
Conospermum triplinervium	Trip 8	Syred	1h	12	0%	45	5.1	5.4	2.7	1061	525	51%	102%
Conospermum triplinervium	Trip 8	Syred	1l	12	50%	28	3.2	3.6	1.6	1137	502	56%	126%
Conospermum triplinervium	Trip 8	Syred	1m	16	0%	41	7.7	8.4	4.2	1086	536	51%	102%
Corymbia calophylla	Trip 1	Beaufort River Flats	1	12	100%	88	10.0	12.3	7.4	1236	740	40%	67%
Corymbia calophylla	Trip 1	Beaufort River Flats	2	12	100%	101	11.4	12.1	7.7	1059	676	36%	57%
Corymbia calophylla	Trip 1	Beaufort River Flats	3	12	100%	110	12.4	15.1	9.5	1214	760	37%	60%
Dodonaea (?) sp.	Trip 5	Snake soak breakaway	1	12	100%	38	4.3	6.2	5.0	1443	1154	20%	25%
Dodonaea (?) sp.	Trip 5	Snake soak breakaway	2	12	100%	30	3.4	4.6	3.7	1356	1082	20%	25%
Dodonaea (?) sp.	Trip 5	Snake soak breakaway	3	12	100%	29	3.3	5.0	3.6	1524	1095	28%	39%
Dodonaea (?) sp.	Trip 5	Snake soak breakaway	4	13	100%	86	10.6	13.3	10.4	1260	986	22%	28%
Dodonaea inaequifolia	Trip 4	Wells Siding Road	1	12	100%	42	4.8	6.5	5.0	1368	1057	23%	29%
Dodonaea inaequifolia	Trip 4	Wells Siding Road	2	12	100%	39	4.4	6.2	4.9	1406	1120	20%	26%
Dodonaea inaequifolia	Trip 4	Wells Siding Road	3	12	100%	50	5.7	7.8	6.1	1379	1077	22%	28%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Dodonaea ptarmicaefolia	Trip 6	Cocanarup pool	1	12	100%	33	3.7	5.3	4.0	1420	1074	24%	32%
Dodonaea ptarmicaefolia	Trip 6	Cocanarup pool	2	12	100%	36	4.1	5.7	4.3	1400	1066	24%	31%
Dodonaea ptarmicaefolia	Trip 6	Cocanarup pool	3	12	100%	43	4.9	6.8	5.1	1398	1051	25%	33%
Dodonea viscosa subsp. angustissima (?)	Trip 3	Johnston Lakes	1	12	100%	39	4.4	5.8	4.3	1315	968	26%	36%
Dodonea viscosa subsp. angustissima (?)	Trip 3	Johnston Lakes	2	12	100%	45	5.1	7.0	5.4	1375	1057	23%	30%
Dodonea viscosa subsp. angustissima (?)	Trip 3	Johnston Lakes	3	12	100%	55	6.2	8.3	6.3	1334	1008	24%	32%
Dryandra arborea	Trip 5	Koolyanobbing	1	12	100%	65	7.4	9.1	6.1	1238	830	33%	49%
Dryandra arborea	Trip 5	Koolyanobbing	2	12	100%	58	6.6	8.5	5.6	1296	851	34%	52%
Dryandra arborea	Trip 5	Koolyanobbing	3	12	100%	65	7.4	9.6	6.4	1306	872	33%	50%
Dryandra nobilis	Trip 6	Brookton	1	12	100%	43	4.9	5.5	3.5	1131	728	36%	55%
Dryandra nobilis	Trip 6	Brookton	2	12	100%	37	4.2	5.3	3.4	1267	808	36%	57%
Dryandra nobilis	Trip 6	Brookton	3	12	100%	47	5.3	6.3	4.0	1185	760	36%	56%
Dryandra sessilis	Trip 2	Brookton Highway	1	12	100%	63	7.1	8.7	5.2	1221	724	41%	69%
Dryandra sessilis	Trip 2	Brookton Highway	2	12	100%	68	7.7	7.9	4.7	1027	610	41%	68%
Dryandra sessilis	Trip 2	Brookton Highway	3	12	100%	82	9.3	10.4	6.5	1121	698	38%	61%
Dryandra sessilis	Trip 8	Metro gravel	2	12	100%	47	5.3	6.5	3.7	1223	702	43%	74%
Dryandra sessilis	Trip 8	Metro gravel	3	12	100%	56	6.3	8.2	4.6	1295	731	44%	77%
Dryandra sessilis	Trip 8	Metro gravel	4	12	100%	46	5.2	6.6	3.9	1269	757	40%	68%
Dryandra sessilis	Trip 8	Metro gravel	5	12	100%	58	6.6	8.1	4.6	1235	703	43%	76%
Dryandra sessilis	Trip 8	Metro gravel	6	12	100%	58	6.6	9.3	5.6	1418	854	40%	66%
Dryandra sessilis	Trip 8	Metro gravel	1h	12	100%	39	4.4	5.7	3.3	1292	739	43%	75%
Dryandra sessilis	Trip 8	Metro gravel	1l	12	100%	60	6.8	8.8	5.1	1297	744	43%	74%
Dryandra sessilis	Trip 8	Metro gravel	1m	12	100%	52	5.9	7.5	4.3	1275	723	43%	76%
Dryandra sessilis	Trip 8	Parking Bay	2	12	100%	42	4.8	5.7	3.5	1200	745	38%	61%
Dryandra sessilis	Trip 8	Parking Bay	3	12	100%	47	5.3	6.1	3.8	1148	722	37%	59%
Dryandra sessilis	Trip 8	Parking Bay	4	12	100%	43	4.9	6.3	3.5	1295	720	44%	80%
Dryandra sessilis	Trip 8	Parking Bay	5	12	100%	46	5.2	6.9	4.1	1326	780	41%	70%
Dryandra sessilis	Trip 8	Parking Bay	6	12	100%	38	4.3	5.9	3.4	1373	789	43%	74%
Dryandra sessilis	Trip 8	Parking Bay	1h	12	100%	41	4.6	5.4	3.4	1165	735	37%	58%
Dryandra sessilis	Trip 8	Parking Bay	1l	12	100%	64	7.2	9.1	5.4	1257	743	41%	69%
Dryandra sessilis	Trip 8	Parking Bay	1m	12	100%	56	6.3	7.7	4.7	1216	748	38%	62%
Duboisia hopwoodii	Trip 5	Bali	1	12	100%	77	8.7	7.5	3.3	861	382	56%	125%
Duboisia hopwoodii	Trip 5	Bali	2	12	100%	32	3.6	3.5	1.9	967	517	47%	87%
Duboisia hopwoodii	Trip 5	Bali	3	12	100%	73	8.3	7.1	4.3	860	523	39%	64%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Duboisia hopwoodii	Trip 5	Sasche Road	1	12	100%	36	4.1	3.8	1.8	933	447	52%	109%
Duboisia hopwoodii	Trip 5	Sasche Road	2	12	100%	58	6.6	6.0	3.2	915	492	46%	86%
Duboisia hopwoodii	Trip 5	Sasche Road	3	12	100%	66	7.5	7.3	3.8	978	514	47%	90%
Eremophila alternifolia	Trip 5	Lake Douglas	1	12	100%	35	4.0	5.1	4.2	1288	1053	18%	22%
Eremophila alternifolia	Trip 5	Lake Douglas	2	12	100%	32	3.6	4.6	3.7	1271	1033	19%	23%
Eremophila alternifolia	Trip 5	Lake Douglas	3	12	100%	43	4.9	6.4	5.0	1316	1026	22%	28%
Eremophila alternifolia (?)	Trip 3	Johnston Lakes East	3	12	100%	70	7.9	9.4	6.9	1187	877	26%	35%
Eremophila alternifolia (?)	Trip 3	Lake Cowan	1	12	100%	43	4.9	5.8	4.9	1193	1012	15%	18%
Eremophila alternifolia (?)	Trip 3	Lake Cowan	2	12	100%	53	6.0	7.3	6.1	1218	1021	16%	19%
Eremophila alternifolia (?)	Trip 3	Lake Cowan	3	12	100%	45	5.1	6.7	5.7	1316	1118	15%	18%
Eremophila caperata (?)	Trip 3	Johnston Lakes East	1	12	100%	42	4.8	5.9	4.4	1242	922	26%	35%
Eremophila caperata (?)	Trip 3	Johnston Lakes East	2	12	100%	67	7.6	8.7	6.2	1148	822	28%	40%
Eremophila deserti	Trip 6	Mt Ney	1	12	100%	40	4.5	5.4	3.9	1194	860	28%	39%
Eremophila deserti	Trip 6	Mt Ney	2	12	100%	32	3.6	4.1	2.9	1133	787	30%	44%
Eremophila deserti	Trip 6	Mt Ney	3	12	100%	49	5.5	6.5	4.8	1173	859	27%	37%
Eremophila interstans	Trip 5	Boorabin	1	12	100%	31	3.5	4.4	3.3	1255	930	26%	35%
Eremophila interstans	Trip 5	Boorabin	2	12	100%	45	5.1	6.4	4.5	1258	886	30%	42%
Eremophila interstans	Trip 5	Boorabin	3	12	100%	47	5.3	6.6	5.0	1242	946	24%	31%
Eremophila longifolia	Trip 4	Madden Road	1	12	100%	63	7.1	8.5	6.6	1193	921	23%	30%
Eremophila longifolia	Trip 4	Madden Road	2	12	100%	55	6.2	7.1	5.6	1141	899	21%	27%
Eremophila longifolia	Trip 4	Madden Road	3	12	100%	55	6.2	7.4	5.7	1190	921	23%	29%
Eremophila longifolia	Trip 5	Lake Douglas	1	12	100%	42	4.8	5.2	3.7	1095	779	29%	41%
Eremophila longifolia	Trip 5	Lake Douglas	2	12	100%	53	6.0	6.7	5.2	1118	873	22%	28%
Eremophila longifolia	Trip 5	Lake Douglas	3	12	100%	31	3.5	4.1	3.0	1169	856	27%	37%
Eremophila miniata	Trip 5	Kalannie rifle range track	1	12	100%	45	5.1	5.6	3.9	1100	772	30%	42%
Eremophila miniata	Trip 5	Kalannie rifle range track	2	12	100%	47	5.3	5.7	4.0	1072	743	31%	44%
Eremophila miniata	Trip 5	Kalannie rifle range track	3	12	100%	63	7.1	7.4	5.2	1039	734	29%	41%
Eremophila miniata	Trip 5	Kanowna Lakes	1	12	100%	44	5.0	5.5	4.0	1105	812	27%	36%
Eremophila miniata	Trip 5	Kanowna Lakes	2	12	100%	38	4.3	4.7	3.3	1094	773	29%	42%
Eremophila miniata	Trip 5	Kanowna Lakes	3	12	100%	46	5.2	6.0	4.5	1153	863	25%	34%
Eremophila oldfieldii	Trip 5	Bali West	1	12	100%	65	7.4	8.1	6.2	1102	845	23%	30%
Eremophila oldfieldii	Trip 5	Bali West	2	12	100%	35	4.0	5.0	3.8	1263	955	24%	32%
Eremophila oldfieldii	Trip 5	Bali West	3	12	100%	44	5.0	6.1	4.7	1226	938	23%	31%
Eremophila oldfieldii	Trip 5	Hamersley Lakes	1	12	100%	41	4.6	5.4	4.2	1165	912	22%	28%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Eremophila oldfieldii	Trip 5	Hamersley Lakes	2	12	100%	44	5.0	5.9	4.7	1186	940	21%	26%
Eremophila oldfieldii	Trip 5	Hamersley Lakes	3	12	100%	50	5.7	6.7	5.2	1185	925	22%	28%
Eremophila oppositifolia	Trip 4	Madden Road	1	12	100%	57	6.4	7.7	5.9	1194	915	23%	31%
Eremophila oppositifolia	Trip 4	Madden Road	2	12	100%	49	5.5	6.4	5.0	1155	893	23%	29%
Eremophila oppositifolia	Trip 4	Madden Road	3	12	100%	57	6.4	7.2	5.5	1117	845	24%	32%
Eremophila psilocalyx (?)	Trip 3	Dundas Hills	1	12	100%	56	6.3	7.8	5.8	1232	911	26%	35%
Eremophila psilocalyx (?)	Trip 3	Dundas Hills	2	12	100%	46	5.2	6.3	4.7	1211	903	25%	34%
Eremophila psilocalyx (?)	Trip 3	Dundas Hills	3	12	100%	50	5.7	7.2	5.4	1273	957	25%	33%
Eremophila scoparia	Trip 5	Powerline	1	12	100%	32	3.6	4.9	3.5	1354	973	28%	39%
Eremophila scoparia	Trip 5	Powerline	2	12	100%	34	3.8	5.4	4.3	1404	1116	21%	26%
Eremophila scoparia	Trip 5	Powerline	3	12	100%	25	2.8	3.7	2.9	1309	1026	22%	28%
Eremophila serrulata (?)	Trip 3	Mount Henry	1	12	100%	46	5.2	6.1	5.0	1173	951	19%	23%
Eremophila serrulata (?)	Trip 3	Mount Henry	2	12	100%	31	3.5	4.1	3.2	1169	916	22%	28%
Eremophila serrulata (?)	Trip 3	Mount Henry	3	12	100%	43	4.9	5.8	4.7	1193	964	19%	24%
Eucalyptus accedens	Trip 5	Calingiri Road	1	12	100%	38	4.3	5.4	3.6	1256	831	34%	51%
Eucalyptus accedens	Trip 5	Calingiri Road	2	12	100%	48	5.4	6.9	5.0	1271	921	28%	38%
Eucalyptus accedens	Trip 5	Calingiri Road	3	12	100%	50	5.7	7.2	5.2	1273	914	28%	39%
Eucalyptus alipes	Trip 3	Crossroads South	1	12	100%	77	8.7	11.2	8.8	1286	1012	21%	27%
Eucalyptus alipes	Trip 3	Crossroads South	2	12	100%	64	7.2	9.4	7.5	1299	1033	20%	26%
Eucalyptus alipes	Trip 3	Crossroads South	3	12	100%	71	8.0	10.3	8.2	1283	1020	20%	26%
Eucalyptus angustissima	Trip 2	Wansborough	1	12	100%	79	8.9	11.0	8.0	1231	899	27%	37%
Eucalyptus angustissima	Trip 2	Wansborough	2	12	100%	93	10.5	12.9	9.0	1226	855	30%	43%
Eucalyptus angustissima	Trip 2	Wansborough	3	12	100%	98	11.1	13.8	9.8	1245	880	29%	42%
Eucalyptus annulata	Trip 6	Ravensthorpe	1	12	100%	32	3.6	4.7	3.4	1299	951	27%	37%
Eucalyptus annulata	Trip 6	Ravensthorpe	2	12	100%	34	3.8	4.7	3.4	1222	887	27%	38%
Eucalyptus annulata	Trip 6	Ravensthorpe	3	12	100%	30	3.4	4.3	3.1	1267	905	29%	40%
Eucalyptus annulata	Trip 8	Chinocup	1	12	100%	54	6.1	7.1	5.5	1163	899	23%	29%
Eucalyptus annulata	Trip 8	Chinocup	2	12	100%	49	5.5	6.8	5.4	1227	967	21%	27%
Eucalyptus annulata	Trip 8	Chinocup	3	12	100%	52	5.9	7.1	5.4	1207	913	24%	32%
Eucalyptus argyphea	Trip 3	Cascades Road	1	12	100%	60	6.8	8.3	6.0	1223	887	27%	38%
Eucalyptus argyphea	Trip 3	Cascades Road	2	12	100%	55	6.2	7.5	5.8	1206	932	23%	29%
Eucalyptus argyphea	Trip 3	Cascades Road	3	12	100%	61	6.9	8.4	6.2	1218	899	26%	35%
Eucalyptus aspratilis	Trip 3	McDermid Rock	1	12	100%	61	6.9	9.5	7.4	1377	1076	22%	28%
Eucalyptus aspratilis	Trip 3	McDermid Rock	2	12	100%	50	5.7	7.2	5.6	1273	994	22%	28%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Eucalyptus aspratilis	Trip 3	McDermid Rock	3	12	100%	58	6.6	8.3	6.7	1265	1023	19%	24%
Eucalyptus astringens	Trip 1	Davenport TAFT	1	12	100%	73	8.3	9.9	6.6	1199	801	33%	50%
Eucalyptus astringens	Trip 1	Davenport TAFT	2	12	100%	84	9.5	11.0	7.9	1158	826	29%	40%
Eucalyptus astringens	Trip 1	Davenport TAFT	3	12	100%	100	11.3	12.6	8.8	1114	776	30%	44%
Eucalyptus astringens subsp. redacta	Trip 8	Mount Melville	1	12	100%	23	2.6	3.3	2.5	1269	942	26%	35%
Eucalyptus astringens subsp. redacta	Trip 8	Mount Melville	2	12	100%	35	4.0	4.6	3.5	1162	872	25%	33%
Eucalyptus astringens subsp. redacta	Trip 8	Mount Melville	3	12	100%	38	4.3	5.3	3.8	1233	891	28%	38%
Eucalyptus balladoniensis	Trip 6	Dingo Rock Road	1	12	100%	35	4.0	5.0	3.6	1263	920	27%	37%
Eucalyptus balladoniensis	Trip 6	Dingo Rock Road	2	12	100%	37	4.2	5.3	3.8	1267	896	29%	41%
Eucalyptus balladoniensis	Trip 6	Dingo Rock Road	3	12	100%	42	4.8	6.1	4.3	1284	914	29%	41%
Eucalyptus brachycorys	Trip 9	Latham Lake	1	12	100%	41	4.6	6.1	4.6	1316	990	25%	33%
Eucalyptus brachycorys	Trip 9	Latham Lake	2	12	100%	47	5.3	6.9	5.2	1298	984	24%	32%
Eucalyptus brachycorys	Trip 9	Latham Lake	3	12	100%	38	4.3	5.8	4.3	1350	998	26%	35%
Eucalyptus burracoppinensis	Trip 5	Cadoux Road	1	12	100%	46	5.2	6.6	5.0	1269	959	24%	32%
Eucalyptus burracoppinensis	Trip 5	Cadoux Road	2	12	100%	50	5.7	7.1	5.6	1256	981	22%	28%
Eucalyptus burracoppinensis	Trip 5	Cadoux Road	3	12	100%	43	4.9	6.3	4.7	1295	966	25%	34%
Eucalyptus camaldulensis var. obtusa (?)	Trip 4	Arrowsmith River	1	12	100%	53	6.0	7.3	3.6	1218	606	50%	101%
Eucalyptus camaldulensis var. obtusa (?)	Trip 4	Arrowsmith River	2	12	100%	66	7.5	9.5	5.0	1273	675	47%	88%
Eucalyptus camaldulensis var. obtusa (?)	Trip 4	Arrowsmith River	3	12	100%	68	7.7	7.4	4.9	962	637	34%	51%
Eucalyptus camaldulensis var. obtusa (?)	Trip 4	Doley's	1	12	100%	88	10.0	12.2	5.7	1226	569	54%	116%
Eucalyptus camaldulensis var. obtusa (?)	Trip 4	Doley's	2	12	100%	83	9.4	11.7	5.1	1246	542	56%	130%
Eucalyptus camaldulensis var. obtusa (?)	Trip 4	Doley's	3	12	100%	86	9.7	11.8	5.3	1213	540	56%	125%
Eucalyptus camaldulensis var. obtusa (?)	Trip 4	Wilroy	1	12	100%	56	6.3	7.6	4.1	1200	651	46%	84%
Eucalyptus camaldulensis var. obtusa (?)	Trip 4	Wilroy	2	12	100%	53	6.0	7.6	4.2	1268	706	44%	80%
Eucalyptus camaldulensis var. obtusa (?)	Trip 4	Wilroy	3	12	100%	63	7.1	8.7	4.8	1221	667	45%	83%
Eucalyptus camaldulensis var. obtusa (?)	Trip 9	Kalannie West	2	12	100%	40	4.5	5.1	2.7	1127	597	47%	89%
Eucalyptus camaldulensis var. obtusa (?)	Trip 9	Kalannie West	3	12	100%	29	3.3	3.9	2.2	1189	656	45%	81%
Eucalyptus camaldulensis var. obtusa (?)	Trip 9	Kalannie West	4	12	100%	59	6.7	8.2	4.7	1229	707	42%	74%
Eucalyptus camaldulensis var. obtusa (?)	Trip 9	Kalannie West	5	12	100%	44	5.0	5.7	2.8	1145	553	52%	107%
Eucalyptus camaldulensis var. obtusa (?)	Trip 9	Kalannie West	6	12	100%	48	5.4	6.7	4.1	1234	746	40%	65%
Eucalyptus camaldulensis var. obtusa (?)	Trip 9	Kalannie West	1h	12	100%	29	3.3	4.1	2.2	1250	662	47%	89%
Eucalyptus camaldulensis var. obtusa (?)	Trip 9	Kalannie West	1l	12	100%	39	4.4	5.5	2.9	1247	660	47%	89%
Eucalyptus camaldulensis var. obtusa (?)	Trip 9	Kalannie West	1m	12	100%	34	3.8	4.8	2.5	1248	640	49%	95%
Eucalyptus capillosa	Trip 5	Snake soak cruiser	1	12	100%	50	5.7	6.9	5.3	1220	944	23%	29%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Eucalyptus capillosa	Trip 5	Snake soak cruiser	2	12	100%	65	7.4	9.6	7.5	1306	1019	22%	28%
Eucalyptus capillosa	Trip 5	Snake soak cruiser	3	12	100%	52	5.9	7.6	5.8	1292	988	24%	31%
Eucalyptus capillosa subsp. polyclada	Trip 9	Pithara	1	12	100%	47	5.3	6.9	5.5	1298	1027	21%	26%
Eucalyptus capillosa subsp. polyclada	Trip 9	Pithara	2	12	100%	31	3.5	4.3	3.1	1226	876	29%	40%
Eucalyptus capillosa subsp. polyclada	Trip 9	Pithara	3	12	100%	46	5.2	6.6	5.2	1269	1000	21%	27%
Eucalyptus celastroides	Trip 5	Snake soak clearing	1	12	100%	55	6.2	8.2	6.7	1318	1069	19%	23%
Eucalyptus celastroides	Trip 5	Snake soak clearing	2	12	100%	62	7.0	8.8	7.1	1255	1013	19%	24%
Eucalyptus celastroides	Trip 5	Snake soak clearing	3	12	100%	57	6.4	8.2	6.6	1272	1019	20%	25%
Eucalyptus clivicola	Trip 6	Moir Road	1	12	100%	37	4.2	5.5	4.1	1314	975	26%	35%
Eucalyptus clivicola	Trip 6	Moir Road	2	12	100%	38	4.3	5.4	4.2	1256	966	23%	30%
Eucalyptus clivicola	Trip 6	Moir Road	3	12	100%	38	4.3	5.6	4.3	1303	991	24%	31%
Eucalyptus conferruminata	Trip 3	Fairlawn	1	12	100%	84	9.5	11.2	7.9	1179	835	29%	41%
Eucalyptus conferruminata	Trip 3	Fairlawn	2	12	100%	102	11.5	13.8	10.2	1196	887	26%	35%
Eucalyptus conferruminata	Trip 3	Fairlawn	3	12	100%	80	9.0	10.9	7.8	1205	860	29%	40%
Eucalyptus cornuta	Trip 8	Silent Grove	1	12	100%	80	9.0	11.3	7.5	1249	825	34%	51%
Eucalyptus cornuta	Trip 8	Silent Grove	2	12	100%	64	7.2	9.1	5.5	1257	753	40%	67%
Eucalyptus cornuta	Trip 8	Silent Grove	3	12	100%	55	6.2	7.5	5.2	1206	828	31%	46%
Eucalyptus dundasii	Trip 3	Norseman West	1	12	100%	80	9.0	11.3	8.9	1249	985	21%	27%
Eucalyptus dundasii	Trip 3	Norseman West	2	12	100%	86	9.7	11.6	9.3	1193	959	20%	24%
Eucalyptus dundasii	Trip 3	Norseman West	3	12	100%	84	9.5	11.5	9.4	1211	992	18%	22%
Eucalyptus eremophila mallet form	Trip 3	Daniell siding	1	12	100%	65	7.4	9.4	7.3	1279	997	22%	28%
Eucalyptus eremophila mallet form	Trip 3	Daniell siding	2	12	100%	62	7.0	8.8	6.9	1255	984	22%	28%
Eucalyptus eremophila mallet form	Trip 3	Daniell siding	3	12	100%	63	7.1	9.2	7.2	1291	1015	21%	27%
Eucalyptus erythrocorys	Trip 4	Beekeeper Road West	1	12	100%	58	6.6	8.0	4.7	1220	709	42%	72%
Eucalyptus erythrocorys	Trip 4	Beekeeper Road West	2	12	100%	70	7.9	9.3	5.6	1175	705	40%	67%
Eucalyptus erythrocorys	Trip 4	Beekeeper Road West	3	12	100%	91	10.3	12.8	8.6	1244	839	33%	48%
Eucalyptus erythrocorys	Trip 7	Beehive	2	12	100%	65	7.4	9.3	5.1	1265	694	45%	82%
Eucalyptus erythrocorys	Trip 7	Beehive	3	12	100%	39	4.4	5.7	3.1	1292	703	46%	84%
Eucalyptus erythrocorys	Trip 7	Beehive	4	12	100%	48	5.4	7.0	4.3	1289	785	39%	64%
Eucalyptus erythrocorys	Trip 7	Beehive	5	12	100%	57	6.4	8.2	4.3	1272	673	47%	89%
Eucalyptus erythrocorys	Trip 7	Beehive	6	12	100%	49	5.5	6.8	3.9	1227	702	43%	75%
Eucalyptus erythrocorys	Trip 7	Beehive	1h	12	100%	47	5.3	6.5	3.8	1223	722	41%	69%
Eucalyptus erythrocorys	Trip 7	Beehive	1l	12	100%	51	5.8	7.3	4.1	1266	718	43%	76%
Eucalyptus erythrocorys	Trip 7	Beehive	1m	12	100%	44	5.0	6.9	3.9	1387	790	43%	76%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Eucalyptus erythronema	Trip 5	Hospital Road	1	12	100%	56	6.3	7.7	5.9	1216	930	24%	31%
Eucalyptus erythronema	Trip 5	Hospital Road	2	12	100%	57	6.4	7.9	6.3	1225	980	20%	25%
Eucalyptus erythronema	Trip 5	Hospital Road	3	12	100%	49	5.5	6.9	5.5	1245	991	20%	26%
Eucalyptus erythronema subsp. marginata	Trip 9	Pithara	1	12	100%	27	3.1	4.1	3.2	1343	1045	22%	29%
Eucalyptus erythronema subsp. marginata	Trip 9	Pithara	2	12	100%	29	3.3	4.4	3.3	1342	1015	24%	32%
Eucalyptus erythronema subsp. marginata	Trip 9	Pithara	3	12	100%	33	3.7	4.9	3.7	1313	981	25%	34%
Eucalyptus ewartiana	Trip 4	Stephens Road	1	12	100%	56	6.3	8.0	6.0	1263	941	26%	34%
Eucalyptus ewartiana	Trip 4	Stephens Road	2	12	100%	48	5.4	7.1	5.5	1308	1013	23%	29%
Eucalyptus ewartiana	Trip 4	Stephens Road	3	12	100%	29	3.3	4.5	3.6	1372	1095	20%	25%
Eucalyptus gomphocephala	Trip 3a	Ludlow	1	12	100%	79	8.9	11.3	6.9	1265	768	39%	65%
Eucalyptus gomphocephala	Trip 3a	Ludlow	2	12	100%	81	9.2	11.3	7.0	1234	759	38%	63%
Eucalyptus gomphocephala	Trip 3a	Ludlow	3	12	100%	78	8.8	10.7	6.5	1213	741	39%	64%
Eucalyptus gratiae	Trip 2	Wansborough	1	12	100%	80	9.0	10.9	7.1	1205	785	35%	54%
Eucalyptus gratiae	Trip 2	Wansborough	2	12	100%	81	9.2	10.3	6.6	1124	715	36%	57%
Eucalyptus gratiae	Trip 2	Wansborough	3	12	100%	77	8.7	10.1	6.8	1160	781	33%	49%
Eucalyptus halophila	Trip 6	Styles Road	1	12	100%	33	3.7	4.9	3.9	1313	1032	21%	27%
Eucalyptus halophila	Trip 6	Styles Road	2	12	100%	36	4.1	5.5	4.2	1351	1029	24%	31%
Eucalyptus halophila	Trip 6	Styles Road	3	12	100%	36	4.1	5.6	4.4	1375	1076	22%	28%
Eucalyptus hypochlamydea subsp. hypochlamydea	Trip 9	Pintharuka East	1	12	100%	33	3.7	5.0	3.2	1340	855	36%	57%
Eucalyptus hypochlamydea subsp. hypochlamydea	Trip 9	Pintharuka East	2	12	100%	41	4.6	6.3	4.2	1359	895	34%	52%
Eucalyptus hypochlamydea subsp. hypochlamydea	Trip 9	Pintharuka East	3	12	100%	52	5.9	7.7	5.4	1309	918	30%	43%
Eucalyptus incrassata	Trip 6	Nindinbillup	1	12	100%	48	5.4	6.9	5.3	1271	984	23%	29%
Eucalyptus incrassata	Trip 6	Nindinbillup	2	12	100%	36	4.1	5.3	4.2	1302	1041	20%	25%
Eucalyptus incrassata	Trip 6	Nindinbillup	3	12	100%	43	4.9	6.4	5.0	1316	1018	23%	29%
Eucalyptus indurata	Trip 6	Dingo Rock Road	1	12	100%	44	5.0	6.7	4.9	1346	987	27%	36%
Eucalyptus indurata	Trip 6	Dingo Rock Road	2	12	100%	39	4.4	5.7	4.0	1292	902	30%	43%
Eucalyptus indurata	Trip 6	Dingo Rock Road	3	12	100%	41	4.6	6.0	4.4	1294	938	28%	38%
Eucalyptus kochii subsp. horistes	Trip 2	Wansborough	1	12	100%	54	6.1	7.6	5.0	1244	825	34%	51%
Eucalyptus kochii subsp. horistes	Trip 2	Wansborough	2	12	100%	62	7.0	8.3	5.9	1184	844	29%	40%
Eucalyptus kochii subsp. horistes	Trip 2	Wansborough	3	12	100%	57	6.4	8.0	5.6	1241	875	30%	42%
Eucalyptus kochii subsp. kochii	Trip 2	Wansborough	1	12	100%	70	7.9	9.8	7.0	1238	882	29%	40%
Eucalyptus kochii subsp. kochii	Trip 2	Wansborough	2	12	100%	80	9.0	10.3	7.3	1138	802	30%	42%
Eucalyptus kochii subsp. kochii	Trip 2	Wansborough	3	12	100%	86	9.7	11.9	8.4	1223	863	29%	42%
Eucalyptus kochii subsp. plenissima	Trip 2	Wansborough	1	12	100%	71	8.0	10.0	6.8	1245	852	32%	46%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Eucalyptus kochii subsp. plenissima	Trip 2	Wansborough	2	12	100%	77	8.7	9.8	6.9	1125	796	29%	41%
Eucalyptus kochii subsp. plenissima	Trip 2	Wansborough	3	12	100%	67	7.6	9.2	6.5	1214	858	29%	42%
Eucalyptus kondininensis	Trip 1	Nepowie TAFT	1	12	100%	92	10.4	13.3	9.6	1278	924	28%	38%
Eucalyptus kondininensis	Trip 1	Nepowie TAFT	2	12	100%	109	12.3	14.7	10.6	1192	858	28%	39%
Eucalyptus kondininensis	Trip 1	Nepowie TAFT	3	12	100%	118	13.3	16.0	11.4	1199	855	29%	40%
Eucalyptus leptopoda	Trip 3	Hyden Fence	1	12	100%	67	7.6	10.0	7.5	1320	983	26%	34%
Eucalyptus leptopoda	Trip 3	Hyden Fence	2	12	100%	70	7.9	10.4	7.7	1314	971	26%	35%
Eucalyptus leptopoda	Trip 3	Hyden Fence	3	12	100%	93	10.5	13.7	10.1	1303	962	26%	35%
Eucalyptus leptopoda subsp. arctata	Trip 7	Swanson	1	12	100%	42	4.8	6.2	4.8	1305	1006	23%	30%
Eucalyptus leptopoda subsp. arctata	Trip 7	Swanson	2	12	100%	38	4.3	5.4	4.1	1256	954	24%	32%
Eucalyptus leptopoda subsp. arctata	Trip 7	Swanson	3	12	100%	37	4.2	5.3	4.0	1267	958	24%	32%
Eucalyptus leptopoda subsp. subluta	Trip 9	Moondon Road	1	12	100%	32	3.6	4.8	3.5	1326	959	28%	38%
Eucalyptus leptopoda subsp. subluta	Trip 9	Moondon Road	2	12	100%	32	3.6	4.7	3.4	1299	926	29%	40%
Eucalyptus leptopoda subsp. subluta	Trip 9	Moondon Road	3	12	100%	36	4.1	5.4	3.9	1326	963	27%	38%
Eucalyptus lesouefii	Trip 3	Jimberlana hill	1	12	100%	74	8.4	10.1	8.2	1207	977	19%	23%
Eucalyptus lesouefii	Trip 3	Jimberlana hill	2	12	100%	74	8.4	10.0	8.0	1195	961	20%	24%
Eucalyptus lesouefii	Trip 3	Jimberlana hill	3	12	100%	62	7.0	8.3	6.6	1184	938	21%	26%
Eucalyptus longicornis	Trip 6	Oval Road	1	12	100%	40	4.5	5.6	3.7	1238	827	33%	50%
Eucalyptus longicornis	Trip 6	Oval Road	2	12	50%	23	2.6	3.1	2.2	1192	842	29%	42%
Eucalyptus longicornis	Trip 6	Oval Road	3	12	100%	39	4.4	5.7	4.0	1292	905	30%	43%
Eucalyptus loxophleba subsp. lissophloia	Trip 2	Wansborough	1	12	100%	71	8.0	9.8	7.0	1220	869	29%	40%
Eucalyptus loxophleba subsp. lissophloia	Trip 2	Wansborough	2	12	100%	79	8.9	9.5	6.3	1063	702	34%	52%
Eucalyptus loxophleba subsp. lissophloia	Trip 2	Wansborough	3	12	100%	87	9.8	10.8	6.9	1098	698	36%	57%
Eucalyptus loxophleba subsp. lissophloia	Trip 5	Joroway	2	12	100%	61	6.9	8.6	5.2	1247	755	39%	65%
Eucalyptus loxophleba subsp. lissophloia	Trip 5	Joroway	3	12	100%	55	6.2	7.7	5.0	1238	799	35%	55%
Eucalyptus loxophleba subsp. lissophloia	Trip 5	Joroway	4	12	100%	57	6.4	8.0	4.9	1241	759	39%	64%
Eucalyptus loxophleba subsp. lissophloia	Trip 5	Joroway	5	12	100%	69	7.8	9.8	6.4	1256	816	35%	54%
Eucalyptus loxophleba subsp. lissophloia	Trip 5	Joroway	6	12	100%	76	8.6	10.8	6.9	1256	799	36%	57%
Eucalyptus loxophleba subsp. lissophloia	Trip 5	Joroway	1h	12	100%	53	6.0	7.4	5.1	1235	851	31%	45%
Eucalyptus loxophleba subsp. lissophloia	Trip 5	Joroway	1l	12	100%	89	10.1	12.3	8.3	1222	824	33%	48%
Eucalyptus loxophleba subsp. lissophloia	Trip 5	Joroway	1m	12	100%	68	7.7	9.5	6.1	1235	798	35%	55%
Eucalyptus loxophleba subsp. lissophloia	Trip 6	Birds	2	12	100%	50	5.7	6.9	4.4	1220	783	36%	56%
Eucalyptus loxophleba subsp. lissophloia	Trip 6	Birds	3	12	100%	47	5.3	6.6	4.3	1242	815	34%	52%
Eucalyptus loxophleba subsp. lissophloia	Trip 6	Birds	4	12	100%	38	4.3	5.5	3.4	1280	779	39%	64%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Eucalyptus loxophleba subsp. lissophloia	Trip 6	Birds	5	12	100%	50	5.7	7.0	4.4	1238	771	38%	61%
Eucalyptus loxophleba subsp. lissophloia	Trip 6	Birds	6	12	100%	46	5.2	6.7	4.4	1288	840	35%	53%
Eucalyptus loxophleba subsp. lissophloia	Trip 6	Birds	1h	12	100%	33	3.7	4.7	3.2	1259	852	32%	48%
Eucalyptus loxophleba subsp. lissophloia	Trip 6	Birds	1l	12	100%	59	6.7	8.3	5.6	1244	842	32%	48%
Eucalyptus loxophleba subsp. lissophloia	Trip 6	Birds	1m	12	100%	39	4.4	5.7	3.8	1292	857	34%	51%
Eucalyptus loxophleba subsp. loxophleba	Trip 1	Davenport TAFT	1	12	100%	73	8.3	9.9	6.5	1199	782	35%	53%
Eucalyptus loxophleba subsp. loxophleba	Trip 1	Davenport TAFT	2	12	100%	90	10.2	11.4	7.2	1120	706	37%	59%
Eucalyptus loxophleba subsp. loxophleba	Trip 1	Davenport TAFT	3	12	100%	98	11.1	13.6	9.1	1227	825	33%	49%
Eucalyptus loxophleba subsp. supralaevis	Trip 9	Latham	1	12	100%	36	4.1	4.9	3.2	1203	781	35%	54%
Eucalyptus loxophleba subsp. supralaevis	Trip 9	Latham	2	12	100%	34	3.8	4.7	3.2	1222	832	32%	47%
Eucalyptus loxophleba subsp. supralaevis	Trip 9	Latham	3	12	100%	25	2.8	3.7	2.4	1309	849	35%	54%
Eucalyptus melanoxylon	Trip 3	Mount Day West	1	12	100%	72	8.1	10.2	7.8	1253	963	23%	30%
Eucalyptus melanoxylon	Trip 3	Mount Day West	2	12	100%	55	6.2	8.0	6.3	1286	1014	21%	27%
Eucalyptus melanoxylon	Trip 3	Mount Day West	3	12	100%	91	10.3	13.5	10.5	1312	1018	22%	29%
Eucalyptus moderata Nicolle (ms)	Trip 9	Old Koorda Road	1	12	100%	27	3.1	4.2	3.0	1375	982	29%	40%
Eucalyptus moderata Nicolle (ms)	Trip 9	Old Koorda Road	2	12	100%	42	4.8	6.0	4.2	1263	888	30%	42%
Eucalyptus moderata Nicolle (ms)	Trip 9	Old Koorda Road	3	12	100%	39	4.4	5.9	4.2	1338	948	29%	41%
Eucalyptus myriadena	Trip 2	Wansborough	1	12	100%	99	11.2	14.1	9.6	1259	861	32%	46%
Eucalyptus myriadena	Trip 2	Wansborough	2	12	100%	74	8.4	10.6	7.6	1267	908	28%	39%
Eucalyptus myriadena	Trip 2	Wansborough	3	12	100%	80	9.0	11.3	7.7	1249	852	32%	47%
Eucalyptus occidentalis	Trip 1	Beaufort River Flats	1	12	100%	143	16.2	19.0	14.5	1175	894	24%	31%
Eucalyptus occidentalis	Trip 1	Beaufort River Flats	2	12	100%	140	15.8	18.3	13.5	1156	851	26%	36%
Eucalyptus occidentalis	Trip 1	Beaufort River Flats	3	12	100%	100	11.3	12.8	9.5	1132	836	26%	35%
Eucalyptus occidentalis	Trip 1	Nepowie TAFT	1	12	100%	109	12.3	13.4	8.9	1087	718	34%	51%
Eucalyptus occidentalis	Trip 1	Nepowie TAFT	2	12	100%	99	11.2	14.0	9.4	1250	842	33%	48%
Eucalyptus occidentalis	Trip 1	Nepowie TAFT	3	12	100%	97	11.0	12.6	7.4	1149	672	42%	71%
Eucalyptus platypus (?)	Trip 3	Fairlawn	1	12	100%	101	11.4	13.7	9.7	1199	849	29%	41%
Eucalyptus platypus (?)	Trip 3	Fairlawn	2	12	100%	71	8.0	9.6	6.9	1196	861	28%	39%
Eucalyptus platypus (?)	Trip 3	Fairlawn	3	12	100%	63	7.1	8.3	5.8	1165	808	31%	44%
Eucalyptus platypus subsp. platypus (?)	Trip 6	Cape Road	1	12	100%	40	4.5	6.0	3.9	1326	869	35%	53%
Eucalyptus platypus subsp. platypus (?)	Trip 6	Cape Road	2	12	100%	35	4.0	5.1	3.4	1288	849	34%	52%
Eucalyptus platypus subsp. platypus (?)	Trip 6	Cape Road	3	12	100%	40	4.5	6.0	4.2	1326	933	30%	42%
Eucalyptus pleurocarpa	Trip 3	Cascades Road IV	1	12	100%	60	6.8	7.7	5.3	1135	780	31%	46%
Eucalyptus pleurocarpa	Trip 3	Cascades Road IV	2	12	100%	64	7.2	8.5	5.5	1174	754	36%	56%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Eucalyptus pleurocarpa	Trip 3	Cascades Road IV	3	12	100%	53	6.0	7.1	4.7	1184	776	35%	53%
Eucalyptus pleurocarpa	Trip 8	Chillinup	2	12	100%	32	3.6	4.8	2.8	1326	785	41%	69%
Eucalyptus pleurocarpa	Trip 8	Chillinup	3	12	100%	47	5.3	7.0	4.8	1317	905	31%	46%
Eucalyptus pleurocarpa	Trip 8	Chillinup	4	12	100%	33	3.7	5.0	3.0	1340	793	41%	69%
Eucalyptus pleurocarpa	Trip 8	Chillinup	5	12	100%	34	3.8	5.1	3.7	1326	949	28%	40%
Eucalyptus pleurocarpa	Trip 8	Chillinup	6	12	100%	38	4.3	5.6	3.5	1303	814	38%	60%
Eucalyptus pleurocarpa	Trip 8	Chillinup	1h	12	100%	35	4.0	5.0	3.2	1263	808	36%	56%
Eucalyptus pleurocarpa	Trip 8	Chillinup	1l	12	100%	43	4.9	6.6	4.1	1357	851	37%	59%
Eucalyptus pleurocarpa	Trip 8	Chillinup	1m	12	100%	39	4.4	5.8	3.6	1315	809	38%	62%
Eucalyptus polybractea	Trip 2	Wansborough	1	12	100%	92	10.4	12.3	8.6	1182	827	30%	43%
Eucalyptus polybractea	Trip 2	Wansborough	2	12	100%	80	9.0	11.4	7.9	1260	869	31%	45%
Eucalyptus polybractea	Trip 2	Wansborough	3	12	100%	92	10.4	13.0	8.9	1249	859	31%	45%
Eucalyptus rudis	Trip 1	Beaufort River Flats	1	12	100%	67	7.6	8.6	4.6	1135	608	46%	87%
Eucalyptus rudis	Trip 1	Beaufort River Flats	2	12	100%	85	9.6	10.9	6.5	1134	674	41%	68%
Eucalyptus rudis	Trip 1	Beaufort River Flats	3	12	100%	82	9.3	10.1	5.3	1089	567	48%	92%
Eucalyptus rudis	Trip 6	Wilgarrup	1	12	100%	53	6.0	6.8	3.1	1134	524	54%	117%
Eucalyptus rudis	Trip 6	Wilgarrup	2	12	100%	42	4.8	5.5	2.8	1158	592	49%	96%
Eucalyptus rudis	Trip 6	Wilgarrup	3	12	100%	47	5.3	7.5	3.2	1411	608	57%	132%
Eucalyptus rudis	Trip 6	Wilgarrup	4	12	100%	42	4.8	6.2	3.1	1305	642	51%	103%
Eucalyptus rudis	Trip 6	Wilgarrup	6	12	100%	46	5.2	5.9	2.6	1134	502	56%	126%
Eucalyptus rudis	Trip 6	Wilgarrup	5h	12	100%	42	4.8	5.5	2.4	1158	512	56%	126%
Eucalyptus rudis	Trip 6	Wilgarrup	5l	12	100%	57	6.4	8.1	3.6	1256	557	56%	126%
Eucalyptus rudis	Trip 6	Wilgarrup	5m	12	100%	44	5.0	5.9	2.7	1186	545	54%	118%
Eucalyptus rudis	Trip 8	Xmas Creek	2	12	100%	54	6.1	7.1	3.0	1163	494	57%	135%
Eucalyptus rudis	Trip 8	Xmas Creek	3	12	100%	40	4.5	5.5	2.4	1216	519	57%	134%
Eucalyptus rudis	Trip 8	Xmas Creek	4	12	100%	32	3.6	4.4	2.0	1216	553	55%	120%
Eucalyptus rudis	Trip 8	Xmas Creek	5	12	100%	49	5.5	6.5	3.1	1173	554	53%	112%
Eucalyptus rudis	Trip 8	Xmas Creek	6	12	100%	44	5.0	6.4	2.9	1286	581	55%	121%
Eucalyptus rudis	Trip 8	Xmas Creek	1h	12	100%	52	5.9	6.9	2.9	1173	491	58%	139%
Eucalyptus rudis	Trip 8	Xmas Creek	1l	12	100%	63	7.1	8.5	3.6	1193	511	57%	134%
Eucalyptus rudis	Trip 8	Xmas Creek	1m	12	100%	54	6.1	7.3	3.0	1195	483	60%	147%
Eucalyptus salmonophloia	Trip 3	Breakaway East II	1	12	100%	61	6.9	8.8	6.6	1276	961	25%	33%
Eucalyptus salmonophloia	Trip 3	Breakaway East II	2	12	100%	78	8.8	10.7	8.1	1213	919	24%	32%
Eucalyptus salmonophloia	Trip 3	Breakaway East II	3	12	100%	64	7.2	9.4	6.9	1299	957	26%	36%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Eucalyptus salubris	Trip 3	Breakaway II	1	12	100%	83	9.4	11.6	9.1	1236	966	22%	28%
Eucalyptus salubris	Trip 3	Breakaway II	2	12	100%	66	7.5	9.1	7.2	1219	961	21%	27%
Eucalyptus salubris	Trip 3	Breakaway II	3	12	100%	64	7.2	8.9	6.9	1230	949	23%	30%
Eucalyptus sargentii	Trip 3	Fairlawn	1	12	100%	80	9.0	10.2	7.8	1127	867	23%	30%
Eucalyptus sargentii	Trip 3	Fairlawn	2	12	100%	80	9.0	10.5	8.1	1161	893	23%	30%
Eucalyptus sargentii	Trip 3	Fairlawn	3	12	100%	74	8.4	9.6	7.4	1147	889	23%	29%
Eucalyptus spathulata	Trip 3	Fairlawn	1	12	100%	84	9.5	11.0	8.2	1158	862	26%	34%
Eucalyptus spathulata	Trip 3	Fairlawn	2	12	100%	73	8.3	9.5	7.0	1151	848	26%	36%
Eucalyptus spathulata	Trip 3	Fairlawn	3	12	100%	76	8.6	9.7	7.1	1129	830	26%	36%
Eucalyptus todtiana	Trip 4	Yanchep North	1	12	100%	71	8.0	9.5	5.2	1183	650	45%	82%
Eucalyptus todtiana	Trip 4	Yanchep North	2	12	100%	55	6.2	7.2	3.7	1157	600	48%	93%
Eucalyptus todtiana	Trip 4	Yanchep North	3	12	100%	35	4.0	5.1	3.0	1288	745	42%	73%
Eucalyptus todtiana	Trip 7	8 km road	1	12	100%	27	3.1	4.0	2.0	1310	662	50%	98%
Eucalyptus todtiana	Trip 7	8 km road	2	12	100%	37	4.2	5.2	2.9	1243	686	45%	81%
Eucalyptus todtiana	Trip 7	8 km road	3	12	100%	34	3.8	4.9	2.5	1274	650	49%	96%
Eucalyptus todtiana	Trip 7	8 km road	4	12	100%	38	4.3	5.5	2.7	1280	626	51%	104%
Eucalyptus todtiana	Trip 7	8 km road	6	12	100%	52	5.9	6.9	4.0	1173	675	42%	74%
Eucalyptus todtiana	Trip 7	8 km road	5h	12	100%	34	3.8	4.6	2.3	1196	598	50%	100%
Eucalyptus todtiana	Trip 7	8 km road	5l	12	100%	42	4.8	6.1	3.5	1284	726	43%	77%
Eucalyptus todtiana	Trip 7	8 km road	5m	12	100%	40	4.5	5.4	2.8	1194	626	48%	91%
Eucalyptus todtiana	Trip 7	Yanchep pines II	1	12	100%	50	5.7	7.1	3.7	1256	647	48%	94%
Eucalyptus todtiana	Trip 7	Yanchep pines II	2	12	100%	52	5.9	7.8	4.4	1326	745	44%	78%
Eucalyptus todtiana	Trip 7	Yanchep pines II	4	12	100%	46	5.2	6.4	3.3	1230	629	49%	96%
Eucalyptus todtiana	Trip 7	Yanchep pines II	5	12	100%	39	4.4	5.5	3.0	1247	676	46%	85%
Eucalyptus todtiana	Trip 7	Yanchep pines II	6	12	100%	41	4.6	5.9	2.7	1272	587	54%	117%
Eucalyptus todtiana	Trip 7	Yanchep pines II	3h	12	100%	37	4.2	4.9	2.4	1171	571	51%	105%
Eucalyptus todtiana	Trip 7	Yanchep pines II	3l	12	100%	71	8.0	9.9	4.8	1233	599	51%	106%
Eucalyptus todtiana	Trip 7	Yanchep pines II	3m	12	100%	43	4.9	5.9	2.7	1213	547	55%	122%
Eucalyptus uncinata	Trip 6	Cocanarup	1	12	100%	42	4.8	6.2	4.8	1305	1002	23%	30%
Eucalyptus uncinata	Trip 6	Cocanarup	2	12	100%	41	4.6	6.5	5.0	1402	1080	23%	30%
Eucalyptus uncinata	Trip 6	Cocanarup	3	12	100%	37	4.2	5.3	4.0	1267	963	24%	32%
Eucalyptus urna	Trip 3	Cronin North II	1	12	100%	82	9.3	11.3	8.7	1218	933	23%	31%
Eucalyptus urna	Trip 3	Cronin North II	2	12	100%	40	4.5	5.4	4.1	1194	911	24%	31%
Eucalyptus urna	Trip 3	Cronin North II	3	12	100%	40	4.5	5.4	4.2	1194	926	22%	29%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Eucalyptus utilis	Trip 6	Boat harbour	1	12	100%	55	6.2	7.1	5.4	1141	865	24%	32%
Eucalyptus utilis	Trip 6	Boat harbour	2	12	100%	55	6.2	7.6	5.7	1222	908	26%	35%
Eucalyptus utilis	Trip 6	Boat harbour	3	12	100%	36	4.1	5.0	3.6	1228	894	27%	37%
Eucalyptus valens	Trip 6	Lignite Road	1	12	100%	36	4.1	5.3	3.7	1302	904	31%	44%
Eucalyptus valens	Trip 6	Lignite Road	2	12	100%	38	4.3	5.6	3.7	1303	870	33%	50%
Eucalyptus valens	Trip 6	Lignite Road	3	12	100%	38	4.3	5.5	3.7	1280	852	33%	50%
Eucalyptus vegrandis	Trip 2	Wansborough	1	12	100%	79	8.9	9.9	7.5	1108	842	24%	32%
Eucalyptus vegrandis	Trip 2	Wansborough	2	12	100%	68	7.7	9.7	7.1	1261	925	27%	36%
Eucalyptus vegrandis	Trip 2	Wansborough	3	12	100%	69	7.8	9.3	6.8	1192	866	27%	38%
Eucalyptus wandoo	Trip 3	Collie-Darkan Road	1	12	100%	61	6.9	8.3	5.8	1203	835	31%	44%
Eucalyptus wandoo	Trip 3	Collie-Darkan Road	2	12	100%	77	8.7	11.1	8.3	1275	948	26%	34%
Eucalyptus wandoo	Trip 3	Collie-Darkan Road	3	12	100%	79	8.9	11.5	8.5	1287	950	26%	35%
Exocarpus aphyllus	Trip 3	Breakaway East	1	12	100%	87	9.8	12.5	9.8	1270	996	22%	28%
Exocarpus aphyllus	Trip 3	Breakaway East	2	12	100%	73	8.3	11.6	8.9	1405	1076	23%	31%
Exocarpus aphyllus	Trip 3	Breakaway East	3	12	100%	69	7.8	9.9	8.1	1269	1038	18%	22%
Exocarpus sparteus	Trip 3	Peak Charles	1	12	100%	78	8.8	10.0	5.6	1134	630	44%	80%
Exocarpus sparteus	Trip 3	Peak Charles	2	12	100%	70	7.9	9.1	5.3	1149	672	42%	71%
Exocarpus sparteus	Trip 3	Peak Charles	3	12	100%	57	6.4	7.4	4.3	1148	659	43%	74%
Exocarpus sparteus	Trip 6	Carracarrup	1	12	100%	41	4.6	5.7	3.2	1229	699	43%	76%
Exocarpus sparteus	Trip 6	Carracarrup	3	12	100%	36	4.1	5.2	3.0	1277	744	42%	72%
Exocarpus sparteus	Trip 6	Carracarrup	4	12	100%	27	3.1	3.7	2.2	1212	704	42%	72%
Exocarpus sparteus	Trip 6	Carracarrup	5	12	100%	40	4.5	5.8	3.7	1282	827	36%	55%
Exocarpus sparteus	Trip 6	Carracarrup	6	12	100%	34	3.8	4.8	3.0	1248	778	38%	61%
Exocarpus sparteus	Trip 6	Carracarrup	2h	12	100%	31	3.5	4.2	2.3	1198	667	44%	79%
Exocarpus sparteus	Trip 6	Carracarrup	2l	12	100%	53	6.0	7.4	4.3	1235	714	42%	73%
Exocarpus sparteus	Trip 6	Carracarrup	2m	12	100%	37	4.2	4.9	2.8	1171	660	44%	78%
Exocarpus sparteus	Trip 6	Lignite Road	1	12	100%	47	5.3	6.6	3.8	1242	713	43%	74%
Exocarpus sparteus	Trip 6	Lignite Road	3	12	100%	50	5.7	6.3	3.6	1114	630	43%	77%
Exocarpus sparteus	Trip 6	Lignite Road	4	12	100%	51	5.8	6.7	3.8	1162	661	43%	76%
Exocarpus sparteus	Trip 6	Lignite Road	5	12	100%	36	4.1	5.1	3.0	1253	739	41%	69%
Exocarpus sparteus	Trip 6	Lignite Road	6	12	100%	49	5.5	6.7	3.8	1209	689	43%	75%
Exocarpus sparteus	Trip 6	Lignite Road	2h	12	100%	35	4.0	4.7	2.8	1187	702	41%	69%
Exocarpus sparteus	Trip 6	Lignite Road	2l	12	100%	55	6.2	7.7	4.7	1238	754	39%	64%
Exocarpus sparteus	Trip 6	Lignite Road	2m	12	100%	42	4.8	5.7	3.4	1200	724	40%	66%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Grevillea argyrophylla	Trip 4	Arrowsmith Siding	1	12	100%	65	7.4	9.2	5.8	1251	792	37%	58%
Grevillea argyrophylla	Trip 4	Arrowsmith Siding	2	12	100%	54	6.1	7.0	4.5	1146	730	36%	57%
Grevillea argyrophylla	Trip 4	Arrowsmith Siding	3	12	100%	63	7.1	9.0	6.1	1263	859	32%	47%
Grevillea cagiana	Trip 5	Waste dump	1	12	100%	44	5.0	5.7	4.0	1145	806	30%	42%
Grevillea cagiana	Trip 5	Waste dump	2	12	100%	39	4.4	5.7	3.8	1292	852	34%	52%
Grevillea cagiana	Trip 5	Waste dump	3	12	100%	42	4.8	6.1	3.8	1284	808	37%	59%
Grevillea candelabroides	Trip 4	Beekeeper Road	1	12	100%	62	7.0	8.0	4.3	1141	618	46%	85%
Grevillea candelabroides	Trip 4	Beekeeper Road	2	12	100%	61	6.9	8.3	4.2	1203	604	50%	99%
Grevillea candelabroides	Trip 4	Beekeeper Road	3	12	100%	86	9.7	11.7	6.2	1203	636	47%	89%
Grevillea candelabroides	Trip 7	Mt Adams Road East	2	12	100%	38	4.3	5.1	2.9	1187	672	43%	76%
Grevillea candelabroides	Trip 7	Mt Adams Road East	3	12	100%	58	6.6	7.6	3.9	1159	598	48%	94%
Grevillea candelabroides	Trip 7	Mt Adams Road East	4	12	100%	45	5.1	5.6	2.9	1100	566	49%	94%
Grevillea candelabroides	Trip 7	Mt Adams Road East	5	12	100%	42	4.8	5.6	3.1	1179	644	45%	83%
Grevillea candelabroides	Trip 7	Mt Adams Road East	6	12	100%	49	5.5	6.6	3.5	1191	624	48%	91%
Grevillea candelabroides	Trip 7	Mt Adams Road East	1h	12	100%	34	3.8	4.7	2.6	1222	687	44%	78%
Grevillea candelabroides	Trip 7	Mt Adams Road East	1l	12	100%	64	7.2	9.0	5.2	1243	714	43%	74%
Grevillea candelabroides	Trip 7	Mt Adams Road East	1m	12	100%	47	5.3	6.5	3.6	1223	673	45%	82%
Grevillea candelabroides	Trip 7	Yandanooka	2	12	100%	52	5.9	7.2	3.8	1224	644	47%	90%
Grevillea candelabroides	Trip 7	Yandanooka	3	12	100%	54	6.1	7.7	4.0	1261	662	48%	91%
Grevillea candelabroides	Trip 7	Yandanooka	4	12	100%	48	5.4	6.7	3.4	1234	617	50%	100%
Grevillea candelabroides	Trip 7	Yandanooka	5	12	100%	49	5.5	6.7	3.7	1209	660	45%	83%
Grevillea candelabroides	Trip 7	Yandanooka	6	12	100%	43	4.9	5.9	3.2	1213	654	46%	86%
Grevillea candelabroides	Trip 7	Yandanooka	1h	12	100%	47	5.3	6.4	3.4	1204	638	47%	89%
Grevillea candelabroides	Trip 7	Yandanooka	1l	12	100%	67	7.6	9.6	5.1	1267	666	47%	90%
Grevillea candelabroides	Trip 7	Yandanooka	1m	12	100%	53	6.0	7.3	3.7	1218	621	49%	96%
Grevillea excelsior	Trip 3	Hyden Fence	1	12	100%	84	9.5	11.5	6.6	1211	699	42%	73%
Grevillea excelsior	Trip 3	Hyden Fence	2	12	100%	83	9.4	11.5	7.0	1225	745	39%	65%
Grevillea excelsior	Trip 3	Hyden Fence	3	12	100%	65	7.4	8.7	5.1	1183	695	41%	70%
Grevillea excelsior	Trip 5	Waste dump	2	12	100%	43	4.9	6.1	3.8	1254	783	38%	60%
Grevillea excelsior	Trip 5	Waste dump	3	12	100%	37	4.2	5.2	3.4	1243	817	34%	52%
Grevillea excelsior	Trip 5	Waste dump	4	12	100%	40	4.5	5.6	3.5	1238	783	37%	58%
Grevillea excelsior	Trip 5	Waste dump	5	12	100%	35	4.0	4.9	3.0	1238	763	38%	62%
Grevillea excelsior	Trip 5	Waste dump	6	12	100%	35	4.0	4.4	2.8	1112	707	36%	57%
Grevillea excelsior	Trip 5	Waste dump	1h	12	100%	36	4.1	4.8	3.0	1179	744	37%	58%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Grevillea excelsior	Trip 5	Waste dump	1l	12	50%	27	3.1	3.7	2.3	1212	756	38%	60%
Grevillea excelsior	Trip 5	Waste dump	1m	12	100%	43	4.9	5.9	3.8	1213	775	36%	56%
Grevillea excelsior	Trip 9	Raingauge	2	12	100%	53	6.0	7.4	4.4	1235	739	40%	67%
Grevillea excelsior	Trip 9	Raingauge	3	12	100%	41	4.6	5.6	3.7	1208	787	35%	53%
Grevillea excelsior	Trip 9	Raingauge	4	12	100%	55	6.2	7.0	4.6	1125	738	34%	53%
Grevillea excelsior	Trip 9	Raingauge	5	12	100%	34	3.8	4.6	2.9	1196	762	36%	57%
Grevillea excelsior	Trip 9	Raingauge	6	12	100%	50	5.7	6.7	4.4	1185	776	34%	53%
Grevillea excelsior	Trip 9	Raingauge	1h	12	100%	40	4.5	5.7	3.2	1260	707	44%	78%
Grevillea excelsior	Trip 9	Raingauge	1l	12	100%	54	6.1	7.7	4.4	1261	720	43%	75%
Grevillea excelsior	Trip 9	Raingauge	1m	12	100%	45	5.1	6.4	3.5	1258	686	45%	83%
Grevillea insignis	Trip 6	Tarin Rock	1	12	100%	48	5.4	7.2	4.6	1326	842	37%	58%
Grevillea insignis	Trip 6	Tarin Rock	2	12	100%	36	4.1	5.2	3.3	1277	811	37%	58%
Grevillea insignis	Trip 6	Tarin Rock	3	12	100%	39	4.4	5.6	3.8	1270	852	33%	49%
Grevillea leucopteris	Trip 4	Drilling track	1	12	100%	66	7.5	7.4	4.1	991	544	45%	82%
Grevillea leucopteris	Trip 4	Drilling track	2	12	100%	67	7.6	8.8	4.4	1161	575	50%	102%
Grevillea leucopteris	Trip 4	Drilling track	3	12	100%	51	5.8	6.3	3.2	1092	558	49%	96%
Grevillea leucopteris	Trip 7	Gas pipeline	2	12	100%	98	11.1	13.0	6.1	1173	551	53%	113%
Grevillea leucopteris	Trip 7	Gas pipeline	3	12	100%	77	8.7	10.6	4.7	1217	544	55%	124%
Grevillea leucopteris	Trip 7	Gas pipeline	4	12	100%	95	10.7	13.0	5.9	1210	551	54%	120%
Grevillea leucopteris	Trip 7	Gas pipeline	5	12	100%	45	5.1	5.8	2.9	1140	572	50%	99%
Grevillea leucopteris	Trip 7	Gas pipeline	6	12	100%	63	7.1	8.2	4.1	1151	580	50%	99%
Grevillea leucopteris	Trip 7	Gas pipeline	1h	12	100%	39	4.4	5.2	2.8	1179	633	46%	86%
Grevillea leucopteris	Trip 7	Gas pipeline	1l	12	100%	95	10.7	12.7	6.3	1182	584	51%	102%
Grevillea leucopteris	Trip 7	Gas pipeline	1m	12	100%	83	9.4	11.5	5.7	1225	603	51%	103%
Grevillea leucopteris	Trip 7	Railway 47	2	12	50%	27	3.1	3.5	1.7	1146	544	53%	111%
Grevillea leucopteris	Trip 7	Railway 47	3	12	100%	42	4.8	5.2	2.4	1095	497	55%	120%
Grevillea leucopteris	Trip 7	Railway 47	4	12	100%	41	4.6	5.6	2.6	1208	563	53%	115%
Grevillea leucopteris	Trip 7	Railway 47	5	12	100%	49	5.5	6.8	2.7	1227	493	60%	149%
Grevillea leucopteris	Trip 7	Railway 47	6	12	100%	36	4.1	4.8	2.1	1179	506	57%	133%
Grevillea leucopteris	Trip 7	Railway 47	1h	12	100%	49	5.5	6.5	3.2	1173	568	52%	106%
Grevillea leucopteris	Trip 7	Railway 47	1l	12	100%	67	7.6	8.8	3.8	1161	507	56%	129%
Grevillea leucopteris	Trip 7	Railway 47	1m	12	100%	51	5.8	6.7	3.2	1162	550	53%	111%
Grevillea nematophylla subsp. Nematophylla (?)	Trip 3	Jimberlana hill	1	12	100%	106	12.0	14.5	9.0	1210	754	38%	60%
Grevillea nematophylla subsp. nematophylla (?)	Trip 3	Jimberlana hill	2	12	100%	96	10.9	12.5	7.4	1151	682	41%	69%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Grevillea nematophylla subsp. Nematophylla (?)	Trip 3	Jimberlana hill	3	12	100%	67	7.6	9.0	5.5	1188	726	39%	64%
Grevillea obliquistigma	Trip 4	Gutha Dump	1	12	100%	44	5.0	6.2	4.7	1246	948	24%	31%
Grevillea obliquistigma	Trip 4	Gutha Dump	2	12	100%	50	5.7	6.8	5.4	1203	955	21%	26%
Grevillea obliquistigma	Trip 4	Gutha Dump	3	12	100%	50	5.7	7.5	5.7	1326	1004	24%	32%
Grevillea pterosperma	Trip 4	Yalgoo Road	1	12	100%	52	5.9	7.0	5.6	1190	951	20%	25%
Grevillea pterosperma	Trip 4	Yalgoo Road	2	12	100%	57	6.4	7.0	4.9	1086	763	30%	42%
Grevillea pterosperma	Trip 4	Yalgoo Road	3	12	100%	52	5.9	6.8	4.8	1156	821	29%	41%
Grevillea vestita	Trip 7	Yanchep pines	1	12	100%	33	3.7	4.7	2.9	1259	766	39%	64%
Grevillea vestita	Trip 7	Yanchep pines	2	12	100%	34	3.8	5.1	2.9	1326	759	43%	75%
Grevillea vestita	Trip 7	Yanchep pines	3	12	100%	69	7.8	10.1	6.0	1294	773	40%	67%
Gyrostemon racemiger	Trip 5	Karalee	2	12	100%	40	4.5	5.1	1.9	1127	418	63%	170%
Gyrostemon racemiger	Trip 5	Karalee	3	12	100%	48	5.4	6.0	2.0	1105	370	67%	199%
Gyrostemon racemiger	Trip 5	Karalee	4	12	100%	44	5.0	5.7	2.1	1145	414	64%	177%
Gyrostemon racemiger	Trip 5	Karalee	5	12	100%	52	5.9	6.1	2.1	1037	354	66%	193%
Gyrostemon racemiger	Trip 5	Karalee	6	12	100%	53	6.0	6.7	2.1	1118	347	69%	222%
Gyrostemon racemiger	Trip 5	Karalee	1h	20	100%	55	16.8	14.0	4.5	831	269	68%	208%
Gyrostemon racemiger	Trip 5	Karalee	1l	12	100%	62	7.0	7.6	2.5	1084	358	67%	203%
Gyrostemon racemiger	Trip 5	Karalee	1m	12	100%	32	3.6	4.2	1.3	1161	362	69%	221%
Gyrostemon racemiger	Trip 7	Brand	2	12	100%	46	5.2	6.2	1.8	1192	340	71%	250%
Gyrostemon racemiger	Trip 7	Brand	3	12	100%	46	5.2	5.9	1.6	1134	300	74%	278%
Gyrostemon racemiger	Trip 7	Brand	4	12	100%	34	3.8	4.5	1.3	1170	343	71%	241%
Gyrostemon racemiger	Trip 7	Brand	5	12	100%	36	4.1	4.6	1.4	1130	339	70%	233%
Gyrostemon racemiger	Trip 7	Brand	6	12	100%	38	4.3	4.8	1.4	1117	326	71%	243%
Gyrostemon racemiger	Trip 7	Brand	1h	12	100%	42	4.8	5.7	1.8	1200	381	68%	215%
Gyrostemon racemiger	Trip 7	Brand	1l	12	100%	51	5.8	6.8	2.0	1179	350	70%	237%
Gyrostemon racemiger	Trip 7	Brand	1m	12	100%	47	5.3	6.5	2.0	1223	367	70%	233%
Gyrostemon ramulosus	JC	Dongara - Grieves	19	12	100%	53	6.0		2.7		447		
Gyrostemon ramulosus	JC	Yalgoo - roadside	41	12	100%	98	11.1		5.7		515		
Gyrostemon ramulosus	Trip 4	Beekeeper Ridge	1	12	100%	69	7.8	9.1	3.8	1166	492	58%	137%
Gyrostemon ramulosus	Trip 4	Beekeeper Ridge	2	12	100%	74	8.4	9.9	3.5	1183	423	64%	180%
Gyrostemon ramulosus	Trip 4	Beekeeper Ridge	3	12	100%	68	7.7	9.0	3.2	1170	411	65%	185%
Gyrostemon ramulosus	Trip 7	8km road	2	12	100%	62	7.0	8.1	2.8	1155	392	66%	195%
Gyrostemon ramulosus	Trip 7	8km road	3	12	100%	39	4.4	5.2	1.9	1179	433	63%	172%
Gyrostemon ramulosus	Trip 7	8km road	4	12	100%	41	4.6	5.7	2.0	1229	440	64%	179%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Gyrostemon ramulosus	Trip 7	8km road	5	12	100%	52	5.9	6.9	2.1	1173	357	70%	229%
Gyrostemon ramulosus	Trip 7	8km road	6	12	100%	63	7.1	8.5	2.8	1193	390	67%	206%
Gyrostemon ramulosus	Trip 7	8km road	1h	12	100%	59	6.7	7.5	2.6	1124	387	66%	191%
Gyrostemon ramulosus	Trip 7	8km road	1l	12	100%	82	9.3	10.5	3.2	1132	348	69%	225%
Gyrostemon ramulosus	Trip 7	8km road	1m	12	100%	70	7.9	9.3	3.0	1175	376	68%	212%
Gyrostemon sp.	Trip 4	Gas Bore	1	12	100%	62	7.0	8.0	1.9	1141	277	76%	312%
Gyrostemon sp.	Trip 4	Gas Bore	2	12	100%	56	6.3	7.3	2.1	1153	332	71%	248%
Gyrostemon sp.	Trip 4	Gas Bore	3	12	100%	66	7.5	8.3	2.7	1112	356	68%	212%
Gyrostemon sp.	Trip 4	Marchagee Road West	1	12	100%	45	5.1	5.5	1.9	1081	373	65%	189%
Gyrostemon sp.	Trip 4	Marchagee Road West	2	12	100%	59	6.7	7.8	2.6	1169	391	67%	199%
Gyrostemon sp.	Trip 4	Marchagee Road West	3	12	100%	54	6.1	6.1	2.3	999	383	62%	161%
Hakea bucculenta	Trip 4	#8 Tank	1	12	100%	61	6.9	9.3	6.9	1348	1003	26%	34%
Hakea bucculenta	Trip 4	#8 Tank	2	12	100%	61	6.9	9.6	7.0	1392	1015	27%	37%
Hakea bucculenta	Trip 4	#8 Tank	3	12	100%	52	5.9	7.6	5.5	1292	940	27%	37%
Hakea francisiana	Trip 3	Hyden Fence	1	12	100%	98	11.1	13.9	8.4	1254	761	39%	65%
Hakea francisiana	Trip 3	Hyden Fence	2	12	100%	90	10.2	12.8	8.2	1258	804	36%	56%
Hakea francisiana	Trip 3	Hyden Fence	3	12	100%	76	8.6	11.3	7.7	1315	899	32%	46%
Hakea invaginata	Trip 4	Stephens Road	1	12	100%	61	6.9	8.3	6.2	1203	904	25%	33%
Hakea invaginata	Trip 4	Stephens Road	2	12	100%	61	6.9	8.5	6.4	1232	920	25%	34%
Hakea invaginata	Trip 4	Stephens Road	3	12	100%	54	6.1	7.8	5.9	1277	968	24%	32%
Hakea laurina	Trip 3	Cascades Road II	1	12	100%	62	7.0	8.9	6.2	1269	888	30%	43%
Hakea laurina	Trip 3	Cascades Road II	2	12	100%	58	6.6	8.1	5.5	1235	845	32%	46%
Hakea laurina	Trip 3	Cascades Road II	3	12	100%	54	6.1	8.0	5.5	1310	899	31%	46%
Hakea minyma	Trip 9	Barrier Fence II	1	12	100%	32	3.6	5.0	3.5	1382	953	31%	45%
Hakea minyma	Trip 9	Barrier Fence II	2	12	100%	42	4.8	6.3	4.3	1326	899	32%	48%
Hakea minyma	Trip 9	Barrier Fence II	3	12	100%	37	4.2	6.0	4.0	1434	965	33%	49%
Hakea multilineata	Trip 3	Lake King Road	1	12	100%	70	7.9	10.7	7.4	1352	937	31%	44%
Hakea multilineata	Trip 3	Lake King Road	2	12	100%	59	6.7	8.7	5.4	1304	808	38%	61%
Hakea multilineata	Trip 3	Lake King Road	3	12	100%	66	7.5	9.9	6.8	1326	906	32%	46%
Hakea oleifolia	Trip 6	Nerragagup	1	12	100%	64	7.2	8.7	4.2	1202	577	52%	108%
Hakea oleifolia	Trip 6	Nerragagup	2	12	100%	51	5.8	7.1	3.8	1231	661	46%	86%
Hakea oleifolia	Trip 6	Nerragagup	3	12	100%	59	6.7	8.2	4.2	1229	634	48%	94%
Hakea oleifolia	Trip 8	Pardelup	2	12	100%	39	4.4	5.5	2.9	1247	667	47%	87%
Hakea oleifolia	Trip 8	Pardelup	3	12	100%	51	5.8	6.8	3.3	1179	569	52%	107%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Hakea oleifolia	Trip 8	Pardelup	4	12	100%	51	5.8	7.1	3.8	1231	650	47%	89%
Hakea oleifolia	Trip 8	Pardelup	5	12	100%	45	5.1	6.2	2.9	1218	578	53%	111%
Hakea oleifolia	Trip 8	Pardelup	6	12	100%	52	5.9	7.3	3.8	1241	643	48%	93%
Hakea oleifolia	Trip 8	Pardelup	1h	12	100%	38	4.3	5.4	2.9	1256	677	46%	86%
Hakea oleifolia	Trip 8	Pardelup	1l	12	100%	47	5.3	6.8	3.6	1279	668	48%	92%
Hakea oleifolia	Trip 8	Pardelup	1m	12	100%	42	4.8	6.1	3.2	1284	663	48%	94%
Hakea oleifolia	Trip 8	Tone River Bridge	2	12	100%	38	4.3	5.8	3.3	1350	770	43%	75%
Hakea oleifolia	Trip 8	Tone River Bridge	3	12	100%	37	4.2	5.5	3.1	1314	750	43%	75%
Hakea oleifolia	Trip 8	Tone River Bridge	4	12	100%	57	6.4	7.4	3.8	1148	591	49%	94%
Hakea oleifolia	Trip 8	Tone River Bridge	5	12	100%	46	5.2	6.7	4.0	1288	777	40%	66%
Hakea oleifolia	Trip 8	Tone River Bridge	6	12	100%	45	5.1	6.3	3.5	1238	688	44%	80%
Hakea oleifolia	Trip 8	Tone River Bridge	1h	12	100%	34	3.8	4.4	2.4	1144	629	45%	82%
Hakea oleifolia	Trip 8	Tone River Bridge	1l	12	100%	42	4.8	6.0	3.5	1263	728	42%	73%
Hakea oleifolia	Trip 8	Tone River Bridge	1m	12	100%	40	4.5	5.4	3.0	1194	661	45%	81%
Hakea petiolaris	Trip 5	The rocks	1	12	100%	63	7.1	8.7	6.0	1221	838	31%	46%
Hakea petiolaris	Trip 5	The rocks	2	12	100%	40	4.5	5.7	3.8	1260	838	34%	50%
Hakea petiolaris	Trip 5	The rocks	3	12	100%	60	6.8	7.6	5.4	1120	799	29%	40%
Hakea preissii	Trip 6	Mount Ridley	1	12	100%	40	4.5	6.2	4.1	1371	913	33%	50%
Hakea preissii	Trip 6	Mount Ridley	2	12	100%	44	5.0	7.0	4.6	1407	916	35%	54%
Hakea preissii	Trip 6	Mount Ridley	3	12	100%	58	6.6	8.7	5.5	1326	840	37%	58%
Hakea prostrata	Trip 1	North Bannister	1	12	100%	90	10.2	10.4	6.3	1022	615	40%	66%
Hakea prostrata	Trip 1	North Bannister	2	12	100%	100	11.3	12.9	7.1	1141	623	45%	83%
Hakea prostrata	Trip 1	North Bannister	3	12	50%	63	7.1	6.6	4.3	926	596	36%	55%
Hakea prostrata	Trip 5	Government Road	2	12	100%	64	7.2	8.9	5.1	1230	700	43%	76%
Hakea prostrata	Trip 5	Government Road	3	12	100%	44	5.0	6.2	3.5	1246	709	43%	76%
Hakea prostrata	Trip 5	Government Road	4	12	100%	41	4.6	5.8	3.5	1251	755	40%	66%
Hakea prostrata	Trip 5	Government Road	5	12	100%	36	4.1	5.4	3.2	1326	791	40%	68%
Hakea prostrata	Trip 5	Government Road	6	12	100%	45	5.1	6.2	3.0	1218	595	51%	105%
Hakea prostrata	Trip 5	Government Road	1h	12	100%	64	7.2	7.7	4.5	1064	620	42%	71%
Hakea prostrata	Trip 5	Government Road	1l	12	100%	44	5.0	5.2	3.3	1045	657	37%	59%
Hakea prostrata	Trip 5	Government Road	1m	12	50%	29	3.3	3.6	2.1	1098	640	42%	71%
Hakea prostrata	Trip 6	Noobijup	1	12	100%	44	5.0	6.6	3.7	1326	750	43%	77%
Hakea prostrata	Trip 6	Noobijup	2	12	100%	36	4.1	5.0	2.7	1228	668	46%	84%
Hakea prostrata	Trip 6	Noobijup	4	12	100%	45	5.1	6.6	3.4	1297	670	48%	94%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Hakea prostrata	Trip 6	Noobijup	5	12	100%	43	4.9	6.4	3.4	1316	699	47%	88%
Hakea prostrata	Trip 6	Noobijup	6	12	100%	49	5.5	7.0	3.7	1263	662	48%	91%
Hakea prostrata	Trip 6	Noobijup	3h	12	100%	29	3.3	3.8	2.2	1159	665	43%	74%
Hakea prostrata	Trip 6	Noobijup	3l	12	100%	52	5.9	7.1	3.7	1207	633	48%	91%
Hakea prostrata	Trip 6	Noobijup	3m	12	100%	40	4.5	5.1	2.8	1127	623	45%	81%
Hakea recurva	Trip 4	Wells Siding Road	1	12	100%	58	6.6	8.6	6.1	1311	931	29%	41%
Hakea recurva	Trip 4	Wells Siding Road	2	12	100%	61	6.9	9.6	7.3	1392	1055	24%	32%
Hakea recurva	Trip 4	Wells Siding Road	3	12	100%	66	7.5	9.8	6.6	1313	886	33%	48%
Hakea stenophylla subsp. notialis (?)	Trip 4	#8 Tank	1	12	100%	51	5.8	7.5	5.2	1300	896	31%	45%
Hakea stenophylla subsp. notialis (?)	Trip 4	#8 Tank	2	12	100%	59	6.7	8.5	5.9	1274	887	30%	44%
Hakea stenophylla subsp. notialis (?)	Trip 4	#8 Tank	3	12	100%	54	6.1	7.8	5.8	1277	942	26%	36%
Jacksonia furcellata	Trip 2	Temple Farm	1	12	100%	48	5.4	6.7	3.3	1234	612	50%	102%
Jacksonia furcellata	Trip 2	Temple Farm	2	12	100%	72	8.1	8.9	4.7	1093	576	47%	90%
Jacksonia furcellata	Trip 2	Temple Farm	3	12	100%	91	10.3	11.9	5.6	1156	541	53%	114%
Jacksonia furcellata	Trip 6	Gordon River	1	12	100%	39	4.4	5.4	2.7	1224	614	50%	99%
Jacksonia furcellata	Trip 6	Gordon River	2	12	100%	45	5.1	6.7	3.9	1316	756	43%	74%
Jacksonia furcellata	Trip 6	Gordon River	3	12	100%	45	5.1	6.6	3.6	1297	698	46%	86%
Jacksonia furcellata	Trip 6	Gordon River	4	12	50%	31	3.5	4.4	2.3	1255	647	48%	94%
Jacksonia furcellata	Trip 6	Gordon River	6	12	100%	37	4.2	5.6	3.1	1338	743	44%	80%
Jacksonia furcellata	Trip 6	Gordon River	5h	12	100%	31	3.5	4.7	2.7	1341	759	43%	77%
Jacksonia furcellata	Trip 6	Gordon River	5l	12	100%	49	5.5	7.4	4.4	1335	792	41%	69%
Jacksonia furcellata	Trip 6	Gordon River	5m	12	100%	37	4.2	5.6	3.2	1338	769	43%	74%
Jacksonia furcellata	Trip 7	Yanchep pines	1	12	100%	38	4.3	5.6	2.7	1303	626	52%	108%
Jacksonia furcellata	Trip 7	Yanchep pines	3	12	100%	53	6.0	7.4	3.6	1235	607	51%	103%
Jacksonia furcellata	Trip 7	Yanchep pines	4	12	100%	38	4.3	5.5	2.6	1280	593	54%	116%
Jacksonia furcellata	Trip 7	Yanchep pines	5	12	100%	33	3.7	4.9	2.5	1313	670	49%	96%
Jacksonia furcellata	Trip 7	Yanchep pines	6	12	100%	41	4.6	6.1	3.3	1316	705	46%	87%
Jacksonia furcellata	Trip 7	Yanchep pines	2h	12	100%	30	3.4	4.4	2.2	1297	643	50%	102%
Jacksonia furcellata	Trip 7	Yanchep pines	2l	12	100%	56	6.3	7.9	3.8	1247	597	52%	109%
Jacksonia furcellata	Trip 7	Yanchep pines	2m	12	100%	42	4.8	5.9	2.9	1242	613	51%	103%
Jacksonia sternbergiana	Trip 1	Beaufort River Flats	1	12	50%	47	5.3	5.3	3.2	997	593	41%	68%
Jacksonia sternbergiana	Trip 1	Beaufort River Flats	2	12	100%	71	8.0	10.0	5.9	1245	735	41%	69%
Jacksonia sternbergiana	Trip 1	Beaufort River Flats	3	12	100%	115	13.0	15.3	7.9	1176	609	48%	93%
Jacksonia sternbergiana	Trip 7	Bennies Road	2	12	100%	47	5.3	6.8	3.3	1279	615	52%	108%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Jacksonia sternbergiana	Trip 7	Bennies Road	3	12	100%	40	4.5	5.5	2.7	1216	592	51%	105%
Jacksonia sternbergiana	Trip 7	Bennies Road	4	12	100%	48	5.4	7.0	3.8	1289	691	46%	87%
Jacksonia sternbergiana	Trip 7	Bennies Road	5	12	100%	63	7.1	9.1	4.6	1277	650	49%	97%
Jacksonia sternbergiana	Trip 7	Bennies Road	6	12	100%	46	5.2	6.8	3.3	1307	636	51%	105%
Jacksonia sternbergiana	Trip 7	Bennies Road	1h	12	100%	27	3.1	4.0	2.1	1310	698	47%	88%
Jacksonia sternbergiana	Trip 7	Bennies Road	1l	12	100%	45	5.1	6.7	3.5	1316	682	48%	93%
Jacksonia sternbergiana	Trip 7	Bennies Road	1m	12	100%	39	4.4	5.7	3.0	1292	676	48%	91%
Jacksonia sternbergiana	Trip 8	Highbury	2	12	50%	34	3.8	4.5	2.4	1170	616	47%	90%
Jacksonia sternbergiana	Trip 8	Highbury	3	12	100%	64	7.2	8.1	4.3	1119	595	47%	88%
Jacksonia sternbergiana	Trip 8	Highbury	4	12	100%	50	5.7	6.6	3.7	1167	658	44%	77%
Jacksonia sternbergiana	Trip 8	Highbury	5	12	100%	47	5.3	6.3	3.3	1185	619	48%	91%
Jacksonia sternbergiana	Trip 8	Highbury	6	12	100%	54	6.1	7.8	3.9	1277	637	50%	101%
Jacksonia sternbergiana	Trip 8	Highbury	1h	12	100%	53	6.0	5.4	3.3	901	546	39%	65%
Jacksonia sternbergiana	Trip 8	Highbury	1l	12	100%	64	7.2	7.0	3.8	967	522	46%	85%
Jacksonia sternbergiana	Trip 8	Highbury	1m	12	100%	58	6.6	6.1	3.4	930	521	44%	78%
Kunzea ericifolia	Trip 2	Temple Farm	1	12	100%	75	8.5	10.4	6.5	1226	767	37%	60%
Kunzea ericifolia	Trip 2	Temple Farm	2	12	100%	60	6.8	8.5	5.5	1253	805	36%	56%
Kunzea ericifolia	Trip 2	Temple Farm	3	12	100%	79	8.9	10.9	6.5	1220	731	40%	67%
Kunzea glabrescens	Trip 4	Yanchep North 2	1	12	100%	51	5.8	6.7	3.6	1162	624	46%	86%
Kunzea glabrescens	Trip 4	Yanchep North 2	2	12	100%	48	5.4	6.5	3.5	1197	648	46%	85%
Kunzea glabrescens	Trip 4	Yanchep North 2	3	12	100%	55	6.2	7.6	4.6	1222	733	40%	67%
Kunzea glabrescens	Trip 7	Moore River SF	2	12	100%	35	4.0	4.6	2.6	1162	654	44%	78%
Kunzea glabrescens	Trip 7	Moore River SF	3	12	100%	35	4.0	4.8	2.7	1213	680	44%	78%
Kunzea glabrescens	Trip 7	Moore River SF	4	12	100%	34	3.8	4.6	2.7	1196	697	42%	72%
Kunzea glabrescens	Trip 7	Moore River SF	5	12	100%	38	4.3	5.3	3.0	1233	696	44%	77%
Kunzea glabrescens	Trip 7	Moore River SF	6	12	100%	34	3.8	4.9	2.6	1274	666	48%	91%
Kunzea glabrescens	Trip 7	Moore River SF	1h	12	100%	28	3.2	3.9	2.3	1232	726	41%	70%
Kunzea glabrescens	Trip 7	Moore River SF	1l	12	100%	65	7.4	9.5	5.6	1292	767	41%	68%
Kunzea glabrescens	Trip 7	Moore River SF	1m	12	100%	30	3.4	4.4	2.6	1297	755	42%	72%
Kunzea glabrescens	Trip 7	Wablin Road	1	12	100%	36	4.1	4.8	2.9	1179	720	39%	64%
Kunzea glabrescens	Trip 7	Wablin Road	2	12	100%	38	4.3	5.6	3.2	1303	738	43%	77%
Kunzea glabrescens	Trip 7	Wablin Road	4	12	100%	45	5.1	6.3	3.5	1238	682	45%	82%
Kunzea glabrescens	Trip 7	Wablin Road	5	12	100%	70	7.9	9.8	5.7	1238	724	42%	71%
Kunzea glabrescens	Trip 7	Wablin Road	6	12	100%	39	4.4	5.5	3.1	1247	691	45%	80%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Kunzea glabrescens	Trip 7	Wablin Road	3h	12	100%	34	3.8	4.8	2.7	1248	689	45%	81%
Kunzea glabrescens	Trip 7	Wablin Road	3l	12	100%	76	8.6	10.2	6.1	1187	714	40%	66%
Kunzea glabrescens	Trip 7	Wablin Road	3m	12	100%	33	3.7	4.8	2.5	1286	670	48%	92%
Lamarchea hakeifolia	Trip 4	#8 Tank	1	12	100%	60	6.8	8.4	5.2	1238	759	39%	63%
Lamarchea hakeifolia	Trip 4	#8 Tank	2	12	100%	52	5.9	7.8	5.1	1326	862	35%	54%
Lamarchea hakeifolia	Trip 4	#8 Tank	3	12	100%	77	8.7	10.8	7.0	1240	799	36%	55%
Lambertia inermis	Trip 6	Hassal	1	12	100%	38	4.3	5.4	2.9	1256	665	47%	89%
Lambertia inermis	Trip 6	Hassal	2	12	100%	44	5.0	6.3	3.4	1266	683	46%	85%
Lambertia inermis	Trip 6	Hassal	3	12	100%	38	4.3	5.6	3.3	1303	768	41%	70%
Lambertia inermis	Trip 8	Boxwood Hill	2	12	100%	47	5.3	6.1	3.3	1148	626	45%	83%
Lambertia inermis	Trip 8	Boxwood Hill	3	12	100%	42	4.8	6.4	3.5	1347	743	45%	81%
Lambertia inermis	Trip 8	Boxwood Hill	4	12	100%	47	5.3	6.8	4.0	1279	751	41%	70%
Lambertia inermis	Trip 8	Boxwood Hill	5	12	100%	45	5.1	6.4	3.5	1258	690	45%	82%
Lambertia inermis	Trip 8	Boxwood Hill	6	12	100%	33	3.7	4.5	2.5	1206	656	46%	84%
Lambertia inermis	Trip 8	Boxwood Hill	1h	12	100%	31	3.5	4.7	2.6	1341	736	45%	82%
Lambertia inermis	Trip 8	Boxwood Hill	1l	12	100%	48	5.4	6.9	3.6	1271	669	47%	90%
Lambertia inermis	Trip 8	Boxwood Hill	1m	12	100%	46	5.2	6.5	3.5	1249	665	47%	88%
Lambertia inermis	Trip 8	Wellstead	2	12	100%	29	3.3	3.9	2.2	1189	668	44%	78%
Lambertia inermis	Trip 8	Wellstead	3	12	100%	34	3.8	4.9	2.5	1274	653	49%	95%
Lambertia inermis	Trip 8	Wellstead	4	12	100%	44	5.0	6.1	3.2	1226	647	47%	89%
Lambertia inermis	Trip 8	Wellstead	5	12	100%	33	3.7	4.8	2.8	1286	737	43%	75%
Lambertia inermis	Trip 8	Wellstead	6	12	100%	58	6.6	8.0	4.3	1220	651	47%	87%
Lambertia inermis	Trip 8	Wellstead	1h	12	100%	25	2.8	3.6	1.9	1273	683	46%	87%
Lambertia inermis	Trip 8	Wellstead	1l	12	100%	41	4.6	5.9	3.2	1272	688	46%	85%
Lambertia inermis	Trip 8	Wellstead	1m	12	100%	38	4.3	5.5	2.9	1280	670	48%	91%
Leptomaria pauciflora	Trip 5	Snake soak track	1	12	100%	59	6.7	8.4	5.4	1259	815	35%	54%
Leptomaria pauciflora	Trip 5	Snake soak track	2	12	100%	34	3.8	4.9	3.4	1274	887	30%	44%
Leptomaria pauciflora	Trip 5	Snake soak track	3	12	100%	37	4.2	5.6	3.9	1338	927	31%	44%
Leptospermum nitens	Trip 3	McDermid Rock	1	12	100%	62	7.0	8.6	6.2	1226	886	28%	38%
Leptospermum nitens	Trip 3	McDermid Rock	2	12	100%	52	5.9	7.5	5.7	1275	961	25%	33%
Leptospermum nitens	Trip 3	McDermid Rock	3	12	100%	78	8.8	10.8	8.2	1224	932	24%	31%
Melaleuca acuminata	Trip 8	Chinocup	1	12	100%	30	3.4	4.5	3.0	1326	887	33%	50%
Melaleuca acuminata	Trip 8	Chinocup	2	12	100%	26	2.9	3.9	2.6	1326	871	34%	52%
Melaleuca acuminata	Trip 8	Chinocup	3	12	100%	29	3.3	4.5	3.0	1372	899	34%	53%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Melaleuca cuticularis	Trip 2	Temple Farm	1	12	100%	74	8.4	10.6	7.2	1267	857	32%	48%
Melaleuca cuticularis	Trip 2	Temple Farm	2	12	100%	64	7.2	9.3	6.0	1285	834	35%	54%
Melaleuca cuticularis	Trip 2	Temple Farm	3	12	100%	78	8.8	10.9	7.1	1236	805	35%	54%
Melaleuca eleuterostachya	Trip 4	Sullivan	1	12	100%	52	5.9	7.9	6.1	1343	1037	23%	30%
Melaleuca eleuterostachya	Trip 4	Sullivan	2	12	100%	51	5.8	7.7	5.7	1335	995	25%	34%
Melaleuca eleuterostachya	Trip 4	Sullivan	3	12	100%	42	4.8	6.4	4.8	1347	1006	25%	34%
Melaleuca fulgens	Trip 9	Xantipe Tank	1	12	100%	27	3.1	4.2	3.0	1375	966	30%	42%
Melaleuca fulgens	Trip 9	Xantipe Tank	2	12	100%	28	3.2	3.7	3.1	1168	969	17%	21%
Melaleuca fulgens	Trip 9	Xantipe Tank	3	12	100%	42	4.8	6.1	4.4	1284	933	27%	38%
Melaleuca globifera	Trip 6	Mount Burdett	1	12	100%	43	4.9	5.8	4.0	1193	818	31%	46%
Melaleuca globifera	Trip 6	Mount Burdett	2	12	100%	38	4.3	5.4	3.8	1256	889	29%	41%
Melaleuca globifera	Trip 6	Mount Burdett	3	12	100%	40	4.5	5.6	3.7	1238	816	34%	52%
Melaleuca globifera	Trip 6	Wharton beach	1	12	100%	66	7.5	9.0	4.7	1206	628	48%	92%
Melaleuca globifera	Trip 6	Wharton beach	2	12	100%	31	3.5	4.3	2.4	1226	693	43%	77%
Melaleuca globifera	Trip 6	Wharton beach	3	12	100%	33	3.7	5.0	2.9	1340	766	43%	75%
Melaleuca halmaturorum	Trip 6	Lake King	1	12	100%	47	5.3	7.0	5.0	1317	931	29%	41%
Melaleuca halmaturorum	Trip 6	Lake King	2	12	100%	31	3.5	4.6	3.4	1312	970	26%	35%
Melaleuca halmaturorum	Trip 6	Lake King	3	12	100%	57	6.4	8.4	6.1	1303	951	27%	37%
Melaleuca hamata	Trip 4	Sullivan	1	12	100%	48	5.4	6.9	5.1	1271	932	27%	36%
Melaleuca hamata	Trip 4	Sullivan	2	12	100%	47	5.3	6.6	4.9	1242	929	25%	34%
Melaleuca hamata	Trip 4	Sullivan	3	12	100%	52	5.9	7.4	5.3	1258	896	29%	40%
Melaleuca hamulosa	Trip 5	Ghooli	1	12	100%	30	3.4	4.3	3.1	1267	920	27%	38%
Melaleuca hamulosa	Trip 5	Ghooli	2	12	100%	56	6.3	7.5	5.4	1184	846	29%	40%
Melaleuca hamulosa	Trip 5	Ghooli	3	12	100%	39	4.4	5.5	3.8	1247	859	31%	45%
Melaleuca hamulosa (?)	Trip 8	Boothy	1	12	100%	47	5.3	6.7	4.1	1260	766	39%	65%
Melaleuca hamulosa (?)	Trip 8	Boothy	2	12	100%	60	6.8	9.1	5.2	1341	769	43%	74%
Melaleuca hamulosa (?)	Trip 8	Boothy	3	12	100%	75	8.5	10.2	6.1	1203	717	40%	68%
Melaleuca hnatiukii	Trip 6	Lignite II	1	12	100%	35	4.0	5.3	3.7	1339	937	30%	43%
Melaleuca hnatiukii	Trip 6	Lignite II	2	12	100%	37	4.2	5.6	4.1	1338	973	27%	38%
Melaleuca hnatiukii	Trip 6	Lignite II	3	12	100%	35	4.0	5.3	3.8	1339	960	28%	39%
Melaleuca huegelii	Trip 4	Arrowsmith Siding	1	12	100%	59	6.7	8.4	5.6	1259	839	33%	50%
Melaleuca huegelii	Trip 4	Arrowsmith Siding	2	12	100%	62	7.0	8.8	6.1	1255	871	31%	44%
Melaleuca huegelii	Trip 4	Arrowsmith Siding	3	12	100%	36	4.1	5.3	3.4	1302	840	35%	55%
Melaleuca incana	Trip 8	Big Brook	2	12	100%	34	3.8	4.9	2.5	1274	637	50%	100%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Melaleuca incana	Trip 8	Big Brook	3	12	100%	32	3.6	4.6	2.5	1271	702	45%	81%
Melaleuca incana	Trip 8	Big Brook	4	12	100%	40	4.5	5.3	2.8	1172	617	47%	90%
Melaleuca incana	Trip 8	Big Brook	5	12	100%	34	3.8	4.7	2.5	1222	637	48%	92%
Melaleuca incana	Trip 8	Big Brook	6	12	100%	41	4.6	5.3	2.9	1143	630	45%	82%
Melaleuca incana	Trip 8	Big Brook	1h	12	100%	30	3.4	4.6	2.3	1356	663	51%	104%
Melaleuca incana	Trip 8	Big Brook	1l	12	100%	55	6.2	7.8	4.2	1254	672	46%	87%
Melaleuca incana	Trip 8	Big Brook	1m	12	100%	43	4.9	6.1	3.3	1254	681	46%	84%
Melaleuca lanceolata	Trip 5	Lassak	1	12	100%	36	4.1	5.3	3.8	1302	928	29%	40%
Melaleuca lanceolata	Trip 5	Lassak	2	12	100%	34	3.8	4.9	3.6	1274	931	27%	37%
Melaleuca lanceolata	Trip 5	Lassak	3	12	100%	31	3.5	4.5	3.3	1284	936	27%	37%
Melaleuca lanceolata	Trip 6	Hopetoun	1	12	100%	42	4.8	6.2	4.2	1305	882	32%	48%
Melaleuca lanceolata	Trip 6	Hopetoun	2	12	100%	35	4.0	5.0	3.4	1263	851	33%	48%
Melaleuca lanceolata	Trip 6	Hopetoun	3	12	50%	26	2.9	3.6	2.5	1224	833	32%	47%
Melaleuca lateriflora	Trip 3	Railway Xing	1	12	100%	39	4.4	5.6	4.1	1270	939	26%	35%
Melaleuca lateriflora	Trip 3	Railway Xing	2	12	100%	40	4.5	5.8	4.3	1282	953	26%	35%
Melaleuca lateriflora	Trip 3	Railway Xing	3	12	100%	45	5.1	6.3	4.9	1238	969	22%	28%
Melaleuca linguiformis	Trip 6	Mt Ney	1	12	100%	39	4.4	5.7	3.8	1292	862	33%	50%
Melaleuca linguiformis	Trip 6	Mt Ney	2	12	100%	38	4.3	5.5	3.7	1280	856	33%	49%
Melaleuca linguiformis	Trip 6	Mt Ney	3	12	100%	38	4.3	5.5	3.7	1280	854	33%	50%
Melaleuca pauperiflora	Trip 3	Mount Day West	1	12	100%	74	8.4	11.2	8.1	1338	962	28%	39%
Melaleuca pauperiflora	Trip 3	Mount Day West	2	12	100%	72	8.1	10.1	7.1	1240	877	29%	41%
Melaleuca pauperiflora	Trip 3	Mount Day West	3	12	100%	49	5.5	7.3	5.0	1317	893	32%	47%
Melaleuca pauperiflora	Trip 5	Millar Road	1	12	100%	45	5.1	6.8	5.0	1336	977	27%	37%
Melaleuca pauperiflora	Trip 5	Millar Road	2	12	100%	44	5.0	6.6	4.6	1326	920	31%	44%
Melaleuca pauperiflora	Trip 5	Millar Road	3	12	100%	42	4.8	6.3	4.8	1326	1013	24%	31%
Melaleuca preissiana	Trip 2	Bandicoot	1	12	100%	147	16.6	19.6	8.1	1179	488	59%	142%
Melaleuca preissiana	Trip 2	Bandicoot	2	12	100%	138	15.6	18.4	8.2	1179	527	55%	124%
Melaleuca preissiana	Trip 2	Bandicoot	3	12	100%	135	15.3	18.3	7.8	1199	512	57%	134%
Melaleuca preissiana	Trip 6	Muir Highway	1	12	100%	43	4.9	6.2	2.9	1275	602	53%	112%
Melaleuca preissiana	Trip 6	Muir Highway	2	12	100%	46	5.2	6.9	3.5	1326	663	50%	100%
Melaleuca preissiana	Trip 6	Muir Highway	3	12	100%	51	5.8	7.3	3.7	1266	633	50%	100%
Melaleuca preissiana	Trip 6	Muir Highway	5	12	100%	41	4.6	5.8	3.1	1251	669	47%	87%
Melaleuca preissiana	Trip 6	Muir Highway	6	12	100%	34	3.8	5.3	2.7	1378	713	48%	93%
Melaleuca preissiana	Trip 6	Muir Highway	4h	12	100%	38	4.3	5.0	2.7	1163	633	46%	84%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Melaleuca preissiana	Trip 6	Muir Highway	4l	12	100%	71	8.0	10.3	5.4	1283	669	48%	92%
Melaleuca preissiana	Trip 6	Muir Highway	4m	12	100%	43	4.9	6.0	3.2	1234	656	47%	88%
Melaleuca preissiana	Trip 8	Marbeluup	2	12	100%	48	5.4	6.9	3.2	1271	584	54%	118%
Melaleuca preissiana	Trip 8	Marbeluup	3	12	100%	48	5.4	7.0	3.0	1289	556	57%	132%
Melaleuca preissiana	Trip 8	Marbeluup	4	12	100%	51	5.8	7.2	2.9	1248	505	60%	147%
Melaleuca preissiana	Trip 8	Marbeluup	5	12	100%	62	7.0	8.7	3.9	1241	558	55%	123%
Melaleuca preissiana	Trip 8	Marbeluup	6	12	100%	49	5.5	7.0	3.1	1263	558	56%	127%
Melaleuca preissiana	Trip 8	Marbeluup	1h	12	100%	48	5.4	6.9	2.5	1271	455	64%	179%
Melaleuca preissiana	Trip 8	Marbeluup	1l	12	100%	56	6.3	7.8	3.0	1232	474	62%	160%
Melaleuca preissiana	Trip 8	Marbeluup	1m	12	100%	50	5.7	7.1	2.6	1256	458	64%	174%
Melaleuca quadrifaria	Trip 6	Lignite Road	1	12	100%	40	4.5	5.6	3.9	1238	862	30%	44%
Melaleuca quadrifaria	Trip 6	Lignite Road	2	12	100%	33	3.7	4.9	3.2	1313	863	34%	52%
Melaleuca quadrifaria	Trip 6	Lignite Road	3	12	100%	35	4.0	5.1	3.4	1288	864	33%	49%
Melaleuca rhaphiophylla	Trip 1	Beaufort River Flats	1	12	100%	97	11.0	13.0	6.0	1185	548	54%	116%
Melaleuca rhaphiophylla	Trip 1	Beaufort River Flats	2	12	100%	113	12.8	15.0	6.6	1174	515	56%	128%
Melaleuca rhaphiophylla	Trip 1	Beaufort River Flats	3	12	100%	64	7.2	7.5	4.0	1036	555	46%	87%
Melaleuca rhaphiophylla	Trip 6	Tone River	2	12	100%	55	6.2	7.9	3.6	1270	584	54%	118%
Melaleuca rhaphiophylla	Trip 6	Tone River	3	12	100%	56	6.3	7.6	3.2	1200	508	58%	136%
Melaleuca rhaphiophylla	Trip 6	Tone River	4	12	100%	58	6.6	8.0	3.6	1220	544	55%	124%
Melaleuca rhaphiophylla	Trip 6	Tone River	5	12	100%	54	6.1	7.3	3.5	1195	570	52%	110%
Melaleuca rhaphiophylla	Trip 6	Tone River	6	12	100%	50	5.7	7.2	3.4	1273	605	53%	111%
Melaleuca rhaphiophylla	Trip 6	Tone River	1h	12	100%	47	5.3	6.5	3.1	1223	583	52%	110%
Melaleuca rhaphiophylla	Trip 6	Tone River	1l	12	100%	74	8.4	10.5	5.0	1255	596	52%	110%
Melaleuca rhaphiophylla	Trip 6	Tone River	1m	12	100%	55	6.2	7.9	3.7	1270	595	53%	114%
Melaleuca rhaphiophylla	Trip 8	Carbarup Road	2	12	100%	49	5.5	6.8	3.1	1227	567	54%	117%
Melaleuca rhaphiophylla	Trip 8	Carbarup Road	3	12	100%	70	7.9	9.8	4.7	1238	591	52%	109%
Melaleuca rhaphiophylla	Trip 8	Carbarup Road	4	12	100%	60	6.8	8.6	4.7	1267	690	46%	84%
Melaleuca rhaphiophylla	Trip 8	Carbarup Road	5	12	100%	85	9.6	11.8	6.0	1227	624	49%	97%
Melaleuca rhaphiophylla	Trip 8	Carbarup Road	6	12	100%	70	7.9	9.8	4.6	1238	579	53%	114%
Melaleuca rhaphiophylla	Trip 8	Carbarup Road	1h	12	100%	45	5.1	6.1	3.1	1199	605	50%	98%
Melaleuca rhaphiophylla	Trip 8	Carbarup Road	1l	12	100%	53	6.0	7.6	3.6	1268	606	52%	109%
Melaleuca rhaphiophylla	Trip 8	Carbarup Road	1m	12	100%	49	5.5	7.0	3.2	1263	581	54%	117%
Melaleuca sp.	Trip 6	Kau	1	12	100%	34	3.8	5.0	3.3	1300	856	34%	52%
Melaleuca sp.	Trip 6	Kau	2	12	100%	36	4.1	5.3	3.7	1302	901	31%	44%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Melaleuca sp.	Trip 6	Kau	3	12	100%	54	6.1	7.9	5.6	1294	922	29%	40%
Melaleuca stereophloia	Trip 4	Sullivan	1	12	100%	37	4.2	5.3	3.9	1267	932	26%	36%
Melaleuca stereophloia	Trip 4	Sullivan	2	12	100%	39	4.4	5.7	4.0	1292	909	30%	42%
Melaleuca stereophloia	Trip 4	Sullivan	3	12	100%	50	5.7	6.9	4.8	1220	849	30%	44%
Melaleuca strobophylla	Trip 1	Nepowie MAFT	1	12	100%	62	7.0	8.0	5.0	1141	706	38%	62%
Melaleuca strobophylla	Trip 1	Nepowie MAFT	2	12	100%	78	8.8	10.9	6.6	1236	744	40%	66%
Melaleuca strobophylla	Trip 1	Nepowie MAFT	3	12	100%	76	8.6	10.5	6.2	1222	715	41%	71%
Melaleuca uncinata	Trip 3	Hyden Fence III	1	12	100%	76	8.6	10.5	7.7	1222	895	27%	37%
Melaleuca uncinata	Trip 3	Hyden Fence III	2	12	100%	57	6.4	8.0	6.0	1241	937	25%	32%
Melaleuca uncinata	Trip 3	Hyden Fence III	3	12	100%	61	6.9	8.1	5.9	1174	857	27%	37%
Melaleuca uncinata	Trip 9	Black Road	1	12	100%	39	4.4	5.7	4.2	1292	954	26%	35%
Melaleuca uncinata	Trip 9	Black Road	2	12	100%	28	3.2	4.1	2.9	1295	919	29%	41%
Melaleuca uncinata	Trip 9	Black Road	3	12	100%	27	3.1	4.1	2.8	1343	920	31%	46%
Melaleuca uncinata "spicate ligno"	Trip 5	Snake soak track	1	14	100%	77	11.0	13.7	10.0	1243	905	27%	37%
Melaleuca uncinata "spicate ligno"	Trip 5	Snake soak track	2	13	100%	73	9.3	10.9	7.2	1169	769	34%	52%
Melaleuca uncinata "spicate ligno"	Trip 5	Snake soak track	3	12	100%	73	8.6	10.3	6.8	1197	794	34%	51%
Melaleuca uncinata form uncinata	Trip 3	Railway Xing	1	12	100%	32	3.6	4.5	3.2	1243	890	28%	40%
Melaleuca uncinata form uncinata	Trip 3	Railway Xing	2	12	100%	50	5.7	7.4	5.4	1309	962	26%	36%
Melaleuca uncinata form uncinata	Trip 3	Railway Xing	3	12	100%	40	4.5	5.7	4.1	1260	902	28%	40%
Melaleuca viminea	Trip 8	Vasse Highway	1	12	100%	45	5.1	6.5	3.1	1277	611	52%	109%
Melaleuca viminea	Trip 8	Vasse Highway	2	12	100%	32	3.6	4.6	2.4	1271	666	48%	91%
Melaleuca viminea	Trip 8	Vasse Highway	3	12	100%	30	3.4	4.3	2.0	1267	595	53%	113%
Myoporum platycarpum	Trip 3	Eyre Highway	1	12	100%	72	8.1	10.2	7.8	1253	952	24%	32%
Myoporum platycarpum	Trip 3	Eyre Highway	2	12	100%	80	9.0	11.4	9.4	1260	1038	18%	21%
Myoporum platycarpum	Trip 3	Eyre Highway	3	12	100%	86	9.7	11.7	8.5	1203	877	27%	37%
Myoporum platycarpum	Trip 3	Eyre Highway	4	12	100%	69	7.8	9.9	7.3	1269	941	26%	35%
Nuytsia floribunda	Trip 1	Beaufort Rubbish Dump	1	12	100%	99	11.2	13.0	5.3	1161	472	59%	146%
Nuytsia floribunda	Trip 1	Beaufort Rubbish Dump	2	12	100%	121	13.7	16.0	6.6	1169	481	59%	143%
Nuytsia floribunda	Trip 1	Beaufort Rubbish Dump	3	12	50%	30	3.4	3.9	1.6	1149	460	60%	150%
Nuytsia floribunda	Trip 6	Winfield	1	12	100%	59	6.7	8.1	3.1	1214	457	62%	166%
Nuytsia floribunda	Trip 6	Winfield	2	12	100%	45	5.1	6.1	2.4	1199	477	60%	151%
Nuytsia floribunda	Trip 6	Winfield	3	12	100%	51	5.8	7.2	3.0	1248	513	59%	143%
Nuytsia floribunda	Trip 6	Winfield	5	12	100%	65	7.4	9.0	3.8	1224	517	58%	137%
Nuytsia floribunda	Trip 6	Winfield	6	12	100%	44	5.0	6.1	2.6	1226	514	58%	138%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Nuytsia floribunda	Trip 6	Winfield	4h	12	100%	40	4.5	5.7	2.4	1260	524	58%	141%
Nuytsia floribunda	Trip 6	Winfield	4l	12	100%	70	7.9	9.9	4.1	1251	518	59%	141%
Nuytsia floribunda	Trip 6	Winfield	4m	12	100%	47	5.3	6.4	2.7	1204	506	58%	138%
Nuytsia floribunda	Trip 7	Wablin Road	2	12	100%	50	5.7	6.6	2.9	1167	504	57%	132%
Nuytsia floribunda	Trip 7	Wablin Road	3	12	100%	31	3.5	4.1	1.8	1169	513	56%	128%
Nuytsia floribunda	Trip 7	Wablin Road	4	12	100%	80	9.0	10.5	4.3	1161	474	59%	145%
Nuytsia floribunda	Trip 7	Wablin Road	5	12	100%	56	6.3	7.6	3.0	1200	478	60%	151%
Nuytsia floribunda	Trip 7	Wablin Road	6	12	100%	49	5.6	6.4	2.9	1146	519	55%	121%
Nuytsia floribunda	Trip 7	Wablin Road	1h	12	100%	39	4.4	5.4	2.5	1224	558	54%	120%
Nuytsia floribunda	Trip 7	Wablin Road	1l	12	100%	68	7.7	9.1	3.7	1183	485	59%	144%
Nuytsia floribunda	Trip 7	Wablin Road	1m	12	100%	59	6.7	7.9	3.4	1184	513	57%	131%
Oxylobium lineare	Trip 8	Tone East	1	11	100%	68	6.2	6.4	4.2	1037	682	34%	52%
Oxylobium lineare	Trip 8	Tone East	2	11	100%	57	5.4	5.4	3.6	997	665	33%	50%
Oxylobium lineare	Trip 8	Tone East	3	14	100%	48	7.4	7.7	4.8	1042	654	37%	59%
Paraserianthes lophantha	GO	Waroona - Olsen	A	40	100%	9	10.7	9.8	4.2	916	392	57%	134%
Paraserianthes lophantha	GO	Waroona - Olsen	B	40	100%	7	8.9	8.1	3.5	911	397	56%	129%
Paraserianthes lophantha	GO	Waroona - Olsen	C	40	100%	7	8.6	8.1	3.5	938	403	57%	133%
Persoonia elliptica	Trip 2	Brookton Highway	1	12	100%	87	9.8	10.7	5.4	1087	546	50%	99%
Persoonia elliptica	Trip 2	Brookton Highway	2	12	100%	81	9.2	9.9	5.3	1081	575	47%	88%
Persoonia elliptica	Trip 2	Brookton Highway	3	12	100%	67	7.6	8.1	4.4	1069	583	45%	83%
Persoonia elliptica	Trip 5	Government Road	2	12	100%	55	6.2	7.6	3.8	1222	617	49%	98%
Persoonia elliptica	Trip 5	Government Road	3	12	100%	66	7.5	8.6	4.3	1152	572	50%	101%
Persoonia elliptica	Trip 5	Government Road	4	12	100%	64	7.2	8.9	4.4	1230	612	50%	101%
Persoonia elliptica	Trip 5	Government Road	5	12	100%	48	5.4	7.0	3.3	1289	613	52%	110%
Persoonia elliptica	Trip 5	Government Road	6	12	100%	38	4.3	5.4	2.9	1256	684	46%	84%
Persoonia elliptica	Trip 5	Government Road	1h	12	100%	67	7.6	9.0	4.6	1188	608	49%	95%
Persoonia elliptica	Trip 5	Government Road	1l	12	100%	90	10.2	12.4	6.9	1218	678	44%	80%
Persoonia elliptica	Trip 5	Government Road	1m	12	100%	72	8.1	9.6	5.0	1179	608	48%	94%
Persoonia elliptica	Trip 8	Brk Hwy Pines	2	12	100%	68	7.7	9.4	4.1	1222	538	56%	127%
Persoonia elliptica	Trip 8	Brk Hwy Pines	3	12	100%	54	6.1	7.7	3.3	1261	547	57%	131%
Persoonia elliptica	Trip 8	Brk Hwy Pines	4	12	100%	69	7.8	10.0	4.7	1281	601	53%	113%
Persoonia elliptica	Trip 8	Brk Hwy Pines	5	12	100%	54	6.1	7.9	3.7	1294	604	53%	114%
Persoonia elliptica	Trip 8	Brk Hwy Pines	6	12	100%	58	6.6	8.5	3.6	1296	544	58%	138%
Persoonia elliptica	Trip 8	Brk Hwy Pines	1h	12	100%	23	2.6	3.4	1.6	1307	596	54%	119%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Persoonia elliptica	Trip 8	Brk Hwy Pines	1l	12	100%	40	4.5	5.9	2.8	1304	615	53%	112%
Persoonia elliptica	Trip 8	Brk Hwy Pines	1m	12	100%	34	3.8	5.2	2.4	1352	629	53%	115%
Persoonia saundersiana	Trip 5	Cottage Garden	1	12	100%	55	6.2	7.9	5.4	1270	873	31%	45%
Persoonia saundersiana	Trip 5	Cottage Garden	2	12	100%	39	4.4	5.3	3.5	1202	791	34%	52%
Persoonia saundersiana	Trip 5	Cottage Garden	3	12	100%	49	5.5	6.8	4.9	1227	877	29%	40%
Persoonia stricta	Trip 5	Daly Road	1	12	100%	53	6.0	7.3	5.4	1218	908	25%	34%
Persoonia stricta	Trip 5	Daly Road	2	12	100%	55	6.2	7.7	5.7	1238	912	26%	36%
Persoonia stricta	Trip 5	Daly Road	3	12	50%	29	3.3	4.0	2.9	1220	884	28%	38%
Pimelea clavata	Trip 8	Diamond tree	1	12	100%	37	4.2	4.2	2.3	1004	542	46%	85%
Pimelea clavata	Trip 8	Diamond tree	2	12	100%	63	7.1	4.8	2.3	674	317	53%	112%
Pimelea clavata	Trip 8	Diamond tree	3	12	100%	35	4.0	3.4	1.9	859	488	43%	76%
Pinus pinaster	Trip 7	Wablin Road	1	12	100%	64	7.3	7.4	3.4	1016	465	54%	118%
Pinus pinaster	Trip 7	Wablin Road	2	12	100%	74	8.4	9.8	3.7	1171	442	62%	165%
Pinus pinaster	Trip 7	Wablin Road	3	12	100%	77	8.7	10.0	4.0	1154	465	60%	148%
Pittosporum angustifolium	Trip 5	Bullfinch	1	12	100%	53	6.0	7.3	5.1	1218	852	30%	43%
Pittosporum angustifolium	Trip 5	Bullfinch	2	12	100%	50	5.7	7.1	5.2	1256	920	27%	37%
Pittosporum angustifolium	Trip 5	Bullfinch	3	12	100%	69	7.8	10.4	6.6	1333	842	37%	58%
Pittosporum angustifolium	Trip 5	Kalannie rifle range	1	12	100%	39	4.4	5.7	3.8	1292	859	34%	50%
Pittosporum angustifolium	Trip 5	Kalannie rifle range	2	12	100%	42	4.8	6.3	4.1	1326	863	35%	54%
Pittosporum angustifolium	Trip 5	Kalannie rifle range	3	12	100%	48	5.4	7.0	4.8	1289	892	31%	45%
Pittosporum phylliraeoides	JC	Mullewa - Critch	36	12	100%	109	12.3		9.2		744		
Pittosporum phylliraeoides	Trip 4	White Cliffs	1	12	100%	62	7.0	8.9	6.1	1269	871	31%	46%
Pittosporum phylliraeoides	Trip 4	White Cliffs	2	12	100%	52	5.9	7.6	5.1	1292	867	33%	49%
Pittosporum phylliraeoides	Trip 4	White Cliffs	3	12	100%	85	9.6	12.3	8.3	1279	862	33%	48%
Santalum acuminatum	Trip 3	Forrestonia Pub	1	12	100%	72	8.1	9.0	6.4	1105	780	29%	42%
Santalum acuminatum	Trip 3	Forrestonia Pub	2	12	100%	98	11.1	13.0	9.8	1173	885	25%	33%
Santalum acuminatum	Trip 3	Forrestonia Pub	3	12	100%	81	9.2	11.1	8.1	1212	882	27%	37%
Santalum acuminatum	Trip 7	8 km road dam	1	12	100%	55	6.2	7.4	4.3	1190	688	42%	73%
Santalum acuminatum	Trip 7	8 km road dam	2	12	100%	40	4.5	5.5	3.3	1216	721	41%	69%
Santalum acuminatum	Trip 7	8 km road dam	3	12	100%	98	11.1	11.0	7.7	992	693	30%	43%
Santalum murrayanum	Trip 1	Dryandra Gravel Pit	1	12	100%	100	11.3	12.4	7.8	1096	689	37%	59%
Santalum murrayanum	Trip 1	Dryandra Gravel Pit	2	12	100%	103	11.6	12.6	7.7	1082	664	39%	63%
Santalum murrayanum	Trip 1	Dryandra Gravel Pit	3	12	100%	95	10.7	11.7	7.1	1089	656	40%	66%
Santalum murrayanum	Trip 6	Kawana	1	12	100%	42	4.8	5.9	3.6	1242	749	40%	66%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Santalum murrayanum	Trip 6	Kawana	3	12	100%	37	4.2	5.6	3.3	1338	781	42%	71%
Santalum murrayanum	Trip 6	Kawana	4	12	100%	47	5.3	6.3	3.5	1185	660	44%	79%
Santalum murrayanum	Trip 6	Kawana	5	12	100%	32	3.6	5.0	3.0	1382	823	40%	68%
Santalum murrayanum	Trip 6	Kawana	6	12	100%	42	4.8	6.0	3.6	1263	764	40%	65%
Santalum murrayanum	Trip 6	Kawana	2h	12	100%	37	4.2	5.1	2.8	1219	679	44%	80%
Santalum murrayanum	Trip 6	Kawana	2l	12	100%	59	6.7	8.0	4.6	1199	692	42%	73%
Santalum murrayanum	Trip 6	Kawana	2m	12	100%	56	6.3	7.2	4.1	1137	649	43%	75%
Santalum murrayanum	Trip 8	Highbury west	2	12	100%	58	6.6	7.7	4.7	1174	709	40%	66%
Santalum murrayanum	Trip 8	Highbury west	3	12	100%	74	8.4	9.8	5.9	1171	700	40%	67%
Santalum murrayanum	Trip 8	Highbury west	4	12	100%	57	6.4	7.5	4.6	1163	718	38%	62%
Santalum murrayanum	Trip 8	Highbury west	5	12	100%	50	5.7	7.3	4.6	1291	808	37%	60%
Santalum murrayanum	Trip 8	Highbury west	6	12	100%	47	5.3	6.5	4.0	1223	745	39%	64%
Santalum murrayanum	Trip 8	Highbury west	1h	12	100%	56	6.3	7.4	4.6	1168	723	38%	62%
Santalum murrayanum	Trip 8	Highbury west	1l	12	100%	73	8.3	10.0	6.3	1211	759	37%	59%
Santalum murrayanum	Trip 8	Highbury west	1m	12	100%	60	6.8	8.2	4.8	1208	709	41%	70%
Senna (?) sp.	Trip 5	Bali	1	12	100%	46	5.2	6.0	3.3	1153	636	45%	81%
Senna (?) sp.	Trip 5	Bali	2	12	100%	41	4.6	5.6	3.2	1208	686	43%	76%
Senna (?) sp.	Trip 5	Bali	3	12	100%	38	4.3	5.6	3.5	1303	807	38%	61%
Senna glutinosa subsp. chatelainiana	Trip 7	Stephens Bank	1	12	100%	68	7.7	9.6	5.0	1248	646	48%	93%
Senna glutinosa subsp. chatelainiana	Trip 7	Stephens Bank	2	12	100%	60	6.8	7.7	4.1	1135	604	47%	88%
Senna glutinosa subsp. chatelainiana	Trip 7	Stephens Bank	3	12	100%	41	4.6	4.9	2.9	1057	632	40%	67%
Senna glutinosa subsp. chatelainiana	Trip 9	Gutha	2	12	100%	62	7.0	7.6	4.6	1084	649	40%	67%
Senna glutinosa subsp. chatelainiana	Trip 9	Gutha	3	12	100%	41	4.6	4.6	2.6	992	569	43%	74%
Senna glutinosa subsp. chatelainiana	Trip 9	Gutha	4	12	100%	46	5.2	5.0	3.1	961	586	39%	64%
Senna glutinosa subsp. chatelainiana	Trip 9	Gutha	5	12	100%	26	2.9	3.0	1.7	1020	571	44%	79%
Senna glutinosa subsp. chatelainiana	Trip 9	Gutha	6	12	100%	36	4.1	4.6	2.3	1130	565	50%	100%
Senna glutinosa subsp. chatelainiana	Trip 9	Gutha	1h	12	100%	29	3.3	3.3	2.2	1006	665	34%	51%
Senna glutinosa subsp. chatelainiana	Trip 9	Gutha	1l	12	100%	30	3.4	3.5	2.1	1032	628	39%	64%
Senna glutinosa subsp. chatelainiana	Trip 9	Gutha	1m	12	100%	30	3.4	3.4	2.0	1002	601	40%	67%
Senna glutinosa subsp. chatelainiana	Trip 9	Stephens II	2	12	100%	45	5.1	6.6	3.4	1297	676	48%	92%
Senna glutinosa subsp. chatelainiana	Trip 9	Stephens II	3	12	100%	27	3.1	3.7	1.9	1212	609	50%	99%
Senna glutinosa subsp. chatelainiana	Trip 9	Stephens II	4	12	100%	30	3.4	4.5	2.4	1326	693	48%	91%
Senna glutinosa subsp. chatelainiana	Trip 9	Stephens II	5	12	100%	39	4.4	4.8	2.6	1088	589	46%	85%
Senna glutinosa subsp. chatelainiana	Trip 9	Stephens II	6	12	100%	35	4.0	4.8	2.6	1213	657	46%	85%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Senna glutinosa subsp. chatelainiana	Trip 9	Stephens II	1h	12	100%	30	3.4	3.5	2.0	1032	595	42%	73%
Senna glutinosa subsp. chatelainiana	Trip 9	Stephens II	1l	12	100%	35	4.0	4.4	2.6	1112	659	41%	69%
Senna glutinosa subsp. chatelainiana	Trip 9	Stephens II	1m	12	100%	33	3.7	4.3	2.5	1152	667	42%	73%
Senna pleurocarpa subsp. (?)	Trip 9	Nabawa East	2	12	100%	56	6.3	6.2	3.7	979	578	41%	69%
Senna pleurocarpa subsp. (?)	Trip 9	Nabawa East	3	12	100%	43	4.9	4.6	2.7	946	553	42%	71%
Senna pleurocarpa subsp. (?)	Trip 9	Nabawa East	4	12	100%	32	3.6	3.8	2.3	1050	638	39%	65%
Senna pleurocarpa subsp. (?)	Trip 9	Nabawa East	5	12	100%	48	5.4	5.1	3.0	939	549	42%	71%
Senna pleurocarpa subsp. (?)	Trip 9	Nabawa East	6	12	100%	41	4.6	4.9	2.8	1057	593	44%	78%
Senna pleurocarpa subsp. (?)	Trip 9	Nabawa East	1h	12	100%	36	4.1	3.8	2.4	933	585	37%	60%
Senna pleurocarpa subsp. (?)	Trip 9	Nabawa East	1l	12	100%	81	9.2	9.1	5.7	993	621	37%	60%
Senna pleurocarpa subsp. (?)	Trip 9	Nabawa East	1m	12	100%	48	5.4	5.2	3.2	958	584	39%	64%
Senna sp. Austin	Trip 9	Jones Lake Road	2	12	100%	27	3.1	4.4	3.7	1441	1195	17%	21%
Senna sp. Austin	Trip 9	Jones Lake Road	3	12	100%	31	3.5	5.1	4.0	1455	1152	21%	26%
Senna sp. Austin	Trip 9	Jones Lake Road	4	12	100%	28	3.2	4.7	3.7	1484	1159	22%	28%
Senna sp. Austin	Trip 9	Jones Lake Road	5	12	100%	34	3.8	5.7	4.5	1482	1173	21%	26%
Senna sp. Austin	Trip 9	Jones Lake Road	6	12	100%	33	3.7	5.5	4.3	1474	1149	22%	28%
Senna sp. Austin	Trip 9	Jones Lake Road	1h	12	100%	33	3.7	5.3	4.1	1420	1107	22%	28%
Senna sp. Austin	Trip 9	Jones Lake Road	1l	12	100%	45	5.1	7.3	5.7	1434	1112	22%	29%
Senna sp. Austin	Trip 9	Jones Lake Road	1m	12	100%	33	3.7	5.4	4.2	1447	1123	22%	29%
Spyridium globulosum	Trip 2	Quaranup	1	12	100%	60	6.8	8.5	5.8	1253	856	32%	46%
Spyridium globulosum	Trip 2	Quaranup	2	12	100%	62	7.0	8.9	6.1	1269	871	31%	46%
Spyridium globulosum	Trip 2	Quaranup	3	12	100%	70	7.9	9.6	6.5	1213	819	33%	48%
Tagasaste	JC	Dongara - Grieves	23	12	100%	57	6.4		5.1		786		
Tagasaste	JC	Dongara - Grieves	25	12	100%	66	7.5		6.1		819		
Taxandria juniperina	Trip 2	Bandicoot	1	12	100%	81	9.2	10.5	4.9	1146	535	53%	114%
Taxandria juniperina	Trip 2	Bandicoot	2	12	100%	88	10.0	11.2	5.4	1125	542	52%	108%
Taxandria juniperina	Trip 2	Bandicoot	3	12	100%	96	10.9	11.9	6.2	1096	566	48%	93%
Taxandria juniperina	Trip 6	Cuthbert	1	12	100%	52	5.9	7.2	3.0	1224	507	59%	142%
Taxandria juniperina	Trip 6	Cuthbert	2	12	100%	35	4.0	4.8	2.4	1213	604	50%	101%
Taxandria juniperina	Trip 6	Cuthbert	3	12	100%	39	4.4	5.3	2.0	1202	456	62%	164%
Taxandria juniperina	Trip 6	Cuthbert	4	12	100%	32	3.6	4.7	2.5	1299	691	47%	88%
Taxandria juniperina	Trip 6	Cuthbert	5	12	100%	40	4.5	5.5	2.5	1216	555	54%	119%
Taxandria juniperina	Trip 6	Cuthbert	6h	12	100%	35	4.0	4.9	2.0	1238	510	59%	143%
Taxandria juniperina	Trip 6	Cuthbert	6l	12	100%	55	6.2	7.9	3.5	1270	558	56%	128%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Taxandria juniperina	Trip 6	Cuthbert	6m	12	100%	37	4.2	5.2	2.2	1243	526	58%	136%
Taxandria juniperina	Trip 8	Marbeluup	2	12	100%	47	5.3	6.4	2.8	1204	527	56%	129%
Taxandria juniperina	Trip 8	Marbeluup	3	12	100%	60	6.8	8.4	4.4	1238	651	47%	90%
Taxandria juniperina	Trip 8	Marbeluup	4	12	100%	49	5.5	6.6	3.3	1191	588	51%	102%
Taxandria juniperina	Trip 8	Marbeluup	5	12	100%	57	6.4	7.8	3.9	1210	599	51%	102%
Taxandria juniperina	Trip 8	Marbeluup	6	12	100%	72	8.1	9.9	4.4	1216	543	55%	124%
Taxandria juniperina	Trip 8	Marbeluup	1h	12	100%	68	7.7	9.1	4.7	1183	614	48%	93%
Taxandria juniperina	Trip 8	Marbeluup	1l	12	100%	73	8.3	9.6	5.0	1163	607	48%	92%
Taxandria juniperina	Trip 8	Marbeluup	1m	12	100%	67	7.6	9.2	4.8	1214	632	48%	92%
Templetonia retusa	Trip 6	Moir Road	1	12	100%	30	3.4	4.9	3.5	1444	1035	28%	40%
Templetonia retusa	Trip 6	Moir Road	2	12	100%	41	4.6	6.5	4.7	1402	1007	28%	39%
Templetonia retusa	Trip 6	Moir Road	3	12	100%	50	5.7	7.9	5.7	1397	1001	28%	40%
Trymalium floribundum	GO	Waroona - Olsen	A	26	100%	9	4.5	5.2	3.3	1143	736	36%	55%
Trymalium floribundum	GO	Waroona - Olsen	B	27	100%	6	3.4	4.1	2.7	1201	777	35%	54%
Trymalium floribundum	GO	Waroona - Olsen	C	27	100%	8	4.4	4.8	3.1	1102	707	36%	56%
Trymalium floribundum	Trip 2	Bevan Road	1	12	100%	105	11.9	12.6	8.1	1061	683	36%	55%
Trymalium floribundum	Trip 2	Bevan Road	2	12	100%	70	7.9	8.0	5.1	1011	648	36%	56%
Trymalium floribundum	Trip 2	Bevan Road	3	12	100%	75	8.5	8.2	5.2	967	614	36%	57%
Trymalium floribundum	Trip 6	Donnelly	1	12	100%	54	6.1	7.1	4.3	1163	711	39%	64%
Trymalium floribundum	Trip 6	Donnelly	3	12	100%	57	6.4	6.9	4.4	1070	681	36%	57%
Trymalium floribundum	Trip 6	Donnelly	4	12	100%	43	4.9	5.5	3.5	1131	711	37%	59%
Trymalium floribundum	Trip 6	Donnelly	5	12	100%	50	5.7	6.7	4.3	1185	757	36%	57%
Trymalium floribundum	Trip 6	Donnelly	6	12	100%	53	6.0	6.5	4.4	1084	731	33%	48%
Trymalium floribundum	Trip 6	Donnelly	2h	12	100%	53	6.0	6.6	4.2	1101	692	37%	59%
Trymalium floribundum	Trip 6	Donnelly	2l	12	100%	61	6.9	7.9	4.8	1145	697	39%	64%
Trymalium floribundum	Trip 6	Donnelly	2m	12	100%	51	5.8	6.4	3.9	1110	673	39%	65%
Trymalium floribundum	Trip 6	Sears Road	2	12	100%	47	5.3	5.5	3.6	1035	668	35%	55%
Trymalium floribundum	Trip 6	Sears Road	3	12	100%	42	4.8	5.3	3.4	1116	707	37%	58%
Trymalium floribundum	Trip 6	Sears Road	4	12	100%	50	5.7	6.0	4.0	1061	702	34%	51%
Trymalium floribundum	Trip 6	Sears Road	5	12	100%	51	5.8	6.3	3.9	1092	678	38%	61%
Trymalium floribundum	Trip 6	Sears Road	6	12	100%	47	5.3	5.5	3.4	1035	640	38%	62%
Trymalium floribundum	Trip 6	Sears Road	1h	12	100%	48	5.4	5.9	3.6	1087	669	38%	63%
Trymalium floribundum	Trip 6	Sears Road	1l	12	100%	50	5.7	5.9	3.8	1043	663	36%	57%
Trymalium floribundum	Trip 6	Sears Road	1m	12	100%	50	5.7	6.1	3.9	1079	683	37%	58%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Viminaria juncea	GO	Waroona - Olsen	A	93	100%	11	76.4	66.5	32.5	871	425	51%	105%
Viminaria juncea	GO	Waroona - Olsen	B	94	100%	9	61.8	51.9	25.9	840	419	50%	101%
Viminaria juncea	GO	Waroona - Olsen	C	92	100%	16	105.2	91.5	45.4	869	432	50%	101%
Viminaria juncea	GO	Waroona - Olsen	D	88	100%	10	60.1	54.5	27.6	906	459	49%	97%
Viminaria juncea	GO	Waroona - Olsen	E	89	100%	10	60.0	49.5	25.2	824	420	49%	96%
Viminaria juncea	GO	Waroona - Olsen	F	88	100%	11	65.4	52.9	27.0	808	413	49%	96%
Viminaria juncea	Trip 8	Cambray Road	2	12	100%	31	3.5	3.6	1.8	1027	502	51%	105%
Viminaria juncea	Trip 8	Cambray Road	3	12	100%	25	2.8	2.5	1.2	884	439	50%	102%
Viminaria juncea	Trip 8	Cambray Road	4	12	100%	37	4.2	3.7	1.9	884	447	49%	98%
Viminaria juncea	Trip 8	Cambray Road	5	12	100%	45	5.1	5.3	2.3	1041	454	56%	129%
Viminaria juncea	Trip 8	Cambray Road	6	12	100%	31	3.5	3.4	1.6	970	459	53%	111%
Viminaria juncea	Trip 8	Cambray Road	1h	12	100%	33	3.7	3.5	1.8	938	485	48%	93%
Viminaria juncea	Trip 8	Cambray Road	1l	12	100%	37	4.2	4.1	2.1	980	507	48%	93%
Viminaria juncea	Trip 8	Cambray Road	1m	12	100%	34	3.8	3.8	1.9	988	489	51%	102%
Viminaria juncea	Trip 8	Metro gravel	2	12	100%	41	4.6	4.7	2.3	1014	494	51%	105%
Viminaria juncea	Trip 8	Metro gravel	3	12	100%	43	4.9	4.4	2.3	905	467	48%	94%
Viminaria juncea	Trip 8	Metro gravel	4	12	100%	54	6.1	6.2	3.5	1015	570	44%	78%
Viminaria juncea	Trip 8	Metro gravel	5	12	100%	47	5.3	4.7	2.5	884	476	46%	86%
Viminaria juncea	Trip 8	Metro gravel	6	12	100%	59	6.7	7.6	3.7	1139	550	52%	107%
Viminaria juncea	Trip 8	Metro gravel	1h	12	100%	48	5.4	5.8	2.8	1068	519	51%	106%
Viminaria juncea	Trip 8	Metro gravel	1l	12	100%	62	7.0	7.7	3.8	1098	538	51%	104%
Viminaria juncea	Trip 8	Metro gravel	1m	12	100%	55	6.2	6.8	3.5	1093	561	49%	95%
Xylomelum angustifolium	Trip 4	Brand Highway	1	12	100%	76	8.6	10.7	5.2	1245	600	52%	107%
Xylomelum angustifolium	Trip 4	Brand Highway	2	12	100%	68	7.7	9.9	5.1	1287	662	49%	94%
Xylomelum angustifolium	Trip 4	Brand Highway	3	12	100%	67	7.6	9.3	4.4	1227	581	53%	111%
Xylomelum angustifolium	Trip 7	Tootbardie	1	12	100%	38	4.3	5.5	2.7	1280	624	51%	105%
Xylomelum angustifolium	Trip 7	Tootbardie	2	12	100%	38	4.3	5.4	2.8	1256	642	49%	96%
Xylomelum angustifolium	Trip 7	Tootbardie	3	12	100%	42	4.8	6.0	3.0	1263	634	50%	99%
Xylomelum angustifolium	Trip 7	Tootbardie	4	12	100%	39	4.4	5.7	3.2	1292	725	44%	78%
Xylomelum angustifolium	Trip 7	Tootbardie	5	12	100%	40	4.5	5.7	2.8	1260	617	51%	104%
Xylomelum angustifolium	Trip 7	Tootbardie	6h	12	100%	36	4.1	5.2	2.5	1277	621	51%	106%
Xylomelum angustifolium	Trip 7	Tootbardie	6l	12	100%	40	4.5	5.5	2.8	1216	608	50%	100%
Xylomelum angustifolium	Trip 7	Tootbardie	6m	12	100%	38	4.3	5.4	2.6	1256	600	52%	109%
Xylomelum angustifolium	Trip 7	Wilcox	2	12	100%	40	4.5	5.6	2.8	1238	623	50%	99%

Species	Source	Location	Tree	Core				Weight		Density		Moist. Cont.	
			no.	Diam.	%	length	Vol	Wet	Oven	Green	Basic	Wet	Dry
Xylomelum angustifolium	Trip 7	Wilcox	3	12	100%	43	4.9	5.6	2.5	1152	510	56%	126%
Xylomelum angustifolium	Trip 7	Wilcox	4	12	100%	57	6.4	7.7	3.4	1194	523	56%	128%
Xylomelum angustifolium	Trip 7	Wilcox	5	12	100%	52	5.9	7.1	3.2	1207	541	55%	123%
Xylomelum angustifolium	Trip 7	Wilcox	6	12	100%	31	3.5	4.5	2.2	1284	625	51%	105%
Xylomelum angustifolium	Trip 7	Wilcox	1h	12	100%	47	5.3	6.3	2.9	1185	551	53%	115%
Xylomelum angustifolium	Trip 7	Wilcox	1l	12	100%	68	7.7	9.7	4.5	1261	588	53%	115%
Xylomelum angustifolium	Trip 7	Wilcox	1m	12	100%	54	6.1	7.5	3.4	1228	553	55%	122%
		AVERAGES		12	99%	53	6.2	7.2	4.5	1204	733	40%	74%

Search Report

Appendix 12

Wood coring data - species summary

Species	Number	Green density				Basic density				Moisture content (green basis)			
		Low	Mean	High	CV	Low	Mean	High	CV	Low	Mean	High	CV
Acacia acuminata subsp. acuminata	1	~	~	~	~	1077	1077	1077	0%	~	~	~	~
Acacia aestivalis	16	1179	1285	1404	6%	841	935	1002	6%	23%	27%	31%	8%
Acacia aff. redolens	5	~	~	~	~	732	782	835	6%	~	~	~	~
Acacia aneura subsp (?)	1	~	~	~	~	952	952	952	0%	~	~	~	~
Acacia anthochaera	4	1384	1417	1444	2%	1007	1047	1099	4%	24%	26%	28%	8%
Acacia b (?)	2	~	~	~	~	875	885	896	2%	~	~	~	~
Acacia bartleana Maslin (ms)	10	1137	1167	1216	4%	718	815	926	9%	26%	35%	41%	23%
Acacia beauverdiana	3	1226	1250	1271	2%	1021	1054	1080	3%	15%	16%	17%	6%
Acacia blakelyi	19	884	1088	1220	8%	551	682	789	8%	33%	37%	44%	7%
Acacia brumalis	10	1125	1169	1228	3%	800	859	918	4%	25%	27%	30%	7%
Acacia burkittii	3	1383	1399	1423	2%	978	1005	1055	4%	26%	28%	30%	7%
Acacia citrinoviridus	1	~	~	~	~	1094	1094	1094	0%	~	~	~	~
Acacia conniana	3	~	~	~	~	723	763	784	5%	~	~	~	~
Acacia coolgardiensis subsp. coolgardiensis	1	~	~	~	~	1013	1013	1013	0%	~	~	~	~
Acacia coolgardiensis subsp. effusa	3	1314	1357	1394	3%	962	1032	1105	7%	21%	24%	29%	20%
Acacia coolgardiensis subsp. latior	3	1352	1390	1428	3%	1139	1150	1157	1%	16%	17%	19%	11%
Acacia cyclops	4	~	~	~	~	780	802	826	2%	~	~	~	~
Acacia enervia subsp. enervia	3	1447	1476	1527	3%	1124	1158	1226	5%	20%	22%	23%	7%
Acacia eremaea	3	1389	1395	1403	0%	1034	1089	1122	4%	20%	22%	26%	17%
Acacia fauntleroyi	8	1074	1184	1259	5%	876	932	986	5%	18%	21%	24%	10%
Acacia inceana subsp. conformis	3	1450	1463	1487	1%	1105	1157	1231	6%	15%	21%	26%	26%
Acacia jennerae	8	1226	1297	1394	5%	886	938	1022	5%	25%	28%	30%	7%
Acacia jibberdingensis	8	1014	1154	1309	9%	704	768	898	8%	28%	33%	37%	9%
Acacia lasiocalyx	27	853	1092	1277	10%	593	762	912	12%	23%	29%	38%	15%
Acacia microbotrya var. borealis	5	1043	1231	1338	13%	757	873	946	8%	27%	29%	33%	10%
Acacia microbotrya var. microbotrya	30	1076	1233	1340	6%	654	832	959	9%	28%	34%	47%	17%
Acacia murrayana	22	1050	1195	1378	9%	522	692	850	12%	36%	42%	52%	9%
Acacia neurophylla subsp. erugata	3	1061	1121	1166	5%	882	944	977	6%	14%	16%	17%	10%
Acacia obtecta	8	1277	1336	1393	3%	870	910	973	4%	29%	32%	36%	7%
Acacia prainii	4	1326	1374	1403	3%	942	1011	1043	5%	26%	27%	29%	6%
Acacia pruinocarpa	1	~	~	~	~	614	614	614	0%	~	~	~	~
Acacia redolens	5	1115	1171	1221	3%	802	822	855	2%	27%	30%	33%	8%
Acacia resinimarginea	3	~	~	~	~	946	1016	1075	6%	~	~	~	~
Acacia rostellifera	13	1223	1272	1309	3%	727	835	948	10%	30%	33%	36%	10%
Acacia saligna	38	884	983	1248	9%	469	596	735	11%	35%	42%	51%	9%
Acacia scirpifolia	19	962	1048	1159	5%	608	688	747	6%	27%	34%	41%	10%
Acacia sclerosperma subsp. sclerosperma	3	~	~	~	~	959	976	1009	3%	~	~	~	~

Species	Number	Green density				Basic density				Moisture content (green basis)			
		Low	Mean	High	CV	Low	Mean	High	CV	Low	Mean	High	CV
Acacia steedmanii	8	1066	1172	1299	7%	748	833	924	6%	25%	29%	36%	13%
Acacia stereophylla var. stereophylla	3	1260	1278	1297	1%	969	1035	1088	6%	16%	19%	23%	19%
Acacia tysonii	8	1326	1364	1426	2%	931	984	1023	3%	25%	28%	31%	8%
Acacia victoriae	2	~	~	~	~	739	814	890	13%	~	~	~	~
Actinostrobus acuminatus	3	954	1027	1098	7%	636	661	689	4%	33%	35%	40%	11%
Actinostrobus arenarius	19	734	1007	1141	10%	536	661	725	6%	26%	34%	46%	15%
Actinostrobus pyramidalis	25	985	1146	1281	7%	585	638	695	5%	30%	44%	51%	12%
Adenanthos cygnorum subsp. cygnorum	19	1105	1194	1256	4%	553	595	640	4%	46%	50%	56%	5%
Adenanthos sericeus subsp. sericeus	19	1197	1264	1326	2%	483	572	658	9%	47%	55%	61%	7%
Adenanthos stictus	20	1173	1249	1316	3%	466	599	696	9%	47%	52%	63%	7%
Agonis flexuosa var. flexuosa	3	1198	1220	1234	2%	746	786	839	6%	32%	36%	38%	9%
Alectryon oleifolius subsp. oleifolius	3	1352	1382	1415	2%	947	1010	1083	7%	23%	27%	30%	12%
Allocasuarina acutivalvis subsp. acutivalvis	6	1238	1275	1326	3%	925	981	1020	4%	21%	23%	25%	7%
Allocasuarina campestris	3	1164	1220	1248	4%	928	975	1004	4%	20%	20%	20%	2%
Allocasuarina dielsiana	3	1311	1343	1371	2%	902	953	995	5%	26%	29%	31%	9%
Allocasuarina huegeliana	4	1027	1076	1117	4%	725	748	778	3%	28%	30%	32%	7%
Alyogyne hakeifolia	3	1169	1200	1234	3%	713	779	814	7%	32%	35%	39%	10%
Alyogyne huegelii var. huegelii	11	1127	1225	1283	4%	605	720	815	11%	35%	41%	49%	11%
Alyogyne sp.	8	1200	1232	1282	2%	634	668	723	4%	44%	46%	48%	3%
Anthocercis littorea	19	813	926	1054	7%	377	473	582	11%	42%	49%	58%	9%
Astartea heteranthera	3	1219	1265	1302	3%	812	815	816	0%	33%	36%	37%	6%
Banksia attenuata	19	1119	1273	1393	6%	645	696	800	6%	38%	45%	49%	7%
Banksia grandis	19	1064	1254	1406	6%	610	672	773	7%	36%	46%	52%	8%
Banksia prionotes	19	1105	1195	1282	4%	593	636	714	5%	41%	47%	53%	8%
Brachychiton gregorii	11	1083	1179	1232	4%	377	461	506	10%	56%	61%	65%	5%
Bursaria occidentalis	12	1179	1250	1326	4%	617	706	834	7%	34%	43%	49%	11%
Callistachys lanceolata	19	1022	1082	1172	3%	536	593	663	5%	42%	45%	49%	5%
Callistemon phoeniceus	6	1247	1298	1365	3%	844	916	953	4%	27%	29%	32%	6%
Callitris canescens	3	1084	1125	1148	3%	744	774	822	5%	28%	31%	35%	11%
Callitris glaucophylla	9	1007	1108	1253	7%	738	786	839	5%	26%	29%	35%	11%
Callitris tuberculata	3	1110	1129	1144	2%	721	739	767	3%	32%	35%	36%	6%
Calothamnus asper	3	1198	1230	1267	3%	759	779	802	3%	36%	37%	37%	0%
Calothamnus tuberosus	3	1291	1301	1309	1%	792	803	819	2%	37%	38%	39%	2%
Calycopeplus paucifolius	3	995	1035	1066	4%	802	843	879	5%	18%	19%	19%	5%
Casuarina obesa	30	1058	1244	1342	5%	597	711	859	9%	28%	43%	51%	12%
Chamaecytisus palmensis	3	~	~	~	~	730	778	819	6%	~	~	~	~
Chamelaucium uncinatum	1	1198	1198	1198	0%	709	709	709	0%	41%	41%	41%	0%

Species	Number	Green density				Basic density				Moisture content (green basis)			
		Low	Mean	High	CV	Low	Mean	High	CV	Low	Mean	High	CV
Codonocarpus cotinifolius	32	1032	1162	1220	4%	297	397	559	19%	50%	67%	74%	8%
Conospermum triplinervium	14	1061	1214	1326	7%	464	530	609	7%	51%	56%	63%	6%
Corymbia calophylla	3	1059	1170	1236	8%	676	725	760	6%	36%	38%	40%	5%
Dodonaea (?) sp.	4	1260	1396	1524	8%	986	1079	1154	6%	20%	23%	28%	17%
Dodonaea inaequifolia	3	1368	1384	1406	1%	1057	1085	1120	3%	20%	22%	23%	6%
Dodonaea ptarmicaefolia	3	1398	1406	1420	1%	1051	1064	1074	1%	24%	24%	25%	2%
Dodonaea viscosa subsp. angustissima (?)	3	1315	1342	1375	2%	968	1011	1057	4%	23%	25%	26%	7%
Dryandra arborea	3	1238	1280	1306	3%	830	851	872	2%	33%	34%	34%	2%
Dryandra nobilis subsp. nobilis	3	1131	1194	1267	6%	728	765	808	5%	36%	36%	36%	1%
Dryandra sessilis var. sessilis	19	1027	1245	1418	7%	610	735	854	6%	37%	41%	44%	6%
Duboisia hopwoodii	6	860	919	978	6%	382	479	523	11%	39%	48%	56%	12%
Eremophila alternifolia (?)	6	1193	1267	1316	4%	1012	1044	1118	4%	15%	18%	22%	15%
Eremophila caperata (?)	3	1148	1193	1242	4%	822	874	922	6%	26%	27%	28%	5%
Eremophila deserti	3	1133	1166	1194	3%	787	835	860	5%	27%	28%	30%	7%
Eremophila interstans subsp. interstans	3	1242	1251	1258	1%	886	921	946	3%	24%	26%	30%	11%
Eremophila longifolia	6	1095	1151	1193	3%	779	875	921	6%	21%	24%	29%	13%
Eremophila miniata	6	1039	1094	1153	3%	734	783	863	6%	25%	28%	31%	8%
Eremophila oldfieldii subsp. oldfieldii	6	1102	1188	1263	5%	845	919	955	4%	21%	23%	24%	6%
Eremophila oppositifolia subsp. angustifolia	3	1117	1155	1194	3%	845	885	915	4%	23%	23%	24%	4%
Eremophila psilocalyx (?)	3	1211	1239	1273	3%	903	924	957	3%	25%	25%	26%	2%
Eremophila scoparia	3	1309	1356	1404	4%	973	1038	1116	7%	21%	23%	28%	18%
Eremophila serrulata (?)	3	1169	1178	1193	1%	916	944	964	3%	19%	20%	22%	8%
Eucalyptus accedens	3	1256	1267	1273	1%	831	889	921	6%	28%	30%	34%	12%
Eucalyptus alipes	3	1283	1289	1299	1%	1012	1022	1033	1%	20%	21%	21%	2%
Eucalyptus angustissima subsp. angustissima	3	1226	1234	1245	1%	855	878	899	3%	27%	29%	30%	6%
Eucalyptus annulata	6	1163	1231	1299	4%	887	920	967	3%	21%	25%	29%	12%
Eucalyptus argyphea	3	1206	1215	1223	1%	887	906	932	3%	23%	25%	27%	10%
Eucalyptus aspratilis	3	1265	1305	1377	5%	994	1031	1076	4%	19%	21%	22%	8%
Eucalyptus astringens subsp. astringens	3	1114	1157	1199	4%	776	801	826	3%	29%	31%	33%	8%
Eucalyptus astringens subsp. redacta	3	1162	1221	1269	4%	872	902	942	4%	25%	26%	28%	5%
Eucalyptus balladoniensis subsp. balladoniensis	3	1263	1271	1284	1%	896	910	920	1%	27%	28%	29%	4%
Eucalyptus brachycorys	3	1298	1321	1350	2%	984	991	998	1%	24%	25%	26%	4%
Eucalyptus burracoppinensis	3	1256	1273	1295	2%	959	969	981	1%	22%	24%	25%	8%
Eucalyptus camaldulensis var. obtusa (?)	17	962	1206	1273	6%	540	636	746	9%	34%	47%	56%	12%
Eucalyptus capillosa subsp. capillosa	3	1220	1273	1306	4%	944	984	1019	4%	22%	23%	24%	3%
Eucalyptus capillosa subsp. polyclada	3	1226	1264	1298	3%	876	967	1027	8%	21%	24%	29%	19%
Eucalyptus celastroides subsp. celastroides	3	1255	1282	1318	3%	1013	1034	1069	3%	19%	19%	20%	3%

Species	Number	Green density				Basic density				Moisture content (green basis)			
		Low	Mean	High	CV	Low	Mean	High	CV	Low	Mean	High	CV
Eucalyptus clivicola	3	1256	1291	1314	2%	966	977	991	1%	23%	24%	26%	6%
Eucalyptus conferruminata	3	1179	1193	1205	1%	835	860	887	3%	26%	28%	29%	6%
Eucalyptus cornuta	3	1206	1237	1257	2%	753	802	828	5%	31%	35%	40%	13%
Eucalyptus dundasii	3	1193	1217	1249	2%	959	979	992	2%	18%	20%	21%	8%
Eucalyptus eremophila subsp. eremophila	3	1255	1275	1291	1%	984	999	1015	2%	21%	22%	22%	1%
Eucalyptus erythrocorys	11	1175	1260	1387	4%	673	731	839	7%	33%	42%	47%	9%
Eucalyptus erythronema var. erythronema	3	1216	1229	1245	1%	930	967	991	3%	20%	21%	24%	9%
Eucalyptus erythronema var. marginata	3	1313	1332	1343	1%	981	1014	1045	3%	22%	24%	25%	7%
Eucalyptus ewartiana	3	1263	1314	1372	4%	941	1016	1095	8%	20%	23%	26%	12%
Eucalyptus gomphocephala	3	1213	1237	1265	2%	741	756	768	2%	38%	39%	39%	1%
Eucalyptus gratiae	3	1124	1163	1205	3%	715	760	785	5%	33%	35%	36%	5%
Eucalyptus halophila	3	1313	1346	1375	2%	1029	1045	1076	3%	21%	22%	24%	6%
Eucalyptus hypochlamydea subsp. hypochlamydea	3	1309	1336	1359	2%	855	889	918	4%	30%	33%	36%	10%
Eucalyptus incrassata	3	1271	1296	1316	2%	984	1014	1041	3%	20%	22%	23%	7%
Eucalyptus indurata	3	1292	1311	1346	2%	902	942	987	4%	27%	28%	30%	6%
Eucalyptus kochii subsp. horistes	3	1184	1223	1244	3%	825	848	875	3%	29%	31%	34%	9%
Eucalyptus kochii subsp. kochii	3	1138	1200	1238	4%	802	849	882	5%	29%	29%	30%	1%
Eucalyptus kochii subsp. plenissima	3	1125	1195	1245	5%	796	835	858	4%	29%	30%	32%	4%
Eucalyptus kondininensis	3	1192	1223	1278	4%	855	879	924	4%	28%	28%	29%	2%
Eucalyptus leptopoda subsp. arctata	3	1256	1276	1305	2%	954	973	1006	3%	23%	24%	24%	3%
Eucalyptus leptopoda subsp. leptopoda	3	1303	1312	1320	1%	962	972	983	1%	26%	26%	26%	1%
Eucalyptus leptopoda subsp. subluta	3	1299	1317	1326	1%	926	949	963	2%	27%	28%	29%	2%
Eucalyptus lesouefii	3	1184	1195	1207	1%	938	959	977	2%	19%	20%	21%	4%
Eucalyptus longicornis	3	1192	1241	1292	4%	827	858	905	5%	29%	31%	33%	7%
Eucalyptus loxophleba subsp. lissophloia	19	1063	1230	1292	5%	698	801	869	6%	29%	35%	39%	8%
Eucalyptus loxophleba subsp. loxophleba	3	1120	1182	1227	5%	706	771	825	8%	33%	35%	37%	6%
Eucalyptus loxophleba subsp. supralaevis	3	1203	1245	1309	5%	781	821	849	4%	32%	34%	35%	5%
Eucalyptus melanoxylon	3	1253	1283	1312	2%	963	998	1018	3%	21%	22%	23%	5%
Eucalyptus moderata	3	1263	1325	1375	4%	888	940	982	5%	29%	29%	30%	2%
Eucalyptus myriadena subsp. myriadena	3	1249	1258	1267	1%	852	874	908	3%	28%	31%	32%	6%
Eucalyptus occidentalis	6	1087	1158	1250	5%	672	802	894	11%	24%	31%	42%	21%
Eucalyptus platypus subsp. platypus (?)	6	1165	1250	1326	6%	808	861	933	5%	28%	31%	35%	9%
Eucalyptus pleurocarpa	11	1135	1276	1357	6%	754	820	949	7%	28%	36%	41%	11%
Eucalyptus polybractea	3	1182	1231	1260	3%	827	851	869	3%	30%	31%	31%	2%
Eucalyptus rudis subsp. rudis	19	1089	1196	1411	6%	483	553	674	10%	41%	54%	60%	9%
Eucalyptus salmonophloia	3	1213	1262	1299	4%	919	946	961	2%	24%	25%	26%	4%
Eucalyptus salubris	3	1219	1228	1236	1%	949	959	966	1%	21%	22%	23%	4%

Species	Number	Green density				Basic density				Moisture content (green basis)			
		Low	Mean	High	CV	Low	Mean	High	CV	Low	Mean	High	CV
Eucalyptus sargentii subsp. sargentii	3	1127	1145	1161	1%	867	883	893	2%	23%	23%	23%	2%
Eucalyptus spathulata	3	1129	1146	1158	1%	830	846	862	2%	26%	26%	26%	2%
Eucalyptus todtiana	19	1157	1238	1326	4%	547	644	745	9%	42%	48%	55%	8%
Eucalyptus uncinata	3	1267	1325	1402	5%	963	1015	1080	6%	23%	23%	24%	2%
Eucalyptus urna	3	1194	1202	1218	1%	911	923	933	1%	22%	23%	24%	3%
Eucalyptus utilis	3	1141	1197	1228	4%	865	889	908	2%	24%	26%	27%	6%
Eucalyptus valens	3	1280	1295	1303	1%	852	875	904	3%	31%	32%	33%	5%
Eucalyptus vegrandis subsp. vegrandis	3	1108	1187	1261	6%	842	877	925	5%	24%	26%	27%	7%
Eucalyptus wandoo subsp. wandoo	3	1203	1255	1287	4%	835	911	950	7%	26%	27%	31%	10%
Exocarpos aphyllus	3	1269	1315	1405	6%	996	1037	1076	4%	18%	21%	23%	13%
Exocarpos sparteus	19	1114	1205	1282	4%	630	703	827	7%	36%	42%	44%	6%
Grevillea argyrophylla	3	1146	1220	1263	5%	730	794	859	8%	32%	35%	37%	7%
Grevillea cagiana	3	1145	1241	1292	7%	806	822	852	3%	30%	34%	37%	11%
Grevillea candelabroides	19	1100	1204	1267	3%	566	642	714	5%	43%	47%	50%	4%
Grevillea excelsior	19	1112	1212	1261	3%	686	747	817	5%	34%	38%	45%	9%
Grevillea insignis subsp. insignis	3	1270	1291	1326	2%	811	835	852	3%	33%	35%	37%	6%
Grevillea leucopteris	19	991	1162	1227	5%	493	554	633	6%	45%	52%	60%	7%
Grevillea nematophylla subsp. nematophylla (?)	3	1151	1183	1210	2%	682	720	754	5%	38%	39%	41%	4%
Grevillea obliquistigma subsp. obliquistigma	3	1203	1258	1326	5%	948	969	1004	3%	21%	23%	24%	9%
Grevillea pterosperma	3	1086	1144	1190	5%	763	845	951	11%	20%	26%	30%	20%
Grevillea vestita subsp. vestita	3	1259	1293	1326	3%	759	766	773	1%	39%	41%	43%	5%
Gyrostemon racemiger	16	831	1122	1223	8%	269	352	418	10%	63%	69%	74%	4%
Gyrostemon ramulosus	13	1124	1171	1229	2%	348	416	515	12%	58%	65%	70%	5%
Gyrostemon sp.	6	999	1109	1169	6%	277	352	391	12%	62%	68%	76%	7%
Hakea bucculenta	3	1292	1344	1392	4%	940	986	1015	4%	26%	27%	27%	3%
Hakea francisiana	3	1254	1275	1315	3%	761	821	899	9%	32%	36%	39%	11%
Hakea invaginata	3	1203	1237	1277	3%	904	931	968	4%	24%	25%	25%	2%
Hakea laurina	3	1235	1271	1310	3%	845	877	899	3%	30%	31%	32%	3%
Hakea minyma	3	1326	1381	1434	4%	899	939	965	4%	31%	32%	33%	3%
Hakea multilineata	3	1304	1327	1352	2%	808	884	937	8%	31%	33%	38%	12%
Hakea oleifolia	19	1144	1239	1350	4%	569	662	777	9%	40%	47%	53%	7%
Hakea petiolaris subsp. trichophylla	3	1120	1200	1260	6%	799	825	838	3%	29%	31%	34%	8%
Hakea preissii	3	1326	1368	1407	3%	840	890	916	5%	33%	35%	37%	5%
Hakea prostrata	19	926	1184	1326	10%	595	667	791	8%	36%	43%	51%	9%
Hakea recurva subsp. recurva	3	1311	1338	1392	3%	886	957	1055	9%	24%	29%	33%	15%
Hakea stenophylla subsp. notialis (?)	3	1274	1284	1300	1%	887	908	942	3%	26%	29%	31%	9%
Jacksonia furcellata	19	1093	1272	1341	5%	541	661	792	11%	41%	48%	54%	8%

Species	Number	Green density				Basic density				Moisture content (green basis)			
		Low	Mean	High	CV	Low	Mean	High	CV	Low	Mean	High	CV
Jacksonia sternbergiana	19	901	1180	1316	12%	521	626	735	9%	39%	47%	52%	8%
Kunzea ericifolia subsp. ericifolia	3	1220	1233	1253	1%	731	768	805	5%	36%	38%	40%	6%
Kunzea glabrescens	19	1162	1232	1303	4%	624	699	767	5%	39%	43%	48%	6%
Lamarchea hakeifolia var. brevifolia	3	1238	1268	1326	4%	759	807	862	6%	35%	36%	39%	5%
Lambertia inermis var. inermis	19	1148	1260	1347	4%	626	687	768	6%	41%	46%	49%	5%
Leptomeria pauciflora	3	1259	1290	1338	3%	815	876	927	6%	30%	32%	35%	8%
Leptospermum nitens	3	1224	1242	1275	2%	886	926	961	4%	24%	25%	28%	8%
Melaleuca acuminata subsp. acuminata	3	1326	1342	1372	2%	871	886	899	2%	33%	34%	34%	2%
Melaleuca cuticularis	3	1236	1262	1285	2%	805	832	857	3%	32%	34%	35%	4%
Melaleuca eleuterostachya	3	1335	1342	1347	0%	995	1013	1037	2%	23%	25%	25%	6%
Melaleuca fulgens subsp. fulgens	3	1168	1276	1375	8%	933	956	969	2%	17%	25%	30%	27%
Melaleuca globifera	6	1193	1243	1340	4%	628	768	889	12%	29%	38%	48%	20%
Melaleuca halmaturorum	3	1303	1311	1317	1%	931	951	970	2%	26%	27%	29%	6%
Melaleuca hamata	3	1242	1257	1271	1%	896	919	932	2%	25%	27%	29%	7%
Melaleuca hamulosa	3	1184	1233	1267	4%	846	875	920	4%	27%	29%	31%	6%
Melaleuca hamulosa (?)	3	1203	1268	1341	5%	717	751	769	4%	39%	41%	43%	4%
Melaleuca hnatiukii	3	1338	1339	1339	0%	937	957	973	2%	27%	29%	30%	5%
Melaleuca huegelii subsp. huegelii	3	1255	1272	1302	2%	839	850	871	2%	31%	33%	35%	7%
Melaleuca incana subsp. incana	8	1143	1243	1356	5%	617	655	702	4%	45%	47%	51%	5%
Melaleuca lanceolata	6	1224	1275	1305	2%	833	894	936	5%	27%	30%	33%	9%
Melaleuca lateriflora subsp. lateriflora	3	1238	1263	1282	2%	939	953	969	2%	22%	25%	26%	10%
Melaleuca linguiformis	3	1280	1284	1292	1%	854	857	862	0%	33%	33%	33%	0%
Melaleuca pauperiflora subsp. pauperiflora	6	1240	1314	1338	3%	877	940	1013	6%	24%	28%	32%	11%
Melaleuca preissiana	19	1163	1253	1378	4%	455	574	713	14%	46%	54%	64%	11%
Melaleuca quadrifaria	3	1238	1280	1313	3%	862	863	864	0%	30%	33%	34%	6%
Melaleuca rhaphiophylla	19	1036	1223	1273	5%	508	581	690	7%	46%	52%	58%	6%
Melaleuca sp.	3	1294	1299	1302	0%	856	893	922	4%	29%	31%	34%	9%
Melaleuca stereophloia	3	1220	1260	1292	3%	849	897	932	5%	26%	29%	30%	7%
Melaleuca strobophylla	3	1141	1199	1236	4%	706	722	744	3%	38%	40%	41%	4%
Melaleuca uncinata form "lignotuberous spicate"	3	1169	1203	1243	3%	769	823	905	9%	27%	32%	34%	12%
Melaleuca uncinata form "non-lignotuberous spicate"	6	1174	1261	1343	5%	857	914	954	4%	25%	27%	31%	9%
Melaleuca uncinata form "uncinata"	3	1243	1271	1309	3%	890	918	962	4%	26%	28%	28%	4%
Melaleuca viminea subsp. viminea	3	1267	1272	1277	0%	595	624	666	6%	48%	51%	53%	6%
Myoporum platycarpum subsp. platycarpum	4	1203	1246	1269	2%	877	952	1038	7%	18%	24%	27%	18%
Nuytsia floribunda	19	1146	1197	1260	3%	457	499	558	5%	54%	58%	62%	3%
Oxylobium lineare	3	997	1025	1042	2%	654	667	682	2%	33%	35%	37%	6%
Paraserianthes lophantha subsp. lophantha	3	911	922	938	2%	392	397	403	1%	56%	57%	57%	1%

Species	Number	Green density				Basic density				Moisture content (green basis)			
		Low	Mean	High	CV	Low	Mean	High	CV	Low	Mean	High	CV
Persoonia elliptica	19	1069	1226	1352	7%	538	599	684	7%	44%	51%	58%	8%
Persoonia saundersiana	3	1202	1233	1270	3%	791	847	877	6%	29%	31%	34%	9%
Persoonia stricta	3	1218	1225	1238	1%	884	901	912	2%	25%	26%	28%	4%
Pimelea clavata	3	674	845	1004	20%	317	449	542	26%	43%	47%	53%	11%
Pinus pinaster	3	1016	1114	1171	8%	442	458	465	3%	54%	59%	62%	7%
Pittosporum angustifolium	6	1218	1286	1333	3%	842	871	920	3%	27%	32%	37%	11%
Pittosporum phylliraeoides	4	1269	1280	1292	1%	744	836	871	7%	31%	32%	33%	3%
Santalum acuminatum	6	992	1148	1216	7%	688	775	885	12%	25%	32%	42%	23%
Santalum murrayanum	19	1082	1202	1382	7%	649	720	823	7%	37%	40%	44%	5%
Schinus sp.	1	1198	1198	1198	0%	583	583	583	0%	51%	51%	51%	0%
Senna (?) sp.	3	1153	1221	1303	6%	636	710	807	12%	38%	42%	45%	8%
Senna glutinosa subsp. chatelainiana	19	961	1110	1326	10%	565	624	693	6%	34%	43%	50%	10%
Senna pleurocarpa subsp. (?)	8	933	982	1057	5%	549	588	638	5%	37%	40%	44%	6%
Senna sp. Austin	8	1420	1455	1484	2%	1107	1146	1195	3%	17%	21%	22%	8%
Spyridium globulosum	3	1213	1245	1269	2%	819	849	871	3%	31%	32%	33%	2%
Taxandria juniperina	19	1096	1205	1299	4%	456	569	691	10%	47%	53%	62%	9%
Templetonia retusa	3	1397	1414	1444	2%	1001	1014	1035	2%	28%	28%	28%	0%
Trymalium floribundum subsp. floribundum	22	967	1092	1201	5%	614	692	777	5%	33%	37%	39%	5%
Viminaria juncea	22	808	957	1139	10%	413	478	570	10%	44%	50%	56%	5%
Xylomelum angustifolium	19	1152	1243	1292	3%	510	601	725	9%	44%	52%	56%	6%

Search Report

Appendix 13

Test protocol for Forest Products Commission

Graeme Siemon
Locked Bag 888
PERTH BUSINESS CENTRE
Western Australia 6849

Don Cooper
Locked bag 104
Bentley Delivery Centre
Western Australia 6983
17/3/2003

Dear Graeme,

I would like to confirm the tests that we are contracting you to perform as a result of your successful tender to RFP 71002.

Wayne O'Sullivan and Stephen Davis are currently collecting logs for 12 species (Table 1) and are expected to finish by Wednesday, 26/3/2003. I expect that there will be six logs for each species, two logs from three separate populations, except where listed in Table 1.

Species	**Sample populations**	**Logs per population**	**Sample logs**
Eucalyptus occidentalis	4	2,1	6
Eucalyptus argyphea	3	2	6
Eucalyptus semivestita	3	2	6
Acacia subfalcata	2	1,2	3
Eucalyptus clivicola	2	2,1	3
Eucalyptus kondininensis	3	2	6
Eucalyptus ornata	3	2	6
Melaleuca rhaphiophylla	3	2	6
Melaleuca preissiana	3	2	6
Taxandria juniperina	3	2	6
Eucalyptus accedens	3	2	6
Acacia aff. redolens[1]	1	2	2

1. One log is of poor quality, but Steve says he can still get some good data from it.

Table 1: Species and number of logs for solid wood testing

For each species we would like the following to be performed:

1. Log dimensions. Measure SEDUB and LEDUB and Length. Calculate log volume. Note any log faults e.g. sweep, large taper, bumps, branches, decay on the end etc and if they will affect recovery.
   Mill each species separately and maintain species identity throughout the trial.
2. Backsaw logs into 105mm * 28mm rough sawn boards. Calculate green sawn recovery for each species (include anecdotal site info in recovery report).
3. Kiln drying, Gary Brennan recommends starting with the Goldfields drying schedule. For the high density species refer to Tables 1 (a) and 1(b) in App B of the Goldfields timber Research Report. Gary believes the schedule in Table 1(c) would be to fast and cause severe surface checking. Mild drying conditions are needed in the early stages of drying.

Sample boards are required to monitor drying rate and degrade.

4. Weekly assessment of sample boards for each species during the drying process for moisture content, surface checking and warping. Adjust drying schedule if drying degrade is occurring.
5. Dress boards to 80mm * 20mm. Larger dimensions may be achieved depending on board shrinkage.
6. Grading (AS 2796, 1999) and recoveries for each grade.
7. $25mm^2$ * 100mm samples for shrinkage, basic and air dry density, and moisture content, five per log. Ensure the samples are free of brittle heart and for shrinkage aim to use perfectly backsawn boards.
8. Hardness, five measurements per log. Hardness is directly related to density so inclusion of this test will depend on budgetary constraints.
9. Glue boards (cold pressing with 24 h curing may need to be employed for high density species) into test panels, then machining and finishing tests: ripping, cross cutting, planing, routing, trenching, boring, sanding and coating, up to three panels per species, number of panels may be limited by recovery. Resorcinol formaldehyde, even Resobond RA 3 – W (winter grade), may need to be used on the high density species and possibly some of the others. Resorcinol produces a dark red glue line and this may cause appearance problems. Urea formaldehyde produces a clear glueline.
10. Cleavage – follow the procedures for assessing wood failure as outlined in AS 1328 – 1987. Glue strength testing involves destructive sampling and this can result in loss of panels, which may be need for other processing assessments and material be display.

11. Colour and Figure –Use Methuen handbook of Colour ?

12. General comments on wood quality and processing characteristics.

If possible we would like to be able to organise site visit(s) at key times to discuss with the scientist/technician the up to date status of our tests. We would like someone to watch the sawing of the timber.

Please provide a quotation based on your tender document for each of the above steps, based on 62 logs, field collection of materials and the final report. It would help our budgeting if the quotation can be supplied before we progress past step 2.

Yours sincerely,

……………

Don Cooper

Search Report

Appendix 14

Draft list of species for solid wood testing

From: Graeme Olsen 29 November 2002

Solid wood testing for Search Project

Species to be assessed

Thank you for the FPC report "Assessment of species for solid wood use" (Graeme Siemon 01 October 2002). We have combined the information in that report with the list of potential solid wood species developed in the Search Project, to identify species for which wood testing information appears to be lacking.

We suggest that testing be carried out for two categories of species:

Category 1: Species that appear not to have been tested previously (see following pages). These species are drawn from the attached table, and have been given a subjective priority rating (high, medium, low) for solid wood investigation.

Category 2: Other species which FPC believes would benefit from additional testing (for example, testing of different provenances of species with large variation between provenances). Of particular interest would be further testing requirements (if any) for the "recommended" species in your report:
Acacia acuminata
Allocasuarina huegeliana
Casuarina obesa
Corymbia calophylla
Eucalyptus astringens
Eucalyptus camaldulensis
Eucalyptus gomphocephala
Eucalyptus longicornis
Eucalyptus occidentalis
Eucalyptus salmonophloia
Eucalyptus wandoo subsp. wandoo
Myoporum platycarpum.

We would appreciate your comments on the need for, and advisability of testing the species listed in Category 1 (especially if other information that we are not aware of on the wood quality of these species is available), and advice on any work required for species that fit in Category 2.

Regards

Graeme Olsen

Category 1 species – high priority

Eucalyptus argyphea

Planted at Dryandra, and now being harvested. Some logs are available at Narrogin. CALM Narrogin is prepared to organise their transport to Harvey.

Included in the Search project's 2003 planting list.

Eucalyptus occidentalis...Flat-topped (or Swamp) Yate

Various reports mention its firewood and pulping suitability, and a recent milling study has been carried out by CSIRO (RIRDC funded): "Wood products from low rainfall (400-600 mm/yr) farm forestry".

Included in the Search project's 2003 planting list.

Performance in earlier SEARCH trials: Benchmark species, fast growth and good form on a variety of sites, salt and waterlogging tolerant, reasonable herbicide tolerance.

Category 1 species – medium priority

Acacia subfalcata (currently incorporated in A. microbotrya)

This "species" has limited distribution near Badgingarra, but good height and form. Timber from cut specimens looks sound.

Included in the Search project's 2003 planting list.

Performance in earlier SEARCH trials: Excellent growth rates, good form, tolerant of locusts, performs well on a variety of soil types, and has reasonable herbicide tolerance (planted 2001 at approx. 13 sites)

Eucalyptus accedens ....Powderbark Wandoo

Treated by sawmillers as wandoo - but is the wood significantly different?

Eucalyptus clivicola ....Green Mallet

This mallet could be a useful species in southern areas, but its performance needs to be tested away from its natural site (breakaways).

Eucalyptus kondininensis ....Kondinin Blackbutt

Has some salt tolerance which could make it more attractive to growers.

Performance in earlier SEARCH trial: Adversely affected by simazine, growth performance only average.

Eucalyptus ornata ....Silver Mallet

Performance in earlier SEARCH trial: Even slower growing than *E. salubris* and *E. salmonophloia*. Temperamental, fussy about for soil conditions.

Eucalyptus todtiana...Coastal Blackbutt

Often has poor form for timber utilisation, but has reasonable prospects for growth in sandy soils of the northern wheatbelt.

<u>Melaleuca rhaphiophylla</u>.. Swamp Paperbark

Likely to be limited by moisture in much of the wheatbelt, but may be useful on the wetter fringes of the wheatbelt, and on water-gaining sites.

<u>Taxandria (previously Agonis) juniperina</u>........................... Wattie

Likely to be limited by moisture in much of the wheatbelt, but may be useful on the wetter fringes of the wheatbelt, and on water-gaining sites.

Category 1 species – low priority

<u>Acacia aff. redolens</u>

Native populations are small and have limited distribution (although this "species" may be poorly collected). Plant height and form is marginal. However, some small pieces of timber have been collected from a site east of Esperance, and could be assessed.

Performance in SEARCH trial: reasonable growth rate, locust resistant, reasonable herbicide tolerance (planted 2001 at approx. 12 sites)

<u>Eucalyptus cornuta</u> .... Yate

Tall tree, very dense wood, but likely to require very moist sites.

<u>Melaleuca lanceolata</u>.. Rottnest Teatree

Small tree, likely to require very moist sites.

		FloraBase	Search project		FPC information[1]		
Testing priority	**Taxon**	**Height (m)**	**Growth potential**	**Field trials**	**Wood properties**	**Work-ability**	**Comments**
	Acacia acuminata	7 (12)	Medium	Trial	1, 3, web	1, 3, web	Slow growing, good form, wide distribution.
Low	*Acacia* aff. *redolens*	3	Medium	Trial	not tested	not tested	Tall tree or shrub with good form, found east of Esperance. Probably a separate species from A. redolens.
	Acacia lasiocalyx	7 (12)	High	Trial	1	1	Tall, good form around granite rocks.
Medium	*Acacia subfalcata*		High	Trial	not tested	not tested	Medium-sized tree, reasonable form, fast growing. Currently classified under A. microbotrya.
	Acacia pruinocarpa	12	Medium		1, 2, web	1, web	Slow growing, arid zone species.
	Allocasuarina huegeliana	10	High	Trial	1, 4, web	1, 4, web	Grows on poor sites, some examples of adaptability.
	Callitris glaucophylla	12	Medium		1, web	1, web	Eastern edge of wheatbelt, slow growing, good form.
	Casuarina obesa	10	High	Trial	4	4	Shark Bay to Albany, susceptible to insects and grazing.
	Corymbia calophylla	40 (60)	High		12, web	12, web	Western fringes of wheatbelt only, large tree, needs selection for form, susceptible to borers when stressed.
Medium	*Eucalyptus accedens*	15 (25)	Medium		not tested	not tested	Fast growing timber species for wetter fringes of wheatbelt.
High	*Eucalyptus argyphea*	15	High	Trial	not tested	not tested	Mallet, planted trees currently cut at Dryandra.
	Eucalyptus astringens	9	High	Trial	3, web	3, web	Mallet, high tannin content, used commercially for timber.
	Eucalyptus brockwayi	20	Medium	Trial	1, web	1, web	Limited distribution, good form, arid edge of wheatbelt.
	Eucalyptus camaldulensis	20	High	Trial	1	1	Potential in northern areas, but local provenance has poor form.
	Eucalyptus capillosa	15 (20)	Medium	Trial	1	1	Tall tree, central and eastern wheatbelt.
Medium	*Eucalyptus clivicola*	15	Medium		not tested	not tested	Green Mallet. Breakaway country inland from south coast.
Low	*Eucalyptus cornuta*	25	Medium		not tested	not tested	Waterlogging tolerant, reasonable growth rate and form.
	Eucalyptus dundasii	21	Medium		1, 6, web	1, 6, web	Good form, but poor performance in wheatbelt trials.
	Eucalyptus gomphocephala	40	High		web	web	Coastal plain species with potential for north western and south eastern fringes of wheatbelt.
Medium	*Eucalyptus kondininensis*	20	High	Trial	not tested	not tested	Mallet, good growth rates, grows on difficult sites.

	Eucalyptus lesouefii	18 (21)	Low		1, 8, web	1, web	Mainly found east of wheatbelt in arid zone.
	Eucalyptus longicornis	24 (30)	High	Trial	1, web	1, web	Widespread through central and southern wheatbelt.
	Eucalyptus loxophleba subsp. *loxophleba*	15	Medium		1, 3, 6, web	3, 6	Often has poor form.
	Eucalyptus melanoxylon	24	Medium	Trial	1, web	1, web	Eastern and SE wheatbelt.
High	*Eucalyptus occidentalis*	20	High	Trial	not tested	not tested	Southern areas, suits wetter sites, insect and parrot prone.
Medium	*Eucalyptus ornata*	10	Low	Trial	not tested	not tested	Mallet, limited distribution.
	Eucalyptus rudis	20	High		web	web	Widespread, fast grower, insect prone, easy to establish, hybridises readily.
	Eucalyptus salicola	15 (25)	Low	Trial	1, web	1, web	Widespread in wheatbelt, grows around salt lakes.
	Eucalyptus salmonophloia	30	High	Trial	1, web	1, web	Slow grower?
	Eucalyptus salubris	15 (24)	Medium	Trial	1, 6, 8, web	1, 6, web	Mallet.
Medium	*Eucalyptus todtiana*	8 (15)	Medium		not tested	not tested	Suit poor sands? Poor form (select provenances carefully).
	Eucalyptus transcontinentalis	15	Low	Trial	1, 6, web	1, 6, web	Suit drier parts of wheatbelt.
	Eucalyptus urna[2] *(ex flocktoniae)*	16	Medium	Trial	1, web	1, web	Good form. Mallet form of E. flocktoniae.
	Eucalyptus wandoo	25	High	Trial	1, web	web	Widespread, good timber, slow growing, much variability.
	Grevillea striata	12 (15)	Low		1, web	1, web	
Low	*Melaleuca lanceolata*	8	Medium	Trial	not tested	not tested	
	Melaleuca preissiana	9	Medium		11 (drying)	11	
Medium	*Melaleuca rhaphiophylla*	10	Medium		not tested	not tested	Moist sites only. Wider distribution than M. preissiana.
	Myoporum platycarpum	8	High		1	1	Mainly arid zone. Good growth rate, size and form.
	Pittosporum phylliraeoides	8	Medium		1, web	1, web	Mainly coastal (esp. Geraldton to Carnarvon), good form, suckers, questionable growth rate, easy to grow from seed.
Medium	*Taxandria juniperina (ex Agonis)*	12 (27)	Medium		not tested	not tested	Tall, fast growing, Busselton to Albany, needs moist sites.

[1] Numbers in these columns refer to reference documents listed in FPC report to the Search Project, 01 October 2002 "Woody Biomass Project: Assessment of species for solid wood use." They are listed at the end of this document.

[2] We have assumed that the published wood quality data for *Eucalyptus flocktoniae* applies to the new taxon, *E. urna* (new name for the mallet form of *E. flocktoniae*).

References cited in table

1. Siemon, G.R. and Kealley, I.G. (1999). Goldfields Timber Research Report. Report by the Research Project Steering Committee. Department of Commerce and Trade, Goldfields Esperance Development Commission, Department of Conservation and Land Management, Curtin University Kalgoorlie Campus.

2. Hill, P. and Brennan, G.K. (2000). Wood properties of southern gidgee (*Acacia pruinocarpa*) from different sites in the Pilbara and Goldfields regions of Western Australia. CALMScience 3(3): 317-322.

3. Brennan, G.K., Siemon, G.R. and Pitcher, J. (1997). Timber properties and market potential of selected Wheatbelt species. 2. Raspberry jam, brown mallet and York gum. Department of Conservation and Land Management, CALM Timber Technology Internal Report.

4. Siemon, G.R. and Pitcher, J. (1996). Timber properties and market potential of selected Wheatbelt species. 2. Rock sheoak and swamp sheoak. Department of Conservation and Land Management, CALM Timber Technology Internal Report.

5. Bootle, K.R. (1983). *Wood in Australia. Types, properties and uses*. McGraw-Hill Book Co, Sydney.

6. Brennan, G.K. and Newby, P. (1992). Potential of Western Australian Eastern goldfields timbers for high quality wood products. Australian Forestry 55: 74-79.

7. Freischmidt, G., Langfors, N.G., Terrill, S., Williams, M.D and Collins, P.J. (1999). Evaluation of Western Australian hardwoods for wood based composites. CSIRO Forestry and Forest Products Client Report.

8. Piper, P. (2000). Drying gimlet and Goldfields blackbutt timber. Department of Conservation and Land Management, Forest Products Division. Unpublished report.

9. Chippendale, G.M. (1973). *Eucalypts of the Western Australian goldfields (and the adjacent wheatbelt*). Australian Government Publishing Service, Canberra.

10. Boland, D.J., Brooker, M.I.H., Chippendale, G.M., Hall, N., Hyland, B.P.M., Johnston, R.D., Kleinig, D.A. and Turner, J.D. (1984). *Forest trees of Australia*. Nelson-CSIRO.

11. Piper, P. (2001). Drying behaviour and utilisation potential of Preiss's paperbark (*Melaleuca preissiana*). Forest Products Commission WA. Unpublished report.

12. Siemon, G.R. (2001). Utilisation of sawn and round marri timber (*Corymbia calophylla*). Forest Products Commission WA. Unpublished report.

Search Report

Appendix 15

SIFT data for Search report

SIFT..........Potential WA wheatbelt species

Species name	Family	Cons. code	Ht	IBRA zones					Selection					Growth rating
				AW	ESP	GS	MAL	No.	SIFT	Added	Test?	Cored		
Acacia acuminata (narrow phyllode)	Mimosaceae		7.0	AW	ESP		MAL	3	YES		no			
Acacia acuminata (small seed)	Mimosaceae		4.0	AW	ESP	GS		3	YES		no			
Acacia acuminata ssp. acuminata	Mimosaceae		7.0	AW	ESP	GS	MAL	4	YES		YES	YES		2
Acacia aestivalis	Mimosaceae		4.0	AW		GS	MAL	3	YES		YES	YES		1
Acacia aff. redolens	Mimosaceae		3.0		ESP		MAL	2		YES	YES	YES		2
Acacia amblyophylla	Mimosaceae		4.0			GS		1	YES		no			
Acacia ampliata	Mimosaceae	P1	5.0	AW		GS		2			no			
Acacia aneura	Mimosaceae		10.0	AW				1	YES		YES	YES		3
Acacia anfractuosa	Mimosaceae		4.5	AW			MAL	2	YES		no			
Acacia anthochaera	Mimosaceae		5.0	AW		GS		2	YES		YES	YES		2
Acacia aulacophylla	Mimosaceae		4.0	AW		GS		2	YES		no			
Acacia ayersiana var. latifolia	Mimosaceae		7.5	AW				1	YES		no			
Acacia bartleana Maslin (ms)	Mimosaceae		7.0					0		YES	YES	YES		1
Acacia beauverdiana	Mimosaceae		8.0	AW			MAL	2	YES		YES	YES		3
Acacia blakelyi	Mimosaceae		3.0	AW		GS		2		YES	YES	YES		2
Acacia brumalis	Mimosaceae		3.0	AW		GS	MAL	3		YES	YES	YES		1
Acacia burkittii	Mimosaceae		7.0	AW		GS	MAL	3	YES		YES	YES		3
Acacia chartacea	Mimosaceae		4.0			GS		1	YES		no			
Acacia citrinoviridus	Mimosaceae		9.0					0		YES	YES	YES		3
Acacia conniana	Mimosaceae		5.0	AW	ESP		MAL	3	YES		YES	YES		2
Acacia coolgardiensis ssp. Cool.	Mimosaceae		7.0	AW		GS	MAL	3	YES		YES	YES		3
Acacia coolgardiensis ssp. effusa	Mimosaceae		7.0	AW				1	YES		YES	YES		2
Acacia coolgardiensis ssp. latior	Mimosaceae		7.0	AW		GS		2	YES		YES	YES		2
Acacia cowaniana	Mimosaceae	P2	5.0	AW			MAL	2			no			
Acacia cyclops	Mimosaceae		4.0	AW	ESP	GS	MAL	4	YES		YES	YES		2
Acacia dempsteri	Mimosaceae		4.0				MAL	1	YES		no			
Acacia denticulosa	Mimosaceae	R	4.0	AW				1			no			
Acacia didyma	Mimosaceae	P3	4.0			GS		1	YES		no			
Acacia drepanophylla	Mimosaceae	P3	4.0			GS		1	YES		no			
Acacia enervia ssp. enervia	Mimosaceae		4.0	AW			MAL	2	YES		YES	YES		3
Acacia enervia ssp. explicata	Mimosaceae		4.0	AW			MAL	2	YES		YES			
Acacia ephedroides	Mimosaceae		4.0	AW			MAL	2	YES		no			
Acacia eremaea	Mimosaceae		4.0	AW		GS		2	YES		YES	YES		3

SIFT..........Potential WA wheatbelt species

Species name	Family	Cons. code	Ht	IBRA zones					Selection					Growth rating
				AW	ESP	GS	MAL	No.	SIFT	Added	Test?	Cored		
Acacia fauntleroyi	Mimosaceae		5.0	AW			MAL	2	YES		YES	YES		2
Acacia galeata	Mimosaceae		6.0			GS		1	YES		no			
Acacia grasbyi	Mimosaceae		4.5			GS		1	YES		no			
Acacia hakeoides	Mimosaceae		3.0				MAL	1		YES	YES			
Acacia harveyi	Mimosaceae		4.0		ESP		MAL	2	YES		maybe			
Acacia heteroclita ssp. heteroclita	Mimosaceae		4.0	AW	ESP		MAL	3	YES		YES			
Acacia hopperiana	Mimosaceae		4.0	AW		GS		2	YES		no			
Acacia inceana ssp. conformis	Mimosaceae		4.0	AW				1	YES		YES	YES		3
Acacia inceana ssp. latifolia	Mimosaceae	P1	4.0	AW				1			no			
Acacia incongesta	Mimosaceae		4.0				MAL	1	YES		no			
Acacia inophloia	Mimosaceae	P3	4.0	AW			MAL	2	YES		YES			
Acacia isoneura ssp. nimia	Mimosaceae	P3	4.0	AW		GS		2	YES		no			
Acacia jamesiana	Mimosaceae		5.0	AW				1	YES		no			
Acacia jennerae	Mimosaceae		6.0	AW			MAL	2	YES		YES	YES		2
Acacia jibberdingensis	Mimosaceae		4.0	AW		GS	MAL	3	YES		YES	YES		3
Acacia kempeana	Mimosaceae		6.0			GS		1	YES		no			
Acacia lasiocalyx	Mimosaceae		7.0	AW	ESP	GS	MAL	4	YES		YES	YES		1
Acacia ligulata	Mimosaceae		4.0	AW		GS		2	YES		no			
Acacia longiphyllodinea	Mimosaceae		4.0	AW		GS		2	YES		no			
Acacia longispinea	Mimosaceae		5.0	AW		GS	MAL	3	YES		no			
Acacia meisneri	Mimosaceae		4.0	AW			MAL	2	YES		no			
Acacia merinthophora	Mimosaceae		4.0	AW			MAL	2	YES		no			
Acacia merrickiae	Mimosaceae	P4	4.0	AW				1	YES		no			
Acacia microbotrya var. borealis	Mimosaceae		5.0	AW		GS	MAL	3	YES		YES	YES		3
Acacia microbotrya var. microbotrya	Mimosaceae		7.0	AW	ESP			2	YES		YES	YES		1
Acacia murrayana	Mimosaceae		5.0	AW	ESP	GS		3	YES		YES	YES		1
Acacia neurophylla ssp. erugata	Mimosaceae		5.0	AW		GS	MAL	3	YES		YES	YES		3
Acacia obtecta	Mimosaceae		3.0	AW				1		YES	YES	YES		3
Acacia oldfieldii	Mimosaceae		4.0			GS		1	YES		YES			
Acacia oswaldii	Mimosaceae		6.0	AW			MAL	2	YES		no			
Acacia papyrocarpa	Mimosaceae		8.0	AW			MAL	2	YES		no			
Acacia paradoxa	Mimosaceae		4.0	AW	ESP			2	YES		no			
Acacia pentadenia	Mimosaceae		5.0		ESP			1	YES		no			

SIFT..........Potential WA wheatbelt species

Species name	Family	Cons. code	Ht	IBRA zones					Selection					Growth rating
				AW	ESP	GS	MAL	No.	SIFT	Added	Test?	Cored		
Acacia prainii	Mimosaceae		3.0	AW			MAL	2		YES	YES	YES		3
Acacia pruinocarpa	Mimosaceae		12.0					0		YES	YES	YES		3
Acacia quadrimarginea	Mimosaceae		6.0	AW				1	YES		no			
Acacia ramulosa var. ramulosa	Mimosaceae		4.0	AW	ESP	GS		3	YES		no			
Acacia redolens	Mimosaceae		3.0		ESP		MAL	2		YES	yes	YES		2
Acacia resinimarginea	Mimosaceae		7.0	AW			MAL	2	YES		YES	YES		2
Acacia resinistipulea	Mimosaceae		4.0				MAL	1	YES		no			
Acacia rhodophloia	Mimosaceae		4.0			GS		1	YES		no			
Acacia rigens	Mimosaceae		6.0	AW			MAL	2	YES		no			
Acacia rostellifera	Mimosaceae		6.0	AW	ESP	GS	MAL	4	YES		YES	YES		1
Acacia roycei	Mimosaceae		6.0			GS		1	YES		no			
Acacia saligna	Mimosaceae		6.0	AW	ESP	GS	MAL	4	YES		YES	YES		1
Acacia scirpifolia	Mimosaceae		4.0	AW		GS		2	YES		YES	YES		2
Acacia sclerosperma ssp. scler.	Mimosaceae		4.0	AW		GS		2	YES		no	YES		3
Acacia signata	Mimosaceae		4.0	AW		GS	MAL	3	YES		no			
Acacia sp. Dandaragan (S.van Leeuwen 26	Mimosaceae	R	6.0	AW		GS		4			no			
Acacia sp. Murchison (B.R.Maslin 7331)	Mimosaceae		5.0	AW				1	YES		no			
Acacia sp. Ravensthorpe (Cowan & Maslin)	Mimosaceae		4.0		ESP		MAL	2	YES		no			
Acacia steedmanii	Mimosaceae		4.0	AW			MAL	2	YES		YES	YES		2
Acacia stereophylla var. cylindrata	Mimosaceae	P2	4.0			GS		1			no			
Acacia stereophylla var. stereophylla	Mimosaceae		4.0	AW		GS		2	YES		YES	YES		3
Acacia stowardii	Mimosaceae		4.0	AW				1	YES		no			
Acacia synoria	Mimosaceae	P2	5.0	AW				1			no			
Acacia tetragonophylla	Mimosaceae		5.0	AW		GS	MAL	3	YES		no			
Acacia trinalis	Mimosaceae	P1	4.0	AW				1			no			
Acacia triptycha	Mimosaceae		4.0		ESP		MAL	2	YES		YES			
Acacia tysonii	Mimosaceae		6.0	AW				1	YES		YES	YES		3
Acacia veronica	Mimosaceae	P3	10.0		ESP			1	YES		YES			
Acacia victoriae	Mimosaceae		5.0	AW		GS		2	YES		YES	YES		2
Acacia vittata	Mimosaceae	P2	4.0			GS		1			no			
Acacia websteri	Mimosaceae	P1	5.0	AW				1			no			
Acacia wiseana	Mimosaceae		4.0			GS		1	YES		no			
Acacia xanthina	Mimosaceae		4.0	AW		GS		2	YES		no			

SIFT..........Potential WA wheatbelt species

Species name	Family	Cons. code	Ht	IBRA zones					Selection					Growth rating
				AW	ESP	GS	MAL	No.	SIFT	Added	Test?	Cored		
Acacia yorkrakinensis ssp. acrita	Mimosaceae		4.0	AW			MAL	2	YES		no			
Acacia yorkrakinensis ssp. yorkrakinensis	Mimosaceae		4.0	AW				1	YES		no			
Actinostrobus acuminatus	Cupress.		0.8			GS		1				YES		
Actinostrobus arenarius	Cupress.		6.0	AW	ESP	GS	MAL	4	YES		YES	YES		3
Actinostrobus pyramidalis	Cupress.		4.0	AW	ESP	GS	MAL	4	YES		YES	YES		3
Adenanthos cygnorum ssp. cygnorum	Proteaceae		4.0	AW		GS	MAL	3	YES		YES	YES		3
Adenanthos sericeus ssp. sericeus	Proteaceae		5.0		ESP			1	YES		YES	YES		3
Adenanthos stictus	Proteaceae		5.0	AW		GS		2	YES		YES	YES		2
Agonis flexuosa var. flexuosa	Myrtaceae		10.0		ESP	GS		2	YES		YES	YES		2
Alectryon oleifolius ssp. oleifolius	Sapindaceae		3.0			GS		1		YES	YES	YES		3
Allocasuarina acutivalvis ssp. acutivalvis	Casuarinaceae		8.0	AW	ESP	GS	MAL	4	YES		YES	YES		2
Allocasuarina acutivalvis ssp. prinsepiana	Casuarinaceae		8.0	AW		GS		2	YES		maybe			
Allocasuarina campestris	Casuarinaceae		3.0	AW	ESP	GS	MAL	4		YES	YES	YES		3
Allocasuarina corniculata	Casuarinaceae		5.0	AW	ESP		MAL	3	YES		no			
Allocasuarina decussata	Casuarinaceae		15.0		ESP			1	YES		no			
Allocasuarina dielsiana	Casuarinaceae		9.0	AW		GS		2	YES		YES	YES		2
Allocasuarina helmsii	Casuarinaceae		5.0	AW	ESP		MAL	3	YES		no			
Allocasuarina huegeliana	Casuarinaceae		10.0	AW	ESP	GS	MAL	4	YES		YES	YES		1
Allocasuarina lehmanniana ssp. Lehmann.	Casuarinaceae		4.0	AW	ESP	GS	MAL	4	YES		no			
Allocasuarina spinosissima	Casuarinaceae		4.0	AW	ESP		MAL	3	YES		no			
Alyogyne hakeifolia	Malvaceae		3.0	AW	ESP	GS	MAL	4		YES	YES	YES		2
Alyogyne huegelii var. glabrescens	Malvaceae		4.0			GS		1	YES		YES			2
Alyogyne huegelii var. huegelii	Malvaceae		3.0			GS		1		YES	YES	YES		1
Alyogyne wrayae	Malvaceae		3.0	AW	ESP	GS	MAL	4		YES	YES			2
Anthocercis littorea	Solanaceae		3.0	AW	ESP	GS		3		YES	YES	YES		1
Aphanopetalum clematideum	Cunoniaceae		5.0			GS		1	YES		no			
Astartea heteranthera	Myrtaceae		2.0	AW	ESP	GS	MAL	4		YES	YES	YES		3
Baeckea recurva	Myrtaceae		4.5	AW		GS	MAL	3	YES		maybe			
Banksia ashbyi	Proteaceae		8.0	AW		GS		2	YES		no			
Banksia attenuata	Proteaceae		10.0	AW	ESP	GS	MAL	4	YES		YES	YES		3
Banksia baxteri	Proteaceae		4.0		ESP			1	YES		no			
Banksia benthamiana	Proteaceae	P4	4.0	AW				1	YES		no			
Banksia brownii	Proteaceae	R	6.0		ESP			1			no			

SIFT..........Potential WA wheatbelt species

Species name	Family	Cons. code	Ht	IBRA zones					Selection					Growth rating
				AW	ESP	GS	MAL	No.	SIFT	Added	Test?	Cored		
Banksia burdettii	Proteaceae		4.0			GS		1	YES		no			
Banksia coccinea	Proteaceae		4.0		ESP			1	YES		no			
Banksia cuneata	Proteaceae	R	4.0	AW				1			no			
Banksia elderiana	Proteaceae		4.0		ESP		MAL	2	YES		no			
Banksia elegans	Proteaceae	P4	4.0	AW		GS		2	YES		no			
Banksia grandis	Proteaceae		10.0	AW	ESP	GS		3	YES		YES	YES		3
Banksia ilicifolia	Proteaceae		10.0		ESP			1	YES		no			
Banksia lemanniana	Proteaceae		5.0		ESP		MAL	2	YES		no			
Banksia littoralis	Proteaceae		12.0	AW	ESP	GS		3	YES		no			
Banksia media	Proteaceae		5.0	AW	ESP		MAL	3	YES		no			
Banksia menziesii	Proteaceae		7.0	AW		GS		2	YES		no			
Banksia occidentalis	Proteaceae		7.0		ESP		MAL	2	YES		no			
Banksia pilostylis	Proteaceae		4.0		ESP		MAL	2	YES		no			
Banksia praemorsa	Proteaceae		4.0		ESP			1	YES		no			
Banksia prionotes	Proteaceae		8.0	AW		GS	MAL	3	YES		YES	YES		2
Banksia sceptrum	Proteaceae		5.0	AW		GS		2	YES		no			
Banksia solandri	Proteaceae	P4	4.0		ESP			1	YES		no			
Banksia speciosa	Proteaceae		6.0		ESP		MAL	2	YES		no			
Banksia sphaerocarpa var. caesia	Proteaceae		4.0	AW			MAL	2	YES		no			
Banksia tricuspis	Proteaceae	P4	4.0			GS		1	YES		no			
Banksia verticillata	Proteaceae	R	6.0		ESP			1			no			
Banksia victoriae	Proteaceae		7.0		ESP	GS		2	YES		no			
Brachychiton gregorii	Sterculiaceae		12.0	AW		GS		2	YES		YES	YES		3
Bursaria occidentalis	Pittosporaceae		8.0	AW		GS		2	YES		YES	YES		1
Callistachys lanceolata	Papilionaceae		7.0		ESP			1	YES		YES	YES		3
Callistemon phoeniceus	Myrtaceae		6.0	AW	ESP	GS	MAL	4	YES		YES	YES		3
Callitris canescens	Cupressaceae		5.0	AW	ESP	GS	MAL	4	YES		YES	YES		3
Callitris drummondii	Cupressaceae		3.0		ESP		MAL	2		YES	no			
Callitris glaucophylla	Cupressaceae		12.0	AW		GS	MAL	3	YES		YES	YES		2
Callitris roei	Cupressaceae		5.0	AW	ESP		MAL	3	YES		YES			
Callitris tuberculata	Cupressaceae		9.0	AW	ESP		MAL	3	YES		YES	YES		3
Calothamnus asper	Myrtaceae		4.0	AW	ESP	GS		3	YES		YES	YES		3
Calothamnus formosus ssp. formosus	Myrtaceae		4.0			GS		1	YES		no			

SIFT.........Potential WA wheatbelt species

Species name	Family	Cons. code	Ht	IBRA zones					Selection					Growth rating
				AW	ESP	GS	MAL	No.	SIFT	Added	Test?	Cored		
Calothamnus formosus ssp. rigidus	Myrtaceae		4.0			GS		1	YES		YES			
Calothamnus rupestris	Myrtaceae	P4	4.0	AW				1	YES		no			
Calothamnus tuberosus	Myrtaceae		3.0	AW	ESP		MAL	3		YES	YES	YES		3
Calycopeplus paucifolius	Euphorbiaceae		5.0	AW			MAL	2	YES		YES	YES		3
Casuarina obesa	Casuarinaceae		10.0	AW	ESP	GS	MAL	4	YES		YES	YES		1
Casuarina pauper	Casuarinaceae		15.0					0		YES	no			
Chamelaucium uncinatum	Myrtaceae		4.0	AW		GS		2	YES		YES	YES		3
Choretrum lateriflorum	Santalaceae		4.5		ESP			1	YES		no			
Chorilaena quercifolia	Rutaceae		5.0		ESP			1	YES		no			
Codonocarpus cotinifolius	Gyrostemonaceae		10.0	AW	ESP	GS	MAL	4	YES		YES	YES		1
Comesperma integerrimum	Polygalaceae		8.0	AW	ESP	GS	MAL	4	YES		no			
Conospermum triplinervium	Proteaceae		4.5	AW	ESP	GS		3	YES		YES	YES		3
Corymbia calophylla	Myrtaceae		40.0	AW	ESP	GS		3	YES		YES	YES		1
Corymbia ficifolia	Myrtaceae		10.0		ESP			1	YES		no			
Corymbia haematoxylon	Myrtaceae		15.0			GS		1	YES		no			
Dodonaea hackettiana	Sapindaceae	P4	5.0		ESP			1	YES		no			
Dodonaea inaequifolia	Sapindaceae		5.0	AW		GS	MAL	3	YES		YES	YES		3
Dodonaea larreoides	Sapindaceae		4.0	AW		GS		2	YES		YES			
Dodonaea ptarmicaefolia	Sapindaceae		4.0	AW	ESP		MAL	3	YES		YES	YES		3
Dodonaea viscosa ssp. angustissima	Sapindaceae		4.0	AW	ESP	GS	MAL	4	YES		YES	YES		3
Dodonaea viscosa ssp. mucronata	Sapindaceae		4.0		ESP			1	YES		no			
Dodonaea viscosa ssp. spatulata	Sapindaceae		4.0	AW	ESP	GS	MAL	4	YES		maybe			
Dryandra anatona	Proteaceae	R	5.0		ESP			1			no			
Dryandra arborea	Proteaceae		8.0					0		YES	YES	YES		2
Dryandra fraseri var. oxycedra	Proteaceae	P3	6.0	AW				1	YES		maybe			
Dryandra hewardiana	Proteaceae		5.0	AW		GS		2	YES		maybe			
Dryandra nobilis ssp. nobilis	Proteaceae		4.0	AW				1	YES		YES	YES		2
Dryandra polycephala	Proteaceae	P4	4.0	AW				1	YES		maybe			
Dryandra sessilis var. cygnorum	Proteaceae		5.0			GS		1	YES		no			
Dryandra sessilis var. flabellifolia	Proteaceae		5.0	AW		GS		2	YES		maybe			
Dryandra sessilis var. sessilis	Proteaceae		5.0	AW	ESP	GS	MAL	4	YES		YES	YES		2
Dryandra squarrosa ssp. squarrosa	Proteaceae		4.0	AW			MAL	2	YES		maybe			
Duboisia hopwoodii	Solanaceae		4.0	AW		GS	MAL	3	YES		YES	YES		2

SIFT.........Potential WA wheatbelt species

Species name	Family	Cons. code	Ht	IBRA zones					Selection					Growth rating
				AW	ESP	GS	MAL	No.	SIFT	Added	Test?	Cored		
Eremaea dendroidea	Myrtaceae		5.0			GS		1	YES		no			
Eremophila alternifolia	Myoporaceae		4.0		ESP		MAL	2	YES		maybe	YES		3
Eremophila caperata	Myoporaceae		3.0	AW				1		YES	YES	YES		3
Eremophila deserti	Myoporaceae		4.0	AW		GS	MAL	3	YES		YES	YES		3
Eremophila interstans ssp. interstans	Myoporaceae		7.0	AW				1	YES		YES	YES		3
Eremophila longifolia	Myoporaceae		6.0	AW		GS		2	YES		YES	YES		2
Eremophila miniata	Myoporaceae		5.0	AW				1	YES		YES	YES		3
Eremophila oldfieldii ssp. angustifolia	Myoporaceae		6.0	AW		GS		2	YES		YES			
Eremophila oldfieldii ssp. oldfieldii	Myoporaceae		5.0	AW		GS		2	YES		YES	YES		2
Eremophila oppositifolia ssp. angustifolia	Myoporaceae		4.0	AW		GS	MAL	3	YES		YES	YES		3
Eremophila psilocalyx	Myoporaceae		3.0		ESP		MAL	2		YES	YES	YES		3
Eremophila pterocarpa ssp. pterocarpa	Myoporaceae		4.0	AW				1	YES		no			
Eremophila scoparia	Myoporaceae		3.0	AW			MAL	2		YES	YES			3
Eremophila serrulata	Myoporaceae		2.0	AW		GS		2		YES	YES			3
Eremophila virens	Myoporaceae	R	5.0	AW				1			no			
Eremophila viscida	Myoporaceae	R	4.0	AW			MAL	2			no			
Erythrina vespertilio	Papilionaceae		15.0				MAL	1	YES		no			
Eucalyptus absita	Myrtaceae	R	10.0			GS		1			no			
Eucalyptus absita x loxophleba	Myrtaceae	P1	10.0			GS		1			no			
Eucalyptus accedens	Myrtaceae		15.0	AW		GS		2	YES		YES	YES		2
Eucalyptus aequioperta	Myrtaceae		8.0	AW	ESP		MAL	3	YES		no			
Eucalyptus albida	Myrtaceae		4.0	AW	ESP	GS	MAL	4	YES		no			
Eucalyptus alipes	Myrtaceae		5.0		ESP		MAL	2	YES		YES	YES		2
Eucalyptus angulosa	Myrtaceae		5.0	AW	ESP		MAL	3	YES		no			
Eucalyptus angustissima ssp. angustiss.	Myrtaceae		4.0		ESP		MAL	2	YES		YES	YES		1
Eucalyptus angustissima ssp. quaerenda	Myrtaceae	P2	4.0		ESP		MAL	2			no			
Eucalyptus annulata	Myrtaceae		8.0	AW	ESP		MAL	3	YES		YES	YES		3
Eucalyptus aquilina	Myrtaceae	P4	7.0		ESP			1	YES		no			
Eucalyptus arachnaea ssp. arachnaea	Myrtaceae		6.0	AW		GS		2	YES		no			
Eucalyptus arachnaea ssp. arrecta	Myrtaceae	P3	10.0	AW		GS		2	YES		no			
Eucalyptus argyphea	Myrtaceae		15.0	AW	ESP		MAL	3	YES		YES	YES		1
Eucalyptus aspersa	Myrtaceae	P4	7.0	AW				1	YES		no			
Eucalyptus aspratilis	Myrtaceae		6.0		ESP		MAL	2	YES		YES	YES		2

SIFT..........Potential WA wheatbelt species

Species name	Family	Cons. code	Ht	IBRA zones					Selection					Growth rating
				AW	ESP	GS	MAL	No.	SIFT	Added	Test?	Cored		
Eucalyptus astringens ssp. astringens	Myrtaceae		9.0	AW	ESP		MAL	3	YES		YES	YES		1
Eucalyptus astringens ssp. redacta	Myrtaceae		15.0		ESP		MAL	2	YES		YES	YES		3
Eucalyptus austrina	Myrtaceae		4.0		ESP		MAL	2	YES		no			
Eucalyptus balanites	Myrtaceae	R	5.0			GS		1			no			
Eucalyptus balanopelex	Myrtaceae	P1	4.0		ESP			1			no			
Eucalyptus balladoniensis ssp. balladon.	Myrtaceae		10.0				MAL	1	YES		YES	YES		3
Eucalyptus baudiniana	Myrtaceae		12.0	AW		GS		2	YES		no			
Eucalyptus beardiana	Myrtaceae	R	5.0	AW		GS		2			no			
Eucalyptus blaxellii	Myrtaceae	R	4.0	AW		GS		2			no			
Eucalyptus brachycalyx	Myrtaceae		8.0		ESP		MAL	2	YES		no			
Eucalyptus brachycorys	Myrtaceae		7.0	AW		GS	MAL	3	YES		YES	YES		2
Eucalyptus brevipes	Myrtaceae	R	5.0	AW				1			no			
Eucalyptus brockwayi	Myrtaceae	P3	20.0				MAL	1	YES		YES			2
Eucalyptus buprestium	Myrtaceae		6.0		ESP		MAL	2	YES		no			
Eucalyptus buprestium x marginata	Myrtaceae	P4	5.0		ESP			1	YES		no			
Eucalyptus buprestium x staeri	Myrtaceae	P4	4.0		ESP			1	YES		no			
Eucalyptus burdettiana	Myrtaceae	R	4.0		ESP			1			no			
Eucalyptus burgmaniana	Myrtaceae	P1	5.0				MAL	1			no			
Eucalyptus burracoppinensis	Myrtaceae		6.0	AW	ESP		MAL	3	YES		YES	YES		2
Eucalyptus caesia ssp. caesia	Myrtaceae	P4	14.0	AW			MAL	2	YES		no			
Eucalyptus caesia ssp. magna	Myrtaceae	P4	10.0	AW				1	YES		no			
Eucalyptus calcareana	Myrtaceae		10.0				MAL	1	YES		no			
Eucalyptus calycogona ssp. calycogona	Myrtaceae		5.0	AW	ESP		MAL	3	YES		no			
Eucalyptus camaldulensis var. obtusa	Myrtaceae		20.0	AW		GS		2	YES		YES	YES		1
Eucalyptus capillosa ssp. capillosa	Myrtaceae		15.0	AW	ESP		MAL	3	YES		YES	YES		2
Eucalyptus capillosa ssp. polyclada	Myrtaceae		6.0	AW	ESP		MAL	3	YES		YES	YES		3
Eucalyptus captiosa	Myrtaceae		4.0	AW	ESP		MAL	3	YES		no			
Eucalyptus celastroides ssp. celastroides	Myrtaceae		8.0	AW			MAL	2	YES		no	YES		3
Eucalyptus celastroides ssp. virella	Myrtaceae		8.0	AW	ESP	GS	MAL	4	YES		YES			
Eucalyptus ceratocorys	Myrtaceae		10.0	AW	ESP		MAL	3	YES		no			
Eucalyptus clelandii	Myrtaceae		15.0	AW				1	YES		no			
Eucalyptus clivicola	Myrtaceae		13.0	AW	ESP		MAL	3	YES		YES	YES		2
Eucalyptus comitae-vallis	Myrtaceae		8.0	AW	ESP		MAL	3	YES		no			

SIFT..........Potential WA wheatbelt species

Species name	Family	Cons. code	Ht	IBRA zones					Selection					Growth rating
				AW	ESP	GS	MAL	No.	SIFT	Added	Test?	Cored		
Eucalyptus communalis	Myrtaceae		4.0		ESP			1	YES		no			
Eucalyptus concinna	Myrtaceae		10.0	AW			MAL	2	YES		no			
Eucalyptus conferruminata	Myrtaceae		8.0		ESP			1	YES		YES	YES		3
Eucalyptus conglobata	Myrtaceae		7.0	AW	ESP		MAL	3	YES		no			
Eucalyptus conveniens	Myrtaceae		4.0			GS		1	YES		no			
Eucalyptus cooperiana	Myrtaceae		5.0		ESP		MAL	2	YES		no			
Eucalyptus cornuta	Myrtaceae		25.0		ESP			1	YES		YES	YES		2
Eucalyptus coronata	Myrtaceae	R	4.0		ESP			1			no			
Eucalyptus corrugata	Myrtaceae		15.0	AW				1	YES		no			
Eucalyptus crassa	Myrtaceae		5.0		ESP		MAL	2	YES		no			
Eucalyptus creta	Myrtaceae	P3	15.0				MAL	1	YES		no			
Eucalyptus crispata	Myrtaceae	R	7.0			GS		1			no			
Eucalyptus crucis ssp. crucis	Myrtaceae	R	8.0	AW				1			no			
Eucalyptus crucis ssp. lanceolata	Myrtaceae		15.0	AW				1	YES		no			
Eucalyptus crucis ssp. praecipua	Myrtaceae	R	15.0			GS		1			no			
Eucalyptus cuprea	Myrtaceae	R	5.0			GS		1			no			
Eucalyptus cylindriflora	Myrtaceae		6.0	AW	ESP		MAL	3	YES		no			
Eucalyptus cylindrocarpa	Myrtaceae		10.0	AW	ESP		MAL	3	YES		no			
Eucalyptus decipiens ssp. adesmophloia	Myrtaceae		9.0	AW	ESP			2	YES		no			
Eucalyptus decipiens ssp. chalara	Myrtaceae		15.0	AW	ESP	GS		3	YES		no			
Eucalyptus decipiens ssp. decipiens	Myrtaceae		15.0			GS		1	YES		no			
Eucalyptus decurva	Myrtaceae		5.0	AW	ESP		MAL	3	YES		no			
Eucalyptus delicata	Myrtaceae		16.0				MAL	1	YES		no			
Eucalyptus densa ssp. densa	Myrtaceae		12.0	AW	ESP		MAL	3	YES		no			
Eucalyptus depauperata	Myrtaceae	P3	4.0	AW	ESP		MAL	3	YES		no			
Eucalyptus desmondensis	Myrtaceae	P4	4.5		ESP			1	YES		no			
Eucalyptus dielsii	Myrtaceae		7.0		ESP		MAL	2	YES		no			
Eucalyptus diminuta	Myrtaceae	P3	5.0	AW		GS		2	YES		no			
Eucalyptus diptera	Myrtaceae		8.0				MAL	1	YES		no			
Eucalyptus dissimulata ssp. dissimulata	Myrtaceae		4.0	AW	ESP		MAL	3	YES		no			
Eucalyptus dissimulata ssp. plauta	Myrtaceae		6.0				MAL	1	YES		no			
Eucalyptus dolichocera	Myrtaceae		6.0	AW		GS	MAL	3	YES		no			
Eucalyptus dolichorhyncha	Myrtaceae	P4	5.0		ESP		MAL	2	YES		no			

SIFT..........Potential WA wheatbelt species

Species name	Family	Cons. code	Ht	IBRA zones					Selection					Growth rating
				AW	ESP	GS	MAL	No.	SIFT	Added	Test?	Cored		
Eucalyptus doratoxylon	Myrtaceae		6.0		ESP		MAL	2	YES		no			
Eucalyptus drummondii ssp. pendiflora	Myrtaceae		4.0	AW				1	YES		no			
Eucalyptus dundasii	Myrtaceae		21.0				MAL	1	YES		YES	YES		2
Eucalyptus ebbanoensis ssp. ebbanoensis	Myrtaceae		10.0	AW		GS		2	YES		no			
Eucalyptus ebbanoensis ssp. photina	Myrtaceae	P4	6.0	AW		GS		2	YES		no			
Eucalyptus erectifolia	Myrtaceae	P4	4.0		ESP			1	YES		no			
Eucalyptus eremophila ssp. eremophila	Myrtaceae		8.0	AW	ESP		MAL	3	YES		YES	YES		3
Eucalyptus eremophila ssp. pterocarpa	Myrtaceae		8.0				MAL	1	YES		maybe			
Eucalyptus erythrocorys	Myrtaceae		8.0	AW		GS		2	YES		YES	YES		2
Eucalyptus erythronema var. erythronema	Myrtaceae		6.0	AW			MAL	2	YES		YES	YES		3
Eucalyptus erythronema var. marginata	Myrtaceae		6.0	AW		GS	MAL	3	YES		YES	YES		3
Eucalyptus eudesmioides	Myrtaceae		8.0	AW		GS		2	YES		no			
Eucalyptus ewartiana	Myrtaceae		7.0	AW		GS		2	YES		YES	YES		2
Eucalyptus exigua	Myrtaceae	P3	5.0	AW			MAL	2	YES		no			
Eucalyptus exilis	Myrtaceae	P4	6.0	AW		GS		2	YES		no			
Eucalyptus extensa	Myrtaceae		8.0		ESP		MAL	2	YES		YES			
Eucalyptus extrica	Myrtaceae		4.0		ESP		MAL	2	YES		no			
Eucalyptus falcata ssp. opima	Myrtaceae		6.0	AW		GS		2	YES		no			
Eucalyptus famelica	Myrtaceae	P3	4.0		ESP			1	YES		no			
Eucalyptus flocktoniae ssp. flocktoniae	Myrtaceae		8.0	AW	ESP		MAL	3	YES		no			
Eucalyptus foecunda ssp. Coolimba	Myrtaceae	P3	4.0			GS		1	YES		no			
Eucalyptus foliosa	Myrtaceae	P1	4.0		ESP			1			no			
Eucalyptus forrestiana	Myrtaceae		6.0		ESP		MAL	2	YES		no			
Eucalyptus fraseri ssp. fraseri	Myrtaceae		20.0				MAL	1	YES		no			
Eucalyptus fruticosa	Myrtaceae		5.0			GS		1	YES		no			
Eucalyptus gardneri ssp. gardneri	Myrtaceae		10.0	AW			MAL	2	YES		no			
Eucalyptus gardneri ssp. ravensthorpe.	Myrtaceae		10.0		ESP			1	YES		no			
Eucalyptus georgei ssp. fulgida	Myrtaceae	P4	20.0				MAL	1	YES		no			
Eucalyptus georgei ssp. georgei	Myrtaceae	P4	20.0				MAL	1	YES		no			
Eucalyptus gittinsii ssp. gittinsii	Myrtaceae		6.0			GS		1	YES		no			
Eucalyptus gittinsii ssp. illucida	Myrtaceae		4.0	AW		GS		2	YES		no			
Eucalyptus glomerifera	Myrtaceae		4.0		ESP		MAL	2	YES		no			
Eucalyptus gomphocephala	Myrtaceae		40.0			GS		1	YES		YES	YES		1

SIFT..........Potential WA wheatbelt species

Species name	Family	Cons. code	Ht	IBRA zones					Selection					Growth rating
				AW	ESP	GS	MAL	No.	SIFT	Added	Test?	Cored		
Eucalyptus goniantha ssp. goniantha	Myrtaceae	P4	10.0		ESP			1	YES		no			
Eucalyptus goniantha ssp. notactites	Myrtaceae		13.0		ESP			1	YES		no			
Eucalyptus goniocarpa	Myrtaceae		5.0				MAL	1	YES		no			
Eucalyptus grasbyi	Myrtaceae		12.0				MAL	1	YES		no			
Eucalyptus gratiae	Myrtaceae		8.0	AW	ESP		MAL	3	YES		YES	YES		1
Eucalyptus griffithsii	Myrtaceae		10.0		ESP			1	YES		no			
Eucalyptus grossa	Myrtaceae		5.0		ESP		MAL	2	YES		no			
Eucalyptus grossifolia	Myrtaceae		6.0		ESP			1	YES		no			
Eucalyptus halophila	Myrtaceae		4.0		ESP		MAL	2	YES		YES	YES		3
Eucalyptus hebetifolia	Myrtaceae		6.0	AW			MAL	2	YES		no			
Eucalyptus histophylla	Myrtaceae	P3	6.0				MAL	1	YES		no			
Eucalyptus hypochlamydea ssp. ecdysiaste	Myrtaceae		5.0	AW		GS	MAL	3	YES		maybe			
Eucalyptus hypochlamydea ssp. hypochlam	Myrtaceae		8.0	AW		GS	MAL	3	YES		YES	YES		2
Eucalyptus incerata	Myrtaceae		12.0				MAL	1	YES		no			
Eucalyptus incrassata	Myrtaceae		5.0	AW	ESP	GS	MAL	4	YES		YES	YES		3
Eucalyptus indurata	Myrtaceae		10.0		ESP		MAL	2	YES		YES	YES		3
Eucalyptus insularis	Myrtaceae	R	8.0		ESP			1			no			
Eucalyptus jucunda	Myrtaceae		8.0	AW		GS		2	YES		no			
Eucalyptus kessellii ssp. eugnosta	Myrtaceae		10.0		ESP		MAL	2	YES		no			
Eucalyptus kessellii ssp. kessellii	Myrtaceae		10.0		ESP		MAL	2	YES		no			
Eucalyptus kochii ssp. amaryssia	Myrtaceae		8.0					0		YES	maybe			
Eucalyptus kochii ssp. horistes	Myrtaceae		9.0	AW		GS		2	YES		YES	YES		1
Eucalyptus kochii ssp. kochii	Myrtaceae		7.0	AW		GS		2	YES		YES	YES		2
Eucalyptus kochii ssp. plenissima	Myrtaceae		12.0	AW	ESP	GS	MAL	4	YES		YES	YES		1
Eucalyptus kondininensis	Myrtaceae		20.0	AW	ESP		MAL	3	YES		YES	YES		1
Eucalyptus kumarlensis	Myrtaceae		10.0				MAL	1	YES		no			
Eucalyptus lane-poolei	Myrtaceae		12.0			GS		1	YES		no			
Eucalyptus latens	Myrtaceae	P4	4.0	AW			MAL	2	YES		no			
Eucalyptus lehmannii ssp. arborella	Myrtaceae		10.0		ESP			1	YES		no			
Eucalyptus lehmannii ssp. lehmannii	Myrtaceae		7.0		ESP		MAL	2	YES		no			
Eucalyptus leprophloia	Myrtaceae	R	5.0			GS		1			no			
Eucalyptus leptamba	Myrtaceae		10.0				MAL	1	YES		no			
Eucalyptus leptocalyx ssp. leptocalyx	Myrtaceae		5.0		ESP		MAL	2	YES		no			

SIFT.........Potential WA wheatbelt species

Species name	Family	Cons. code	Ht	IBRA zones					Selection					Growth rating
				AW	ESP	GS	MAL	No.	SIFT	Added	Test?	Cored		
Eucalyptus leptocalyx ssp. petilipes	Myrtaceae		8.0				MAL	1	YES		no			
Eucalyptus leptophylla	Myrtaceae		6.0	AW	ESP		MAL	3	YES		no			
Eucalyptus leptopoda ssp. arctata	Myrtaceae		8.0	AW		GS		2	YES		YES	YES		2
Eucalyptus leptopoda ssp. elevata	Myrtaceae		5.0	AW		GS		2	YES		YES			2
Eucalyptus leptopoda ssp. leptopoda	Myrtaceae		6.0	AW			MAL	2	YES		YES	YES		2
Eucalyptus leptopoda ssp. subluta	Myrtaceae		6.0	AW			MAL	2	YES		maybe	YES		2
Eucalyptus lesouefii	Myrtaceae		18.0	AW				1	YES		YES	YES		3
Eucalyptus ligulata	Myrtaceae	P4	4.0		ESP			1	YES		no			
Eucalyptus litorea	Myrtaceae	P2	6.0		ESP			1			no			
Eucalyptus livida	Myrtaceae		10.0	AW	ESP		MAL	3	YES		no			
Eucalyptus longicornis	Myrtaceae		24.0	AW	ESP		MAL	3	YES		YES	YES		1
Eucalyptus loxophleba ssp. lissophloia	Myrtaceae		8.0	AW			MAL	2	YES		YES	YES		1
Eucalyptus loxophleba ssp. loxophleba	Myrtaceae		15.0	AW	ESP	GS	MAL	4	YES		YES	YES		2
Eucalyptus loxophleba ssp. supralaevis	Myrtaceae		15.0	AW		GS	MAL	3	YES		YES	YES		2
Eucalyptus loxophleba x wandoo	Myrtaceae	P4	20.0	AW		GS		2	YES		no			
Eucalyptus luteola	Myrtaceae		5.0		ESP		MAL	2	YES		no			
Eucalyptus macrandra	Myrtaceae		8.0	AW	ESP			2	YES		no			
Eucalyptus macrocarpa ssp. elachantha	Myrtaceae	P4	4.0			GS		1	YES		no			
Eucalyptus macrocarpa ssp. macrocarpa	Myrtaceae		5.0	AW			MAL	2	YES		no			
Eucalyptus macrocarpa x pyriformis	Myrtaceae	P3	6.0	AW		GS		2	YES		no			
Eucalyptus mannensis ssp. vespertina	Myrtaceae		8.0			GS		1	YES		no			
Eucalyptus marginata ssp. marginata	Myrtaceae		30.0	AW	ESP	GS	MAL	4	YES		no			
Eucalyptus marginata x pachyloma	Myrtaceae	P4	5.0	AW	ESP			2	YES		no			
Eucalyptus medialis	Myrtaceae		6.0		ESP		MAL	2	YES		no			
Eucalyptus megacarpa	Myrtaceae		35.0		ESP			1	YES		no			
Eucalyptus megacornuta	Myrtaceae		12.0		ESP			1	YES		no			
Eucalyptus melanophitra	Myrtaceae	P4	7.0		ESP			1	YES		no			
Eucalyptus melanoxylon	Myrtaceae		24.0	AW	ESP		MAL	3	YES		YES	YES		2
Eucalyptus merrickiae	Myrtaceae	R	4.0		ESP		MAL	2			no			
Eucalyptus mimica ssp. continens	Myrtaceae	P3	6.0				MAL	1	YES		no			
Eucalyptus mimica ssp. mimica	Myrtaceae	P2	8.0				MAL	1			no			
Eucalyptus misella	Myrtaceae	P3	3.0		ESP		MAL	2		YES	no			
Eucalyptus moderata	Myrtaceae		15.0	AW		GS	MAL	3	YES		YES	YES		3

SIFT..........Potential WA wheatbelt species

Species name	Family	Cons. code	Ht	IBRA zones					Selection					Growth rating
				AW	ESP	GS	MAL	No.	SIFT	Added	Test?	Cored		
Eucalyptus myriadena ssp. myriadena	Myrtaceae		12.0	AW	ESP	GS	MAL	4	YES		YES	YES		1
Eucalyptus myriadena ssp. parviflora	Myrtaceae	P1	10.0	AW			MAL	2			no			
Eucalyptus neutra	Myrtaceae		9.0	AW	ESP		MAL	3	YES		no			
Eucalyptus newbeyi	Myrtaceae	P3	8.0		ESP			1	YES		no			
Eucalyptus obconica	Myrtaceae		10.0		ESP			1	YES		no			
Eucalyptus obesa	Myrtaceae		6.0		ESP		MAL	2	YES		no			
Eucalyptus obtusiflora ssp. cowcowensis	Myrtaceae		5.0	AW			MAL	2	YES		no			
Eucalyptus obtusiflora ssp. dongarraensis	Myrtaceae		8.0			GS		1	YES		no			
Eucalyptus occidentalis	Myrtaceae		20.0	AW	ESP		MAL	3	YES		YES	YES		1
Eucalyptus oleosa ssp. corvina	Myrtaceae		10.0		ESP			1	YES		maybe			
Eucalyptus oleosa ssp. cylindroidea	Myrtaceae		8.0				MAL	1	YES		YES			
Eucalyptus oleosa ssp. repleta	Myrtaceae		11.0				MAL	1	YES		maybe			
Eucalyptus oleosa ssp. wylieana	Myrtaceae		10.0				MAL	1	YES		maybe			
Eucalyptus olivina	Myrtaceae		7.0	AW	ESP		MAL	3	YES		no			
Eucalyptus optima	Myrtaceae		12.0		ESP		MAL	2	YES		no			
Eucalyptus oraria	Myrtaceae		15.0			GS		1	YES		no			
Eucalyptus orbifolia	Myrtaceae		8.0	AW				1	YES		no			
Eucalyptus ornata	Myrtaceae		10.0				MAL	1	YES		YES			
Eucalyptus ovularis	Myrtaceae	P3	15.0		ESP		MAL	2	YES		no			
Eucalyptus pachyloma	Myrtaceae		4.0	AW	ESP			2	YES		no			
Eucalyptus pallida	Myrtaceae		8.0			GS		1	YES		no			
Eucalyptus pendens	Myrtaceae	P4	5.0	AW		GS		2	YES		no			
Eucalyptus perangusta	Myrtaceae		5.0	AW	ESP		MAL	3	YES		no			
Eucalyptus petila	Myrtaceae	P2	4.0		ESP			1			no			
Eucalyptus petraea	Myrtaceae		10.0	AW				1	YES		no			
Eucalyptus petrensis	Myrtaceae		4.0			GS		1	YES		no			
Eucalyptus phaenophylla ssp. interjacens	Myrtaceae		4.0	AW	ESP		MAL	3	YES		no			
Eucalyptus phaenophylla ssp. phaenophylla	Myrtaceae		6.0	AW	ESP	GS	MAL	4	YES		no			
Eucalyptus phenax ssp. phenax	Myrtaceae		7.0	AW	ESP		MAL	3	YES		no			
Eucalyptus pileata	Myrtaceae		10.0	AW	ESP		MAL	3	YES		no			
Eucalyptus platycorys	Myrtaceae		12.0	AW	ESP		MAL	3	YES		no			
Eucalyptus platypus ssp. congregata	Myrtaceae		6.0		ESP		MAL	2	YES		maybe			
Eucalyptus platypus ssp. Platypus	Myrtaceae		10.0	AW	ESP		MAL	3	YES		YES	YES		3

SIFT..........Potential WA wheatbelt species

Species name	Family	Cons. code	Ht	IBRA zones					Selection					Growth rating
				AW	ESP	GS	MAL	No.	SIFT	Added	Test?	Cored		
Eucalyptus pleurocarpa	Myrtaceae		4.0		ESP	GS	MAL	3	YES		YES	YES		3
Eucalyptus pleurocorys	Myrtaceae		5.0		ESP		MAL	2	YES		no			
Eucalyptus pluricaulis ssp. pluricaulis	Myrtaceae		5.0	AW	ESP	GS	MAL	4	YES		no			
Eucalyptus polita	Myrtaceae		10.0	AW			MAL	2	YES		no			
Eucalyptus praetermissa	Myrtaceae	P4	12.0		ESP			1	YES		no			
Eucalyptus preissiana x staeri	Myrtaceae	P4	6.0		ESP			1	YES		no			
Eucalyptus prolixa	Myrtaceae		8.0				MAL	1	YES		no			
Eucalyptus protensa	Myrtaceae		10.0	AW	ESP		MAL	3	YES		YES			
Eucalyptus pruiniramis	Myrtaceae	R	7.0	AW		GS		2			no			
Eucalyptus punicea	Myrtaceae	P1	7.0		ESP			1			no			
Eucalyptus pyriformis	Myrtaceae		5.0	AW		GS		2	YES		no			
Eucalyptus quadrans	Myrtaceae		8.0		ESP		MAL	2	YES		no			
Eucalyptus ravida	Myrtaceae		20.0	AW			MAL	2	YES		no			
Eucalyptus recta	Myrtaceae	P1	15.0	AW				1			no			
Eucalyptus redunca	Myrtaceae		4.5	AW	ESP	GS	MAL	4	YES		no			
Eucalyptus rhodantha var. rhodantha	Myrtaceae	R	4.0	AW		GS		2			no			
Eucalyptus rhomboidea	Myrtaceae	P1	10.0				MAL	1			no			
Eucalyptus rigens	Myrtaceae		4.0		ESP		MAL	2	YES		no			
Eucalyptus rigidula	Myrtaceae		5.0	AW		GS	MAL	3	YES		no			
Eucalyptus robur	Myrtaceae		8.0				MAL	1	YES		no			2
Eucalyptus roycei	Myrtaceae		6.0			GS		1	YES		no			
Eucalyptus rudis ssp. rudis	Myrtaceae		20.0	AW		GS		2	YES		YES	YES		1
Eucalyptus rugosa	Myrtaceae		9.0		ESP		MAL	2	YES		no			
Eucalyptus rugulata	Myrtaceae		15.0				MAL	1	YES		no			
Eucalyptus salicola	Myrtaceae		15.0	AW			MAL	2	YES		no			
Eucalyptus salmonophloia	Myrtaceae		30.0	AW	ESP	GS	MAL	4	YES		YES	YES		1
Eucalyptus salubris	Myrtaceae		15.0	AW	ESP	GS	MAL	4	YES		YES	YES		2
Eucalyptus sargentii ssp. fallens	Myrtaceae	P1	6.0			GS		1			no			
Eucalyptus sargentii ssp. onesia	Myrtaceae		6.5	AW				1	YES		maybe			
Eucalyptus sargentii ssp. sargentii	Myrtaceae		12.0	AW			MAL	2	YES		YES	YES		3
Eucalyptus scyphocalyx ssp. scyphocalyx	Myrtaceae		6.0		ESP		MAL	2	YES		no			
Eucalyptus scyphocalyx ssp. triadica	Myrtaceae		5.0		ESP		MAL	2	YES		no			
Eucalyptus sepulcralis	Myrtaceae		8.0		ESP			1	YES		no			

SIFT..........Potential WA wheatbelt species

Species name	Family	Cons. code	Ht	IBRA zones					Selection					Growth rating
				AW	ESP	GS	MAL	No.	SIFT	Added	Test?	Cored		
Eucalyptus sheathiana	Myrtaceae		15.0	AW	ESP		MAL	3	YES		no			
Eucalyptus singularis	Myrtaceae		6.0				MAL	1	YES		no			
Eucalyptus sp.B Ravensthorpe (Newbey)	Myrtaceae	P1	4.0		ESP			1			no			
Eucalyptus sparsicoma	Myrtaceae	P2	6.0	AW			MAL	2			no			
Eucalyptus spathulata	Myrtaceae		12.0	AW	ESP		MAL	3	YES		YES	YES		3
Eucalyptus sporadica ssp. unicaulis	Myrtaceae		7.0		ESP			1	YES		no			
Eucalyptus spreta	Myrtaceae		10.0				MAL	1	YES		no			
Eucalyptus staeri	Myrtaceae		15.0	AW	ESP			2	YES		no			
Eucalyptus steedmanii	Myrtaceae	R	8.0		ESP		MAL	2			no			
Eucalyptus stoatei	Myrtaceae	P4	7.5		ESP		MAL	2	YES		no			
Eucalyptus stowardii	Myrtaceae		7.0	AW		GS		2	YES		no			
Eucalyptus stricklandii	Myrtaceae		11.0	AW				1	YES		no			
Eucalyptus subangusta ssp. cerina	Myrtaceae		8.0	AW				1	YES		no			
Eucalyptus subangusta ssp. pusilla	Myrtaceae		9.0	AW		GS	MAL	3	YES		no			
Eucalyptus subangusta ssp. subangusta	Myrtaceae		6.0	AW		GS	MAL	3	YES		no			
Eucalyptus subangusta ssp. virescens	Myrtaceae	P1	5.0	AW		GS	MAL	3			no			
Eucalyptus suberea	Myrtaceae	R	4.0			GS		1			no			
Eucalyptus subtenuis	Myrtaceae		4.0		ESP		MAL	2	YES		no			
Eucalyptus suggrandis ssp. suggrandis	Myrtaceae		4.5	AW	ESP		MAL	3	YES		no			
Eucalyptus synandra	Myrtaceae	R	10.0	AW				1			no			
Eucalyptus systremma	Myrtaceae		9.0				MAL	1	YES		no			
Eucalyptus talyuberlup	Myrtaceae		8.0		ESP			1	YES		no			
Eucalyptus tenera	Myrtaceae		4.0	AW			MAL	2	YES		no			
Eucalyptus tenuis	Myrtaceae		12.0				MAL	1	YES		no			
Eucalyptus tephroclada	Myrtaceae		5.0	AW			MAL	2	YES		no			
Eucalyptus terebra	Myrtaceae		11.0		ESP		MAL	2	YES		no			
Eucalyptus tetragona	Myrtaceae		8.0		ESP	GS	MAL	3	YES		no			
Eucalyptus thamnoides ssp. megista	Myrtaceae		4.0	AW	ESP		MAL	3	YES		no			
Eucalyptus thamnoides ssp. thamnoides	Myrtaceae		6.0		ESP			1	YES		no			
Eucalyptus todtiana	Myrtaceae		8.0	AW		GS		2	YES		YES	YES		2
Eucalyptus torquata	Myrtaceae		11.0			GS	MAL	2	YES		no			
Eucalyptus tortilis	Myrtaceae		10.0				MAL	1	YES		no			
Eucalyptus transcontinentalis ssp. transcon	Myrtaceae		12.0				MAL	1	YES		no			

SIFT..........Potential WA wheatbelt species

Species name	Family	Cons. code	Ht	IBRA zones					Selection					Growth rating
				AW	ESP	GS	MAL	No.	SIFT	Added	Test?	Cored		
Eucalyptus trichopoda	Myrtaceae		10.0				MAL	1	YES		no			
Eucalyptus tumida	Myrtaceae		4.0		ESP		MAL	2	YES		no			
Eucalyptus uncinata	Myrtaceae		8.0	AW	ESP		MAL	3	YES		YES	YES		3
Eucalyptus unita	Myrtaceae		4.0		ESP			1	YES		no			
Eucalyptus urna	Myrtaceae		16.0	AW			MAL	2	YES		YES	YES		2
Eucalyptus utilis	Myrtaceae		15.0		ESP		MAL	2	YES		YES	YES		3
Eucalyptus valens	Myrtaceae		14.0		ESP		MAL	2	YES		YES	YES		2
Eucalyptus varia ssp. salsuginosa	Myrtaceae	P1	4.0		ESP		MAL	2			no			
Eucalyptus varia ssp. varia	Myrtaceae		7.0		ESP			1	YES		no			
Eucalyptus vegrandis ssp. fine leaf	Myrtaceae		5.0	AW			MAL	2	YES		no			
Eucalyptus vegrandis ssp. recondita	Myrtaceae		4.0		ESP			1	YES		no			
Eucalyptus vegrandis ssp. vegrandis	Myrtaceae		4.0	AW	ESP		MAL	3	YES		no	YES		3
Eucalyptus victrix	Myrtaceae		12.0			GS		1	YES		no			
Eucalyptus wandoo ssp. pulverea	Myrtaceae		15.0	AW		GS		2	YES		maybe			
Eucalyptus wandoo ssp. wandoo	Myrtaceae		25.0	AW	ESP	GS	MAL	4	YES		YES	YES		1
Eucalyptus woodwardii	Myrtaceae		15.0				MAL	1	YES		no			
Eucalyptus wubinensis	Myrtaceae		8.0	AW				1	YES		no			
Eucalyptus x carnabyi	Myrtaceae		6.0	AW		GS		2	YES		no			
Eucalyptus x chrysantha	Myrtaceae		5.0		ESP			1	YES		no			
Eucalyptus x erythrandra	Myrtaceae		5.0		ESP		MAL	2	YES		no			
Eucalyptus x kalganensis	Myrtaceae		7.0		ESP			1	YES		no			
Eucalyptus x missilis	Myrtaceae	P4	5.0		ESP			1	YES		no			
Eucalyptus x stoataptera	Myrtaceae	P2	4.0		ESP			1			no			
Eucalyptus xanthonema ssp. apposita	Myrtaceae		5.0		ESP			1	YES		no			
Eucalyptus xanthonema ssp. xanthonema	Myrtaceae		5.0	AW	ESP		MAL	3	YES		no			
Eucalyptus yalatensis	Myrtaceae		6.0				MAL	1	YES		no			
Eucalyptus yilgarnensis	Myrtaceae		6.0	AW	ESP		MAL	3	YES		no			
Eucalyptus zopherophloia	Myrtaceae	P4	4.0			GS		1	YES		no			
Eutaxia sp. Peak Eleanora	Papilionaceae	P1	5.0				MAL	1			no			
Exocarpos aphyllus	Santalaceae		5.0	AW	ESP	GS	MAL	4	YES		YES	YES		3
Exocarpos sparteus	Santalaceae		4.0	AW	ESP	GS	MAL	4	YES		YES	YES		2
Gastrolobium bilobum	Papilionaceae		4.0	AW	ESP		MAL	3	YES		no			
Grevillea annulifera	Proteaceae	P3	4.0			GS		1	YES		no			

SIFT..........Potential WA wheatbelt species

Species name	Family	Cons. code	Ht	IBRA zones					Selection					Growth rating
				AW	ESP	GS	MAL	No.	SIFT	Added	Test?	Cored		
Grevillea argyrophylla	Proteaceae		6.0	AW		GS		2	YES		no	YES		2
Grevillea cagiana	Proteaceae		4.0	AW	ESP		MAL	3	YES		YES	YES		3
Grevillea candelabroides	Proteaceae		4.0	AW		GS		2	YES		YES	YES		2
Grevillea candicans	Proteaceae	P3	5.0	AW		GS		2	YES		no			
Grevillea eriobotrya	Proteaceae	P3	4.0	AW				1	YES		no			
Grevillea eriostachya	Proteaceae		5.0	AW	ESP	GS	MAL	4	YES		no			
Grevillea excelsior	Proteaceae		8.0	AW	ESP		MAL	3	YES		YES	YES		2
Grevillea gordoniana	Proteaceae		7.0			GS		1	YES		no			
Grevillea hookeriana ssp. hookeriana	Proteaceae		4.0	AW	ESP	GS	MAL	4	YES		no			
Grevillea insignis ssp. insignis	Proteaceae		5.0	AW			MAL	2	YES		YES	YES		3
Grevillea juncifolia ssp. juncifolia	Proteaceae		5.0	AW				1	YES		no			
Grevillea juncifolia ssp. temulenta	Proteaceae		5.0	AW				1	YES		no			
Grevillea leucopteris	Proteaceae		4.0	AW		GS		2	YES		YES	YES		2
Grevillea nematophylla ssp. nematophylla	Proteaceae		6.0	AW				1	YES		no	YES		2
Grevillea nematophylla ssp. supraplana	Proteaceae		5.0	AW				1	YES		no			
Grevillea obliquistigma ssp. obliquistigma	Proteaceae		4.0	AW		GS	MAL	3	YES		YES	YES		2
Grevillea olivacea	Proteaceae	P4	4.5			GS		1	YES		no			
Grevillea plurijuga ssp. superba	Proteaceae		4.0		ESP		MAL	2	YES		no			
Grevillea polybotrya	Proteaceae		4.0	AW		GS		2	YES		no			
Grevillea pterosperma	Proteaceae		4.0	AW		GS	MAL	3	YES		YES	YES		2
Grevillea rogersoniana	Proteaceae	P2	4.0			GS		1			no			
Grevillea stenobotrya	Proteaceae		4.0			GS		1	YES		no			
Grevillea vestita ssp. vestita	Proteaceae		3.0	AW		GS		2		YES	YES	YES		2
Gyrostemon racemiger	Gyrostemon.		4.0	AW		GS	MAL	3	YES		YES	YES		2
Gyrostemon ramulosus	Gyrostemon.		5.0	AW		GS	MAL	3	YES		YES	YES		1
Hakea adnata	Proteaceae		4.0	AW	ESP		MAL	3	YES		no			
Hakea bucculenta	Proteaceae		4.5			GS		1	YES		YES	YES		3
Hakea cucullata	Proteaceae		5.0		ESP			1	YES		no			
Hakea drupacea	Proteaceae		5.0		ESP		MAL	2	YES		no			
Hakea elliptica	Proteaceae		4.0		ESP			1	YES		no			
Hakea francisiana	Proteaceae		6.0	AW		GS	MAL	3	YES		YES	YES		2
Hakea hookeriana	Proteaceae	P2	5.0		ESP			1			no			
Hakea invaginata	Proteaceae		4.0	AW		GS		2	YES		no	YES		3

SIFT..........Potential WA wheatbelt species

Species name	Family	Cons. code	Ht	IBRA zones					Selection					Growth rating
				AW	ESP	GS	MAL	No.	SIFT	Added	Test?	Cored		
Hakea kippistiana	Proteaceae		4.5	AW			MAL	2	YES		no			
Hakea lasiantha	Proteaceae		4.0		ESP			1	YES		no			
Hakea lasiocarpha	Proteaceae	P3	6.0		ESP			1	YES		no			
Hakea laurina	Proteaceae		6.0	AW	ESP		MAL	3	YES		YES	YES		2
Hakea linearis	Proteaceae		5.0		ESP			1	YES		no			
Hakea lorea ssp. lorea	Proteaceae		9.0					0		YES	YES			
Hakea minyma	Proteaceae		3.0	AW				1		YES	YES	YES		2
Hakea multilineata	Proteaceae		5.0	AW	ESP		MAL	3	YES		YES	YES		2
Hakea nitida	Proteaceae		4.0	AW	ESP		MAL	3	YES		no			
Hakea oleifolia	Proteaceae		6.0		ESP			1	YES		YES	YES		2
Hakea pandanicarpa ssp. crassifolia	Proteaceae		4.5	AW	ESP		MAL	3	YES		no			
Hakea petiolaris ssp. trichophylla	Proteaceae		2.0	AW			MAL	2		YES	YES	YES		2
Hakea platysperma	Proteaceae		4.0	AW		GS	MAL	3	YES		no			
Hakea preissii	Proteaceae		6.0	AW	ESP	GS	MAL	4	YES		YES	YES		3
Hakea prostrata	Proteaceae		5.0	AW	ESP	GS	MAL	4	YES		YES	YES		2
Hakea psilorrhyncha	Proteaceae		4.0			GS		1	YES		no			
Hakea recurva ssp. recurva	Proteaceae		6.0	AW		GS		2	YES		YES	YES		3
Hakea stenophylla ssp. Notialis	Proteaceae		4.0			GS		1	YES		no	YES		3
Hakea trifurcata	Proteaceae		4.0	AW	ESP	GS	MAL	4	YES		no			
Haloragodendron racemosum	Haloragaceae		4.0		ESP			1	YES		no			
Homalospermum firmum	Myrtaceae		4.0		ESP			1	YES		no			
Jacksonia cupulifera	Papilionaceae		4.0			GS		1	YES		no			
Jacksonia furcellata	Papilionaceae		4.0	AW	ESP		MAL	3	YES		YES	YES		2
Jacksonia intricata	Papilionaceae	P2	30.0		ESP			1			no			
Jacksonia sternbergiana	Papilionaceae		5.0	AW		GS	MAL	3	YES		YES	YES		1
Kennedia nigricans	Papilionaceae		4.0	AW	ESP			2	YES		no			
Kunzea baxteri	Myrtaceae		4.0	AW	ESP		MAL	3	YES		no			
Kunzea ericifolia ssp. ericifolia	Myrtaceae		3.0		ESP			1		YES	maybe	YES		3
Kunzea glabrescens	Myrtaceae		4.0	AW				1	YES		YES	YES		2
Lamarchea hakeifolia var. brevifolia	Myrtaceae		5.0			GS		1	YES		YES	YES		3
Lamarchea hakeifolia var. hakeifolia	Myrtaceae		5.0			GS		1	YES		no			
Lambertia ericifolia	Proteaceae		5.0		ESP		MAL	2	YES		no			
Lambertia inermis var. drummondii	Proteaceae		7.0	AW	ESP		MAL	3	YES		YES			2

SIFT.........Potential WA wheatbelt species

Species name	Family	Cons. code	Ht	IBRA zones					Selection					Growth rating
				AW	ESP	GS	MAL	No.	SIFT	Added	Test?	Cored		
Lambertia inermis var. inermis	Proteaceae		7.0		ESP		MAL	2	YES		maybe	YES		2
Lambertia uniflora	Proteaceae		4.0		ESP			1	YES		no			
Leptomeria pauciflora	Santalaceae		5.0	AW	ESP	GS	MAL	4	YES		YES	YES		3
Leptospermum nitens	Myrtaceae		3.0	AW	ESP	GS	MAL	4		YES	YES	YES		3
Marianthus candidus	Pittosporaceae		5.0	AW				1	YES		no			
Marianthus erubescens	Pittosporaceae		4.0	AW	ESP	GS		3	YES		no			
Melaleuca acuminata ssp. acuminata	Myrtaceae		3.0	AW	ESP		MAL	3		YES	YES	YES		3
Melaleuca acuminata ssp. websteri	Myrtaceae		3.0	AW				1		YES	YES			
Melaleuca adenostyla	Myrtaceae		5.0	AW			MAL	2	YES		no			
Melaleuca adnata	Myrtaceae		5.0	AW	ESP	GS	MAL	4	YES		no			
Melaleuca brevifolia	Myrtaceae		4.0	AW	ESP	GS	MAL	4	YES		maybe			
Melaleuca ctenoides	Myrtaceae		4.0	AW			MAL	2	YES		no			
Melaleuca cucullata	Myrtaceae		5.0		ESP		MAL	2	YES		no			
Melaleuca cuticularis	Myrtaceae		7.0	AW	ESP		MAL	3	YES		YES	YES		3
Melaleuca eleuterostachya	Myrtaceae		3.0	AW	ESP	GS	MAL	4		YES	YES	YES		3
Melaleuca elliptica	Myrtaceae		4.0	AW	ESP		MAL	3	YES		no			
Melaleuca fulgens ssp. fulgens	Myrtaceae		3.0	AW	ESP	GS	MAL	4		YES	YES	YES		3
Melaleuca globifera	Myrtaceae		6.0		ESP			1	YES		YES	YES		3
Melaleuca halmaturorum	Myrtaceae		3.5	AW	ESP		MAL	3	YES		YES	YES		3
Melaleuca hamata	Myrtaceae		4.0	AW				1	YES		no	YES		3
Melaleuca hamulosa	Myrtaceae		6.0	AW	ESP	GS	MAL	4	YES		YES	YES		3
Melaleuca hamulosa	Myrtaceae		6.0	AW	ESP	GS	MAL	4	YES		YES	YES		3
Melaleuca hnatiukii	Myrtaceae		3.0		ESP		MAL	2		YES	YES	YES		3
Melaleuca huegelii ssp. huegelii	Myrtaceae		5.0			GS		1	YES		YES	YES		3
Melaleuca incana ssp. incana	Myrtaceae		3.0	AW		GS		2		YES	YES	YES		3
Melaleuca incana ssp. tenella	Myrtaceae	P3	2.0		ESP		MAL	2		YES	YES			
Melaleuca lanceolata	Myrtaceae		8.0	AW	ESP	GS	MAL	4	YES		YES	YES		2
Melaleuca lasiandra	Myrtaceae		5.0	AW		GS		2	YES		no			
Melaleuca lateriflora ssp. acutifolia	Myrtaceae		8.0	AW		GS		2	YES		YES			
Melaleuca lateriflora ssp. lateriflora	Myrtaceae		5.0	AW	ESP	GS	MAL	4	YES		YES	YES		2
Melaleuca leiocarpa	Myrtaceae		5.0	AW		GS	MAL	3	YES		YES			2
Melaleuca linguiformis	Myrtaceae		2.5		ESP		MAL	2		YES	YES	YES		3
Melaleuca macronychia ssp. macronychia	Myrtaceae		5.0	AW	ESP		MAL	3	YES		no			

SIFT..........Potential WA wheatbelt species

Species name	Family	Cons. code	Ht	IBRA zones					Selection					Growth rating
				AW	ESP	GS	MAL	No.	SIFT	Added	Test?	Cored		
Melaleuca macronychia ssp. trygonoides	Myrtaceae	P3	4.0				MAL	1	YES		no			
Melaleuca micromera	Myrtaceae	P3	4.0	AW	ESP			2	YES		no			
Melaleuca microphylla	Myrtaceae		5.0		ESP			1	YES		no			
Melaleuca nematophylla	Myrtaceae		4.0	AW		GS		2	YES		no			
Melaleuca nesophila	Myrtaceae		2.5	AW	ESP	GS	MAL	4		YES	YES			2
Melaleuca pauperiflora ssp. fastigiata	Myrtaceae		6.0	AW	ESP		MAL	3	YES		YES			
Melaleuca pauperiflora ssp. pauperiflora	Myrtaceae		2.5		ESP		MAL	2		YES	maybe	YES		3
Melaleuca preissiana	Myrtaceae		9.0	AW	ESP	GS		3	YES		no	YES		2
Melaleuca quadrifaria	Myrtaceae		6.0				MAL	1	YES		maybe	YES		3
Melaleuca rhaphiophylla	Myrtaceae		10.0	AW	ESP	GS		3	YES		YES	YES		2
Melaleuca sheathiana	Myrtaceae		5.0				MAL	1	YES		no			
Melaleuca sp.Wongan Hills (R.Davis 1959)	Myrtaceae		7.0	AW			MAL	2	YES		no			
Melaleuca sparsiflora	Myrtaceae		4.0	AW	ESP		MAL	3	YES		no			
Melaleuca stereophloia	Myrtaceae		5.0	AW		GS		2	YES		YES	YES		3
Melaleuca strobophylla	Myrtaceae		12.0	AW	ESP	GS	MAL	4	YES		YES	YES		2
Melaleuca subalaris	Myrtaceae		5.0		ESP		MAL	2	YES		no			
Melaleuca subfalcata	Myrtaceae		2.0		ESP		MAL	2		YES	YES			
Melaleuca teretifolia	Myrtaceae		5.0	AW		GS		2	YES		no			
Melaleuca thyoides	Myrtaceae		5.0	AW	ESP	GS	MAL	4	YES		no			
Melaleuca uncinata form "ligno spicate"	Myrtaceae		5.0	AW	ESP	GS	MAL	4	YES		YES	YES		2
Melaleuca uncinata form "non-ligno spicate"	Myrtaceae		5.0	AW	ESP	GS	MAL	4	YES		YES	YES		3
Melaleuca uncinata form "uncinata"	Myrtaceae		5.0	AW	ESP	GS	MAL	4	YES		YES	YES		3
Melaleuca viminea ssp. appressa	Myrtaceae	P2	4.5		ESP			1			no			
Melaleuca viminea ssp. demissa	Myrtaceae		5.0		ESP		MAL	2	YES		no			
Melaleuca viminea ssp. viminea	Myrtaceae		5.0	AW	ESP	GS	MAL	4	YES		YES	YES		2
Myoporum insulare	Myoporaceae		5.0		ESP	GS		2	YES		no			
Myoporum montanum	Myoporaceae		4.0	AW		GS		2	YES		maybe			
Myoporum platycarpum ssp. platycarpum	Myoporaceae		8.0		ESP			1	YES		YES	YES		1
Nemcia luteifolia	Papilionaceae	R	5.0		ESP			1			no			
Nemcia sp.Mt Magog (S.Barrett 55)	Papilionaceae		5.0		ESP			1	YES		maybe			
Nuytsia floribunda	Loranthaceae		8.0	AW	ESP	GS	MAL	4	YES		YES	YES		3
Oxylobium lineare	Papilionaceae		4.0			GS		1	YES		YES	YES		2
Paraserianthes lophantha ssp. lophantha	Mimosaceae		10.0		ESP	GS		2	YES		YES	YES		2

SIFT..........Potential WA wheatbelt species

Species name	Family	Cons. code	Ht	IBRA zones					Selection					Growth rating
				AW	ESP	GS	MAL	No.	SIFT	Added	Test?	Cored		
Persoonia elliptica	Proteaceae		8.0	AW				1	YES		YES	YES		2
Persoonia longifolia	Proteaceae		5.0		ESP			1	YES		no			
Persoonia saundersiana	Proteaceae		5.0	AW		GS	MAL	3	YES		YES	YES		3
Persoonia stricta	Proteaceae		5.0	AW		GS		2	YES		YES	YES		3
Petalostylis labicheoides	Caesalpiniaceae		4.0			GS		1	YES		no			
Physopsis chrysophylla	Chloanthaceae	P3	5.0			GS		1	YES		no			
Pimelea argentea	Thymelaeaceae		2.0	AW	ESP	GS	MAL	4		YES	YES			
Pimelea clavata	Thymelaeaceae		4.0		ESP			1	YES		YES	YES		3
Pittosporum angustifolium	Pittosporaceae		8.0	AW	ESP	GS	MAL	4	YES		YES	YES		2
Pittosporum phylliraeoides	Pittosporaceae		8.0	AW		GS	MAL	3	YES		YES	YES		2
Regelia megacephala	Myrtaceae	P4	5.0	AW				1	YES		maybe			
Regelia velutina	Myrtaceae		6.0	AW	ESP			2	YES		maybe			
Santalum acuminatum	Santalaceae		7.0	AW	ESP	GS	MAL	4	YES		YES	YES		3
Santalum lanceolatum	Santalaceae		7.0	AW	ESP			2	YES		no			
Santalum murrayanum	Santalaceae		5.0	AW	ESP		MAL	3	YES		YES	YES		3
Santalum spicatum	Santalaceae		5.0	AW	ESP	GS	MAL	4	YES		no			
Senna glutinosa ssp. chatelainiana	Caesalpiniaceae		3.0	AW	ESP	GS	MAL	4		YES	YES	YES		3
Senna pleurocarpa	Caesalpiniaceae		1.5	AW		GS	MAL	3		YES	YES	YES		1
Senna sp. Austin	Caesalpiniaceae		3.0	AW		GS		2		YES	YES	YES		2
Sollya drummondii	Pittosporaceae	P4	4.0		ESP			1	YES		no			
Spyridium globulosum	Rhamnaceae		5.0		ESP	GS	MAL	3	YES		YES	YES		2
Taxandria juniperina	Myrtaceae		12.0		ESP			1	YES		YES	YES		2
Taxandria linearifolia	Myrtaceae		4.0	AW	ESP			2	YES		no			
Taxandria marginata	Myrtaceae		4.0		ESP			1	YES		no			
Taxandria parviceps	Myrtaceae		3.0		ESP			1	YES		no			
Templetonia retusa	Papilionaceae		4.0	AW	ESP	GS	MAL	4	YES		maybe	YES		3
Trymalium floribundum ssp. floribundum	Rhamnaceae		5.0	AW		GS		2	YES		YES	YES		2
Trymalium floribundum ssp. trifidum	Rhamnaceae		9.0		ESP			1	YES		maybe			
Viminaria juncea	Papilionaceae		4.0	AW	ESP	GS	MAL	4	YES		YES	YES		1
Xylomelum angustifolium	Proteaceae		7.0	AW		GS	MAL	3	YES		YES	YES		3

YES	582	48	245	230	1	36
maybe			31		2	95

SIFT..........Potential WA wheatbelt species

Species name	Family	Cons. code	Ht	IBRA zones					Selection					Growth
				AW	ESP	GS	MAL	No.	SIFT	Added	Test?	Cored		rating
													3	108
						Total			582	48	276	230		239

Search Report

Appendix 16

Draft species list
for Forest Products Commission

Taxon	Height (m)	Basic density			Growth potential	FPC website	Search trials	Comments
		Mean	Range	Samples				
Acacia acuminata subsp. acuminata	7 (12)	1077	1077 - 1077	1	Medium	FPC	Trial	Slow, good form, long term 30-40yrs, fence posts, wide distribution, sandalwood host
Acacia aff. redolens	3	782	732 - 835	6	Medium		Trial	Tall tree or shrub with good form - unlike other A. redolens. Probably a separate species, possible priority taxa. Found east of Esperance.
Acacia aneura	10	952	952 - 952	1	Low	FPC		Arid zone, genetically complex
Acacia grasbyi	4.5 (6)				Low	FPC		Arid zone bordering on the wheatbelt. Slow growing, hard wood.
Acacia lasiocalyx	7 (12)	732	593 - 912	27	High		Trial	Tall, good form around granite rocks
Acacia bartleana Maslin (ms)		815	718 - 959	10	High		Trial	Largest "subspecies", reasonable form, fast growing
Acacia papyrocarpa	8 (10)				Low	FPC		Arid zone species
Acacia pruinocarpa	12	614	614 - 614	1	Medium	FPC		Slow growing, arid zone species
Agonis juniperina	12 (27)	569	456 - 691	19	Medium			Tall, fast growing, found from Busselton to Albany, suits moist sites only
Allocasuarina huegeliana	10	748	725 - 778	4	High	FPC	Trial	Grows on poor country, some examples of adaptability across sites
Brachychiton gregorii	12	461	377 - 506	11	Low		Trial	Arid margins of the wheatbelt. Large tree, probably slow growing
Callitris glaucophylla	12	786	738 - 839	9	Medium	FPC		Eastern edge of wheatbelt, slow growing, good form
Casuarina obesa	10	711	597 - 859	30	High		Trial	Shark Bay to Albany, susceptible to insects and grazing
Casuarina pauper	15				Low	FPC	Trial	Large tree on arid fringe of wheatbelt
Corymbia calophylla	40 (60)	725	676 - 760	3	High			Western fringes of wheatbelt only, large tree, needs selection for form, susceptible to borers when stressed
Eremophila oldfieldii subsp. oldfieldii	5	919	845 - 955	6	Medium	FPC		Goomalling to Shark Bay, poor germination, small, slow grower, interesting chemistry (resins)
Eucalyptus accedens	15 (25)	889	831 - 921	3	Medium			Fast growing timber species for wetter fringes of wheatbelt
Eucalyptus argyphea	15	906	887 - 932	3	High			Mallet, currently cut at Dryandra
Eucalyptus astringens subsp. astringens	9	801	776 - 826	3	High	FPC	Trial	Mallet, high tannin content, used commercially for timber
Eucalyptus astringens subsp. redacta	15	902	872 - 942	3	Low			Restricted to southern areas
Eucalyptus brockwayi	20			0	Medium	FPC	Trial	Limited distribution, good form, edge of wheatbelt/pastoral country
Eucalyptus camaldulensis var. obtusa	20	636	540 - 746	17	High		Trial	Long term potential in northern areas, but northern wheatbelt provenance has poor form

Taxon	Height (m)	Basic density			Growth potential	FPC website	Search trials	Comments
		Mean	Range	Samples				
Eucalyptus capillosa subsp. capillosa	15 (20)	984	944 - 1019	3	Medium		Trial	
Eucalyptus clelandii	15				Low	FPC		
Eucalyptus cornuta	25	802	753 - 828	3	Medium			Waterlogging tolerant, reasonable growth rate, reasonable form
Eucalyptus dundasii	21	979	959 - 992	3	Medium	FPC		Good timber species, good form, but poor performance in wheatbelt trials
Eucalyptus flocktoniae subsp. flocktoniae	8 (15)				Low	FPC		A mallee - related to E. urna (mallet form)
Eucalyptus gomphocephala	40	756	741 - 768	3	High			Coastal plain specieswith potential for north western and south eastern fringes of wheatbelt
Eucalyptus kondininensis	20	879	855 - 924	3	High		Trial	Mallet, good growth rates, grows on difficult sites
Eucalyptus lesouefii	18 (21)	959	938 - 977	3	Low	FPC		Mainly found east of wheatbelt in arid zone.
Eucalyptus longicornis	24 (30)	858	827 - 905	3	High	FPC	Trial	
Eucalyptus loxophleba subsp. loxophleba	15	771	706 - 825	3	Medium	FPC		Often has poor form
Eucalyptus loxophleba subsp. supralaevis	15	821	781 - 849	3	Medium			Found mainly in northern wheatbelt, not genetically different from subsp. loxophleba
Eucalyptus melanoxylon	24	998	963 - 1018	3	Medium	FPC		Eastern and SE wheatbelt
Eucalyptus occidentalis	20	802	672 - 894	6	High		Trial	Southern areas, suits wetter sites, insect and parrot prone
Eucalyptus ornata	10				Low		Trial	Mallet, limited distribution
Eucalyptus rudis subsp. rudis	20	553	483 - 674	19	High	FPC		Widespread, fast grower, insect prone, easy to establish, hybridises readily
Eucalyptus salicola	15 (25)				Low	FPC		
Eucalyptus salmonophloia	30	946	919 - 961	3	High	FPC	Trial	Slow grower?
Eucalyptus salubris	15 (24)	959	949 - 966	3	Medium	FPC	Trial	Mallet
Eucalyptus todtiana	8 (15)	644	547 - 745	19	Medium			Suit poor sands? Poor form (need selected provenances), good fence posts
Eucalyptus transcontinentalis	15				Low	FPC		
Eucalyptus urna	16	923	911 - 933	3	Medium		Trial	Good form. Mallet form of E. flocktoniae
Eucalyptus wandoo subsp. wandoo	25	911	835 - 950	3	High	FPC		Widespread, good timber, slow growing, large variability between provenances

Taxon	Height (m)	Basic density			Growth potential	FPC website	Search trials	Comments
		Mean	Range	Samples				
Grevillea excelsior	8	747	695 - 817	19	Medium			Non-ligno-tuberous, good form, quick grower, widespread
Grevillea striata	12 (15)				Low	FPC		
Hakea laurina	6	877	845 - 899	3	Medium		Trial	Non-lignotuberous, specialty timber? Widespread on S coast
Melaleuca lanceolata	8	894	833 - 936	6	Medium		Trial	
Melaleuca preissiana	9	574	455 - 713	19	Medium			
Melaleuca rhaphiophylla	10	581	508 - 690	19	Medium			Moist sites only. Wider distribution than M. preissiana
Myoporum platycarpum subsp. platycarpum	8	952	877 - 1038	4	High			Kalgoorlie to Eyre. One specimen at Esperance. Good growth rate, size and form. M. insulare may be good also, though restricted to coast
Pittosporum angustifolium	8	871	842 - 920	6	Medium			Inland species (was previously P. phyll. var. microcarpa). Good form, suckers, questionable growth rate, easy to grow from seed
Pittosporum phylliraeoides	8	836	744 - 871	4	Medium	FPC		Mainly coastal (esp. Geraldton to Carnarvon). Specialty timber (var. microcarpa), good form, suckers, questionable growth rate, easy to grow from seed
Santalum lanceolatum	7				Low	FPC		Mainly northern and arid zones. A few specimens in the wheatbelt. Hemiparasite.
Santalum spicatum	5				Low	FPC		Wide distribution, hemiparasite, slow growing, well studied already.

Notes:

Height - from FloraBase (www.calm.wa.gov.au/science/florabase)
Basic density - from Search project wood coring.
Growth potential - consensus assessment of botanical and revegetation experts.
FPC website - species for which timber characteristics are listed on the FPC website (www.fpc.wa.gov.au).
Search trials - species that have been planted in Search project trials.
Comments - additional information form botanical and revegetation experts.

Search Report

Appendix 17

Summary of CALM Timber Technology Centre reports on low-rainfall species

Gary Brennan

Summary of utilisation trials conducted by CALM Timber Technology using trees from low rainfall zones of W.A.

Report 1

Wood properties of southern gidgee (Acacia pruinocarpa) from different sites in the Pilbara and Goldfields regions of Western Australia. By P. Hill and G.K. Brennan. CALM Science 3(3) 317-322 (2000).

Aspects studied

Initial moisture contents, fibre saturation points, density (green, air-dry and basic density) and shrinkage (tangential, radial and longitudinal).

Sample size and distribution

Samples were taken from the Pilbara (Savoury Creek, Hamersley and Fortescue Valley), north eastern Goldfields (Lake Carnegie and Yakabindie Station) and north western Goldfields (Mt Magnet – east and Mt Magnet - north-east) regions. One tree was sampled from each location, except Lake Carnegie where three trees were sampled.

Results

Low initial moisture contents (24 to 35 percent) observed for southern gidgee from the areas studied is a product of the dry environment in which the species grows, and the high density of its wood. The mean basic density, air-dry density and green density for all sites were 926 $kg.m^{-3}$, 1083 $kg.m^{-3}$and 1203 $kg.m^{-3}$ respectively.

The estimated fibre saturation point was 21.2 per cent, lower than that of most other species. The mean tangential, radial and longitudinal shrinkages from green to 12 per cent moisture content for this study were 2.5 per cent, 1.68 per cent and 0.12 per cent respectively.

Southern gidgee has an attractive dark ebony colour and very dense wood, giving the species the potential for value-adding into furniture, craftwood and musical instruments.

Report 2

G.R. Siemon and I.G. Kealley (1999). *Goldfields Timber Research Report*. Report by the Research Project Steering Committee. Department of Commence and Trade, Goldfields Esperance Development Commission, Department of Conservation and Land Management, Goldfields Specialty Timber Industry Group Inc. and Curtin University, Kalgoorlie Campus.

The Project has concentrated primarily on the most common Goldfields eucalypt species, that in addition to being available in quantity, were considered to have most economic potential for sawlogs and specialty timber uses. They included:

redwood	(*Eucalyptus transcontinentalis*)
Goldfields blackbutt	(*E. lesouefii*)
gimlet	(*E. salubris*)
salmon gum	(*E. salmonophloia*)
black morrel	(*E. melanoxylon*)
red morrel	(*E. longicornis*)
giant mallee	(*E. oleosa*)

Other smaller and less available species with commercial potential were partially assessed included:

mulga	(*Acacia aneura*)
gidgee	(*A. pruinocarpa*)
Western Myall	*(A. papyrocarpa)*
miniritchie	(*A. grasbyi*)
black oak	(*Casuarina pauper*)
Cleland's blackbutt	(*Eucalyptus clelandii*)
merrit	(*E. flocktoniae*)
salt gum	(*E. salicola*)
pixie bush	(*Eremophila oldfieldii*)
turpentine bush	(*E. fraseri*)
beefwood	(*Grevillea striata*)
corkwood	(*Hakea suberea*)
native willow	(*Pittosporum phylliraeoides*)
sandalwood	(*Santalum spicatum*)

Logs from the latter group tend to be considerably smaller than those from the major species, but the timber is considered by craftsmen to have considerable potential for a range of specialty uses, including inlays, craft items, woodturning and musical instruments. In addition a large number of test sample boards prepared by Goldfields Specialty Timber Industry Group Inc. (GSTIG) and from the timber library held by CALM/GSTIG was available to provide information on air-dry density and working properties of a larger number of Goldfields timbers.

Aspects studied

Harvesting methods, sawmilling, timber drying (commercial kiln and research kiln drying trials), wood properties, general utilisation and processing and marketing development.

Wood properties research included:
- estimating moisture content - initial moisture content, fibre saturation point, variations for Goldfields species and equilibrium moisture content.
- estimating density - green density, basic density, air-dry density.
- estimating tangential and radial shrinkage during seasoning.
- taking microphotographs of transverse sections.
- Describing a range of species, including colour, grain, figure etc.
- strength properties – hardness, bending strength (modulus of rupture), stiffness (modulus of elasticity) and compression strength (maximum crushing strength).

General utilisation and processing research included:

The research and development project arranged and undertook extensive opportunistic trials on processing and various uses of the craftwoods, green sawn and seasoned timber. Objectives included assessment of the following:
- Machining and working characteristics
- Gluing properties (e.g. methods and recommendations)
- Craft, furniture and specialty purpose uses. These included manufacture of small furniture items for demonstration purposes, woodturning, carving, inlays and veneers and use in musical instruments.
- Use of residues (e.g. activated carbon).

In addition, anecdotal evidence from craftsmen and local businesses was seen as providing important information. These assessments were predominantly done in Kalgoorlie by private enterprise, GSTIG members and some specialist furniture and craft manufacturers.

Assessments of workability or working properties (e.g. turning, dressing, drilling etc.), were assessed using a semi-quantitative rating scales, from 1 – very poor to 5 – excellent.

Results

The Goldfields species studied have potential uses in furniture, flooring, musical instruments (both woodwind and stringed), general craftwood, carving, inlays and veneers and wood turning.

For further results see the report by Siemon and Kealley (1999).

Report 3

Potential of Western Australian eastern Goldfields timbers for high quality wood products. Brennan G.K. and Newby, P. (1992). Australian Forestry Vol 55 pp 74-79.

Aspects studied

This study assessed sawing, drying, processing and wood properties (heartwood and sapwood initial moisture contents and green basic and air-dry density). The species studied were Dundas blackbutt (*E. dundasii*), York gum (*E. loxophleba* spp *loxophleba*), gimlet (*E. salubris*), redwood (*E. transcontinentalis*), mulga (*Acacia aneura*) and northern cypress pine (*Callitris columellaris*).

Sample size and distribution

The logs selected for this trial were harvested from near Kalgoorlie Western Australia. Sample size for this trial consisted of between 6 and 10 logs for each species assessed. Sawmilling trials produced a representative sample for drying and processing trials, which include gluing trials.

Results

Mean sawn recoveries ranged from 21.5 per cent to 33.6 per cent and initial moisture contents ranged from 27 per cent to 42 per cent. The low initial moisture contents were low compared to jarrah and karri, which have moisture contents greater than 70 per cent. The eucalypts and mulga had high densities, with mean basic density ranging from 850 kg/m^3 to 960 kg/m^3, whereas the northern cypress pine had lower densities with a mean basic density of 655 kg/m^3. The high density of these Goldfields species results from thick cell walls and small cavities, hence less space available for free water. The climate of the Goldfields Region is classed as semi-desert with annual rainfalls between 150 mm and 300 mm. Temperatures range from -3^o C minimum to 45^o C maximum. These extreme environmental conditions and the cell structure of these timbers could contribute to low initial moisture contents.

The high density of the eucalypts and mulga made it difficult to saw and dress the timber at conventional feed speed, which are used to process jarrah. A slower cutting speed was used to mill these logs to enable a straight cut to be maintained and to avoid overheating the saw blade. To dress and sand these timbers to a smooth even finish required a slow feed and high cutter head speed. Northern cypress pine had excellent sawing and planing properties and conventional feed and cutter head speeds could be used.

The higher density species were difficult to edge-glue by hot press in ‘Orma’ commercial press operating at 95^o C and 290 kPa pressure for 10 minutes. It is recommended to use a cold pressing cycle of hand clamping boards at room temperature and a curing time of 12 hours. This method allowed the glue to penetrate into the pores of these higher density timbers and produce strong glue joints. Northern cypress pine was successfully glued using hot pressing.

There is considerable potential for small craftwood industries to utilise these and other speciality timbers from the Goldfields and Wheatbelt Regions. The scale of a speciality timber industry would result in minimal effect on the conservation values of the unique nature of the arid and semi-arid eucalypt and acacia woodland of the Goldfields Region. This industry would also provide niche markets for farmers in the Wheatbelt planting these species on cleared farm land.

Report 4

Siemon, G.R. and Pitcher, J.A. (1996). *Timber properties and market potential of selected Wheatbelt species. 1. Rock sheoak and swamp sheoak.* Department of Conservation and Land Management, Timber Technology unpublished report.

Aspects studied

Sawmilling, drying, wood properties (shrinkage and density), wood quality and processing properties (including gluing trials).

Sample size and distribution

Five rock sheoak logs from Coleman's property, 13 km west of Katanning and ten swamp sheoak logs from Smith's Property, 25 km north east of Katanning were assessed. The age of the rock sheoak trees ranged from 40 years to 90 years. A number of these logs contained extensive rot. The swamp sheoak logs were from trees growing in a 8 ha 20-year-old plantation.

Results

The mean green sawn recovery of the rock sheoak was 16.6 per cent, which is lower than expected, owing to extensive rot. If there was no rot in the logs there is a potential to achieve a recovery of 29 per cent. Swamp sheoak logs produced a green sawn recovery of 33 per cent. Dry dressed recoveries are also given.

The timber was dried in a CALM solar-assisted kiln, using a standard jarrah schedule. The sheoak timbers dried at a similar rate as jarrah. Rock sheoak had a mean basic density of 720 kg/m^3 and swamp sheoak 650 kg/m^3. Green and air-dry densities are also given.

Mean tangential and radial shrinkages for rock sheoak were 6.4 per cent and 3.3 per cent, and swamp sheoak 9.2 per cent and 3.2 per cent. The normal ratio of tangential to radial shrinkage is 2 : 1. Shrinkages for rock sheoak had this ratio, but for swamp sheoak the ratio is 3 : 1. Both species have greater shrinkage than W.A. sheoak (*Allocasuarina fraseriana*).

On a qualitative rating scale of 1 – very poor to 5 – excellent, the working properties of sawing, sanding and planing were rate 4 for both species.

Boards were edge-glued using urea formaldehyde adhesive ('Grasp') in a commercial 'Orma' glue press. The results indicated that the rock sheoak panels had better quality gluelines than the swamp sheoak panels. With the swamp sheoak sample ten gluelines out of twenty five assessed had complete glueline failure, and these results are not acceptable under the requirement of AS 1328-1987 for dry cleavage tests. Further gluing trials are required for swamp sheoak.

The rock sheoak is a deep red colour, with very pronounced rays, and has undoubted aesthetic appeal. The swamp sheoak is more straw coloured to creamy-brown and comparatively nondescript. However, the features provided by the extensive occurrence of knots resulted in a more marketable product.

Grading the dried boards to the W.A Industry standard for appearance timbers, resulted in very low recoveries, with rock sheoak having a recovery of 2.5 per cent and swamp sheoak 2.9 per cent. While rot was the major defect in rock sheoak and knots in swamp sheoak, both occurring in over 90 per cent of the boards, the high occurrence of wane indicated the problems of milling small logs with poor stem form.

The features and characteristics of the sheoak species are sufficiently different to those of the commercial eucalypts, particularly jarrah and karri, to justify a separate specification.

Report 5

Brennan, G.K., Siemon, G.R. and Pitcher, J.A. (1997). *Timber properties and market potential of selected Wheatbelt species. 2. Raspberry jam, brown mallet and York gum.* Department of Conservation and Land Management, Timber Technology unpublished report.

Aspects studied

Sawmilling, wood properties (shrinkage and density), wood quality and processing properties (including gluing trials).

Sample size and distribution

The table below gives the source and age of logs used in this trial. Timber milled from these logs gave an good sample for drying, processing and gluing trials.

Log source, age and number of logs harvested for raspberry jam, brown mallet and York gum

Species	Log source	Age (years)	No of logs harvested
Raspberry jam	P.P.	30 - 40	4
	S.F.	Unknown	5
Brown mallet	P.P.	25 - 30	4
	S.F.	62	4
York gum	P.P.	40	8
	S.F.	60 - 70	1

Note : - P.P. - private property.
- S.F. - State Forest.
- The brown mallet logs from State Forest were plantation grown.

Results

Green sawn recoveries indicated that logs with mean small end diameters under bark between 22 cm and 24 cm can give the following recoveries : raspberry jam - 23.0 per cent, brown mallet 34.4 per cent and York gum 30.9 per cent. The irregular shape of the logs would have caused lower recoveries from the raspberry jam logs. Mean basic densities recorded were 940 kg/m^3 for raspberry jam, 865 kg/m^3 for brown mallet and 885 kg/m^3 for York gum. Air-dry and green densities are also given.

Tangential and radial shrinkages are also given. Appearance grade recoveries based on log volume indicated that 7.5 per cent of raspberry jam, 20.5 per cent of brown mallet and 13.4 per cent of York gum made Prime Grade. Raspberry jam had a high proportion of boards with knots and knots associated with rot, which reduced recovery into Prime Grade.

Six different gluing schedules were tested to develop successful methods for gluing all species. It is recommended to use cold pressing and hand clamping to successfully glue these high density timbers and using a winter grade resorcinol formaldehyde (Resobond RA 3 –W manufactured by Bunning's Timbachem) when gluing under cooler winter ambient condition. Standard Resobond RA 3 could be used when curing under summer ambient conditions. More detail on the different gluing schedules is given in Brennan *et al*. (1997).

Wood working properties of sawing, planing, sanding, routing and finishing were assessed. On a scale of 1 – very poor to 5 – excellent, the three species were rated as either 4 or 5 for the different wood working properties. In this sample, dressing and routing was excellent due to the fine grain, however timber with interlocking grain can be difficult to dress to a smooth surface. Routers and lathes overcome most of these difficulties. Nailing dry boards resulted in nails bending when about a quarter of the nail was hammered into the sample or the timber split. It is recommended that for dried boards, all three timbers be pre-drilled before nailing.

Wood quality

The smoothness of the wood surface and straight or interlocked grain makes raspberry jam, brown mallet and York gum excellent timbers for furniture, turning and carving. Attractive colours are common, with raspberry jam a reddish brown to dark brown or honey brown with green streaks in the timber, brown mallet a pale red-brown to grey-brown with dark streaks and York gum a yellowish brown to dark brown.

Report 6

Brennan, G.K., Hill, P. and Siemon, G.R (1999). *Processing and drying 25 mm thick redwood (E. transcontinentalis Maiden), red morrel (E. longicornis F.Muell. ex Maiden), black morel (E. melanoxylon Maiden) and Goldfields blackbutt (E. lesouefii Maiden) boards using a low temperature batch kiln*. In : G.R. Siemon and I.G. Kealley *Goldfields Timber Research Report*. Report by the Research Project Steering Committee. Department of Commence and Trade, Goldfields Esperance Development Commission, Department of Conservation and Land Management, Goldfields Specialty Timber Industry Group Inc. and Curtin University, Kalgoorlie Campus.

Aspects studied:

Sawn recoveries, wood properties (densities and shrinkage), drying properties and wood quality.

Sample size and distribution

A sample of fourteen logs was harvested from a 86-year-old regrowth redwood (*E. transcontinentalis*) trees growing on Woolibah Station (40 km south of Kalgoorlie). Fourteen red morrel (*E. longicornis*) logs and one black morel (*E. melanoxylon*) log were harvested from 76-year-old regrowth trees growing on Jaurdi Station (120 km west of Kalgoorlie. Fifteen Goldfields blackbutt (*E. lesouefii*) logs were harvested from 71-year-old regrowth trees from Woolibah Station.

These logs produced a sufficient sample of boards to conduct three drying trials in a 1 m^3 batch kiln at CALM Timber Technology. The first charge was 100 x 25 mm redwood boards, the second red and black morrel boards and the third Goldfields blackbutt boards.

Results

Logs had mean sedub ranging from 24.7 cm to 28.7 cm and the following green sawn recoveries were achieved redwood – 35.9 per cent, red morrel – 38.1 per cent, black morrel – 33.9 per cent and Goldfields blackbutt – 25.2 per cent. Dry dressed recoveries are also given in the report.

Mean basic densities assessed for redwood, red and black morrel were; 870 kg/m^3, 865 kg/m^3 and 900 kg/m^3. Air-dry density figures are also given. Density of the Goldfields blackbutt boards was not measured.

Width and thickness shrinkages were assessed for all species. For width mean shrinkage ranged from 5.9 per cent (Goldfield blackbutt) to 7.5 per cent (redwood) and thickness, mean shrinkage ranged from 4.7 per cent (Goldfield blackbutt) to 7.0 per cent (red morrel).

Drying trials showed that the two charges of redwood, and red and black morrel could be dried from an initial moisture content of 36 per cent to a final moisture content of 10 per cent in 122 days (redwood) and 103 day (red and black morrel). The Goldfields blackbutt boards were dried at a faster rate (0.43 per cent/day) from 30.4 per cent to 9.4 per cent moisture content in 50 days. The results of the Goldfield blackbutt trial indicate that the other species could be dried at a faster rate than achieved in these trials.

Appearance grading using the FIFWA Industry Standard indicated that a high proportion of Prime Grade and Standard Grade can be achieved from the species studied.

Report 7

Fence post durability trials – field assessments conducted in 1994/95. Progress Report for SPP No 95/004. G.K. Brennan, J.A. Pitcher, S.C. Bates and E.L. Smith. (1995). Department of Conservation and Land Management, Timber Technology unpublished report.

Aspects studied

This study assessed the in-ground performance of eucalypt, pine and sheoak fence posts, treated with different wood preservatives and installed at different geographical regions. This trial included rock and swamp sheoak posts harvested from the Narrogin area of the W.A. Wheatbelt, which have been in-service at Popanyinning for 8 years.

Sample size and distribution

Twenty-one rock sheoak and eleven swamp sheoak posts, treated with high temperature creosote have been install in a fence line at Lazeaway Caravan Park, Popanyinning.

Results

The amount of end splitting and barrel (longitudinal) checking was assessed. Rock sheoak posts had significantly more end splitting and barrel checking than swamp sheoak. After eight years in-ground contact, posts from both species are perform well, with no signs of decay or insect attack in both the above and below ground sections.

Report 8

Wood density assessments by CALM (1985 to 1995). G.K. Brennan (1996). Department of Conservation and Land Management, Timber Technology unpublished report.

Aspects studied

The densities of many different timbers have been assessed in trials conducted at CALM Timber Technology from 1985 to 1995. This report summaries the densities (green, basic and air-dry) of different timber species, including species from the low rainfall areas of the W.A. Wheatbelt and Goldfields.

Wheatbelt and Goldfields timbers assessed for density from 1985 to 1995 were:

Acacia

Acacia acuminata and A. aneura

Sheoak

Allocasuarina huegeliana and Casuarina obesa

Cypress pine

Callitris columellaris and C. glaucophylla

Eucalypts

Eucalyptus astringens, E. dundasii, E. loxophleba, E. salubris, E. transcontinentalis and E. wandoo.

Gary Brennan Farm Forestry Unit

4th June 2002

Search Report

Appendix 18

Voucher specimen form for WA Herbarium

Gary Brennan

Herbarium collection data form

Det.name: ....

Field ident: .... Family: ....

Habit
Form: Climber, Prostrate, Shrub, Mallee, Marlock, Mallet, Small tree, Tree, Other: ....
....

Height (m): .... Crown width (m): ....
Average stand height (m): ....
Average stand health: ....

Other observations: ....
....

Inflorescence	Foliage	Bark
Buds:	Glossy:	Rough: ....
Flower:	Matt:	Smooth: ....
Fruit:	Discolorous:	Stocking: ....
Sterile:	Juvenile:	Peeling: ....
	Colour	Colour: ....

Other observations: ....
....

Population description
Occurrence: Occasional, Frequent, Abundant, Dominant, Other; ....
Muirs classification: ....
Associated Vegetation: ....

Site details
Topography: ....
....
Underlying material:
Granite, Laterite, Limestone, Sandstone, other; ....
Soil type: Sand, Loam, Clay, Silt, Gravel, other; ....
Soil colour: White, Yellow, Grey, Red, Brown, Black, other: ....

Location details
Latitude ....S Longitude ....E Altitude ....(m)
Map: 1:100,000 / 250,000; other .... Map Sheet: ....
State: Western Australia. Shire ....
Locality ....
....
....

Records
Photo: ....
Voucher for: NSW, MEL, CANB, PERTH, other; ....

N°: DJC .... Date: / / .

Collector: Don Cooper. C/O CALM: FFU, COMO

Search Report

Appendix 19

REX’96 characters

From: Graeme Olsen 01 December 2000

Characters used in REX'96

REX'96 data fields

Level 1	Level 2	Level 3	No.	Level 4	Field Name	Code
Taxon	Identification		1	Reference number	RexRef	num
			2	Plant ID	Taxon ID Number	num
			3	Family	Family	txt
			4	Genus	Genus	txt
			5	Species	Species	txt
			6	Sub Species	sub species	txt
			7	Variety	variety	txt
			8	Sub Variety	sub variety	txt
			9	Forma	forma	txt
			10	Sub Forma	sub forma	txt
			11	Cultivar	cultivar	txt
			12	Hybrid	hybrid	txt
			13	Synonyms	Synonyms	txt
			14	Common Names	Common names	txt
Plant	Appearance		15	Plant Type	Plant Type	pf
			16	Appearance/Habit	Appearance	ap
		Longevity	17	Longevity Plant	Plant Longevity	hf
		Growth Form	18	Growth Form	Growth Form	hb
			19	Mature Height upper	MaxHeightUpper	num
			20	Mature Height lower	MaxHeightLower	num
			21	Mature Width upper	MaxWidthUpper	num
			22	Mature Width Lower	MaxWidthLower	num
		Bark	23	Bark appearance	Bark Colour	bc
			24	Bark texture	Bark Texture	bt
		Foliage	25	Foliage appearance	Fol Appearance	fa
			26	Foliage Longevity	Fol Longevity	fl
			27	Foliage colour	Fol Colour	fc
			28	Foliage odour	Fol Odor	fo
		Flowers	29	Flower Colour	Flower Colour	wc
			30	Flower Odour	Flower Odor	wo
			31	Flowering Period	Flower Period	wp
		Ornamental characteristics	32	Ornamental Characteristics	Ornamental Char	oc
	Distribution	Natural Occurrence	33	Natural Occurrence	Natural Occurrence	st
			34	Botanical Regions	Botanical Regions	num
	Survival		35	Nitrogen Fixing	Nitrogen Fixing	nf
			36	Propagation	Propagation	pr
			37	Nutrition/relationship	Nutrition Relationship	ls
			38	Growth Rate	Growth Rate	gr
	Tolerances		39	Salt Tolerance	Salt Tolerance	pt
			40	Other tolerances	Other Tolerance	ot
			41	pH (acidity)	Soil Acidity	ph
			42	Pest and disease tolerance	Pests and Diseases Tolerance	dt
			43	Pest and disease susceptibilty	Pests and Diseases Susceptibility	ds
			44	Frost resistance	Frost Resistance	fr
			45	Cutting back	CuttingBack	cb
	Problems		46	Problems	Problems	q2

Level 1	Level 2	Level 3		Level 4	Field Name	Code
Site	Climate		47	Climate Type	Climate Type	ct
			48	Mean annual minimum	RainfallMin	num
			49	Mean annual maximum	RainfallMax	num
			50	Rainfall Distribution	Rainfall Distrib	rd
			51	Elevation	Alpine	el
	Soil		52	Soil type	Soil Type	sl
			53	Soil depth	Soil Depth	sd
	Landform		54	Landform	Landform	lf
			55	Aspect	Aspect	fs
Uses	Nature Conservation		56	Wildlife food sources	Wildlife Food Sources	ba
			57	Nature Habitat	Nature Habitat	q1
			58	Nature - General	Nature General	ng
	Land and water conservation		59	Effluent and nutrient stripping uses	Effluent Uses	ef
			60	Stabilising soils	Stabilising Soils	ss
			61	Windbreak role	Wind Breaks	wb
	Gardening		62	Gardening - General	Gardening General	p8
			63	Landscaping	Landscaping	q0
		Extracts	64	Toxins and pesticides	Toxins and Pesticides	p7
	Extracts		65	Extracts	Extracts	p5
			66	Medicinal and veterinary	Medicinal and Veterinary	p2
	Products		67	Wood uses	Wood	p1
		Extracts	68	Fibre and reconstituted products	Fibre	q6
			69	Energy - Industrial and commercial	Energy	q5
			70	Food items	Food Items	q8
			71	Fodder values	Fodder	p3
			72	Decorative	Decorative	p6
			73	Domestic	Domestic	q7
			74	Other General	Uses other	p4
			75	Aboriginal Values	Aboriginal Values	av
Other				Botanical Description Notes	MBotDescrip	memo
				Nature Conservation Notes	MNatureConserv	memo
				Use Notes	MUse	memo
				General Notes	MGeneral	memo
				Further reading	Further Reading	re

Comments on relevance of each REX'96 character to SIFT

Plant characters

15 Plant Type Conifer Daisy Fan flower Grasstree Guinea flower Heath Iris Kangaroo paw Lily Mintbush Orchid Pea Rice flower Rose Saltbush Sheoak Trigger plant Wattle	*Not relevant to SIFT.* *Plant types will be extracted using Family or Genus, if required.*
16 Appearance Bushy/dense Clump-forming Compact Erect Ground-cover Mat-forming Open Rounded Spreading Straggly Strap-like leaves Variable Weeping	*A reduced set of these states (erect, bushy, prostrate) could be useful, to indicate the type of harvest challenge which may be faced.* *However, this character will not be included in SIFT at the start, and rough approximations of plant shape will be inferred from the data in 18 (Growth Form)*
17 Plant Longevity Annual Biennial Ephemeral Herbaceous perennial Perennial	*Useful for sorting taxa. Will be included in SIFT.*
18 Growth Form Chenopod shrub Cycad/palm Fern Grass Mallee Moss/lichen Sedge/rush Shrub Tree Vine	*Useful for sorting taxa. Will be included in SIFT.* *The WA Herbarium has agreed to provide this data for all WA taxa. Some information is already coded in WACENSUS for each Family, eg Fern, Moss/Lichen, Monocot, Dicot, Gymnosperm. Other information will come from specimen records in Florabase, eg. tree, shrub, mallee, vine, etc.*
19 MaxHeightUpper Height	*Very useful as an indication of biomass production.* *The WA Herbarium has agreed to provide this data for all WA taxa.*

20 MaxHeightLower Height	*Not relevant to SIFT*
21 MaxWidthUpper Width	*Not immediately relevant to SIFT. May have implications for harvesting later.*
22 MaxWidthLower Width	*Not relevant to SIFT*
23 Bark Colour Black Blue Brown Coppery Cream Dark Greenish Grey Mottled Orange Pale Pink Purplish Red Salmon Silver Stippled White Yellow	*Not relevant to SIFT*
24 Bark Texture Box Corky Fibrous Flaky Furrowed Ironbark Minniritchi Mostly smooth Papery Powdery Prickly Rough Rough stocking Scaly Shiny Smooth Stringy Tessellated Woolly	*Not immediately relevant to SIFT.*

25 Fol Appearance Concolorous Discolorous Dull Fleshy Glabrous (bald) Glaucous (ashy) Glossy Hairy Leathery Prominent oil glands Sticky Warty Waxy Woolly/furry	*Not relevant to SIFT*
26 Fol Longevity Deciduous Evergreen Semi-deciduous	*Not immediately relevant for WA Search, but may be useful in other parts of Australia.*
27 Fol Colour Blue-green Bright green Bronze etc.	*Not relevant to SIFT*
28 Fol Odor Aromatic Foetid Odourless	*Not immediately relevant, but could be used later as an indicator of extractive content.*
29 Flower Colour Black Blue Bronze etc.	*Not relevant to SIFT*
30 Flower Odor Foetid Odourless Perfumed	*Not relevant to SIFT*
31 Flower Period Jan Feb etc.	*Not immediately relevant to SIFT – although the information may be useful for planning trips to identify taxa, or for estimating seed collection times.* *However, this information can be got from other sources as needed.*
32 Ornamental Char Bark Buds Flowers Foliage Fruit	*Not relevant to SIFT*

33 Natural Occurrence ACT Exotic NSW NT SA Tas Vic WA	*Not relevant for the WA Search.* *Data from the WA Herbarium (WA Census) includes a field which identifies plants that have naturalised here. That field could be used to code for other exotics if the need arose. However, the current Search project is targeted at local plants, so no exotic plants will be considered.*
34 Botanical Regions NSW region 59 - North coast NSW region 60 - Central coast etc. WA region 1 - Gardner WA region 2 - Fitzgerald WA region 3 - Hall WA region 4 - Dampier WA region 5 - Mueller WA region 6 - Canning WA region 7 - Keartland WA region 8 - Carnegie WA region 9 - Giles WA region 10 - Helms WA region 11 - Eucla WA region 12 - Fortescue WA region 13 - Ashburton WA region 14 - Carnarvon WA region 15 - Austin WA region 16 - Irwin WA region 17 - Drummond WA region 18 - Dale WA region 19 - Menzies WA region 20 - Warren WA region 21 - Eyre WA region 22 - Roe WA region 23 - Avon WA region 24 – Coolgardie	*SIFT will include a field for IBRA regions in the first instance (because data for WA taxa is available for each IBRA region). Later work, when the list of potential species has been greatly reduced, may be done using spatial data.*
35 Nitrogen Fixing Yes	*Include in SIFT.*
36 Propagation Bulb, corm or rhizome Cuttings Division Grafting Layering Root pieces Seed Spores Suckering Tissue culture Transplants	*Consider using a shortened list, or a modified list.* *Search needs to know:* ∗ *whether a taxon is easy or hard to propagate for large scale deployment. The propagation technique is less relevant, except for direct seeding (see below),* ∗ *whether a taxon will propagate from direct seeding, or whether it needs to be raised in a nursery and then planted out.*

37 Nutrition Relationship Carnivorous/insectivorous Commensal Epiphytic Lithophytic Partially parasitic Saprophytic Symbiont Totally parasitic	*Consider a shortened list of states for taxa which are most likely to be commercial (e.g totally parasitic, partially parasitic, preferred host).*
38 Growth Rate Fast growing Slow growing	*Essential for SIFT. Consider expanding the number of states to at least three (fast, medium and slow).* *This is a subjective and relative criterion, but it will be useful until measured data is available. There is an underlying assumption that growth rates in nature are related to growth rates in a farm paddock.* *An additional character ('Measured growth rate') is needed for real data on farm-grown species.*
39 Salt Tolerance Extremely tolerant Intolerant to salt Moderately salt tolerant Slightly tolerant Very tolerant	*Include in SIFT.*
40 Other Tolerance Air pollution Coastal (exposed) Coastal (sheltered) Drought (moderate) Drought (very) Dry shade Fire Inundation Lime Moist shade Salt spray Snow Waterlogging Waterlogging (seasonal) Wind	*Include a reduced list of states in the WA version of SIFT. In order of importance – waterlogging, salt, frost, herbicides, wind.*
41 Soil Acidity Very acid (<4.5) Acid (4.5 - 6.0) Neutral (6.0 - 7.5) Alkaline (7.5 - 8.5) Very alkaline (>8.5) Wide range	*Include in SIFT. Data may be hard to get for many species.*
42 Pests and Diseases Tolerance Armillaria Borer Dieback (Phytophthora) Nematode Termite	*Important character at a later stage when initial screening has reduced the number of taxa to consider (reducing the data gathering task).*

43 Pests and Diseases Susceptibility Aphids Armillaria Bag shelter moth Borer Caterpillars Dieback (Phytophthora) Fire blight beetles Fruit fly Fungi Gall-forming wasps Grasshoppers Gum tree slave Leaf blister sawfly Leaf eaters Leaf miners Leaf spot Lerps Longicorns Lyctus Mildew Mistletoes Mites Nematodes (eelworms) Painted apple moths Psyllids Sawflies Scale Skeletoniser moths Snails/slugs Sooty mould Termite Thrips Webbing caterpillars Weevils Wood moths	*Important character at a later stage when initial screening has reduced the number of taxa to consider (reducing the data gathering task).* *Consider using a different approach, based on severity of attack, such as 'high', 'medium', and 'low' susceptibility (with a comment field to record the type of organism doing the damage).*
44 Frost Resistance Frost tender Highly tolerant Moderately tolerant	*An important character, especially for plant establishment, but data may be hard to get for the wide range of species which have not previously been cultivated in the open.*
45 Cutting Back Coppicing Mowing Pollarding Pruning	*Ability to resprout after harvest (at or near ground level) will be an important criterion for choosing crops suited to alley farming (sprouters essential) and phase farming (non-sprouters preferred).*

46 Problems Allelopathic Allergies Cutting edges Disease host Drops large fruit/leaves Flammable (very) Invasive weed Irritant Limb dropping Pest host Root competitive Roots invasive Spiny Toxic Warning Weed potential	*In SIFT, separate fields will be devoted to the major problems – allelopathy, weed risk in agriculture, weed risk in native vegetation, and toxicity to stock.*

Site

47 Climate Type Arid Cool temperate Semi-arid Sub-tropical Tropical Warm temperate	*Not included in the first version of SIFT. Sorting on IBRA boundaries will be a surrogate for sorting by climatic type.* *If SIFT were to be used later for assessing taxa introduced into an area, then this character would be useful for preliminary identification of suitable taxa, before doing more sophisticated bioclimatic analysis.*
48 RainfallMin 150 mm 200 mm 250 mm 350 mm 450 mm 550 mm 650 mm 750 mm 850 mm 950+ mm	*SIFT will include rainfall fields, because rainfall varies considerably within each IBRA region.* *Actual minimum rainfall figures will be used instead of ranges.*
49 RainfallMax 150 mm 200 mm 250 mm 350 mm 450 mm 550 mm 650 mm 750 mm 850 mm 950+ mm	*May not be included in SIFT, as high rainfall is seldom a limiting factor, especially in the 250 – 500 mm range.*
50 Rainfall Distrib Bimodal Even Summer max. Winter max.	*As for 47 above.*
51 Alpine (Elevation) Alpine	*Not relevant for the WA Search. May be useful in other areas.*
52 Soil Type Calcareous/limestone Clay Clay loam Gravel soils Loam Peaty Sand Sandy clay Sandy loam Skeletal (rocky)	*SIFT will attempt to use this character. However, the WA Herbarium has warned that data on soils for the specimens in its collection is of doubtful quality and value.* *Broad categories ('light', 'medium' and 'heavy') may be more useful than the categories used here. Data could be easier to get, and be more accurate, despite the apparent coarseness of the categories.* *More intensive data on soils will be needed for species as they enter the industry development phase.*

53 Soil Depth Deep (>80 cm) Moderate (30 - 80 cm) Shallow (<30 cm)	*This information would be very useful, but little is known of the requirements of many species. An added complication is the interaction between soil depth and rainfall (soil depth is sometimes used as a surrogate for soil moisture availability).* *For some tall plants, a minimum depth may be needed to ensure physical stability.*
54 Landform Coastal dune Hill slope Inland dune Intertidal Lake/playa/lagoon Mountain top Plain/flat/valley flat Scarp/breakaway Stream bed Stream/river bed Swale Swamp	*SIFT will include WA Herbarium descriptions of 'habitat' for each taxon.*
55 Aspect N NE E SE S SW W NW	*Unlikely to be an important character for most taxa with commercial potential growing in agricultural areas of south-western WA.* *May be important for south-eastern Australia, in areas of greater relief, or higher latitude.*

Uses

56 Wildlife Food Sources Birds - fruit eaters Butterfly attractors Insects (general) Mammals - fruit and seed eaters etc.	*Useful, if data is available.* *Usefulness of native perennial crops will depend on how they are managed (layouts, harvest age, etc)*
57 Nature Habitat Bark habitat Nesting habitat (not hollows) Nesting hollows Nesting materials source	*As above.*
58 Nature General Rare or endangered	*The conservation status of each WA taxon is included in SIFT (courtesy of WA Herbarium)*
59 Effluent Uses Edging water bodies Effluent water use Nutrient stripping Solids filtering	*Not relevant to Search.*
60 Stabilising Soils Dunes Gully erosion control Landslips Mine sites Rehabilitation Sand binder Stream sides	*Not relevant to Search.*
61 Wind Breaks High Low shrubby Medium height Suited as single species	*If necessary, this character can be derived from other characters (plant height, plant form, growth rate).*
62 Gardening General Bonsai Companion plants Container plants etc.	*Not relevant to Search*
63 Landscaping Bank Care needed near sewers Large garden Recreation Safe under power lines Shade Shelter etc.	*Not relevant to Search*
64 Toxins and Pesticides Anti-viral Bactericides Fungicides Herbicides Insect repellents Insecticides Pesticides	*Record under 'known uses'.*

65 Medicinal and Veterinary Extracts Alcohols (non potable) Alkaloids Bush medicine Herbal medicine	*Record under 'known uses'.*
66 Other Extracts Aromatic and essential oils Dyes Emulsifiers Perfumery Resins Rubbers Tannins	*Record under 'known uses'.*
67 Wood Boat-building Boxes and cases Bridge/wharf construction Cabinet work Carriages/wagons Chipwood Cooperage Craft/specialty timber Dowels Fence post and rails Flooring Flush doors Formwork Framing General construction Handles Heavy construction Interior work Joinery Lattice construction Linings Machine bearings Mining timber Model making Mouldings Panelling Pattern making Paving blocks Peeler/veneer logs Piles in water Plywood Poles for overhead lines Posts and poles Pulpwood Railway sleepers Sheave blocks Shelving Shingles Smoking (BBQ etc) Stakes Stave manufacture Stumps Weatherboards Wheel-making	*Simplify and record under 'known uses' for wood.*

68 Fibre Fibre (thread, sacking) Fibreboard/particleboard Fishing nets/lines Paper and cardboard Ropes Wood wool	*Record under 'known uses'.*
69 Energy Charcoal Ethanol (feedstock) Firewood	*Record under 'known uses'.*
70 Food Items Algae Bush tucker Colouring Exudates Flavouring Flowers Fruits Fungi Honey Leaves and shoots Roots, tubers and bulbs Seeds Water sources and beverages	*Record under 'known uses'.*
71 Fodder Fodder shrub Fodder tree Grazing Nectar for honeybees Pollen for honeybees Unpalatable	*Record under 'known uses'.*
72 Decorative Bark pictures Brush Decorative woodware Dried flowers Dried foliage Dyed flowers Fresh cut flowers Fresh cut foliage Fruits, nuts or pods Pressed flowers	*Not relevant to SIFT.*
73 Domestic Bobbins Building materials Candles Clothes pegs Fireplace whitener Furniture Kitchen utensils Ornaments Shoe heels Soap (saponins) Toys Walking sticks	*Most are not relevant to SIFT.* *Information on higher volume uses (such as 'building materials') will be included under the appropriate character (solid wood products).*

74 Uses other Potpourri Weaving Wood carving Wood turning	*Not relevant to SIFT.*
75 Aboriginal Values Adornment Building materials Calendar plant Cooking aids Fish poison Food and drink Glue Medicine Musical instruments Tool/weapon Utensil	*Information from aboriginal sources will be included in the appropriate 'known use'.*

Search Report

Appendix 20

SIFT characters

From: Graeme Olsen 05 December 2000

Suggested data for SIFT

Introduction

'SIFT' is the working name for the database and set of queries being developed by the Search project. It will be used to produce short lists of species with commercial potential. In this early stage of its development SIFT will be restricted to WA taxa.

This document contains a draft list of data fields to be used by SIFT. In the jargon used here each data field is called a *'character'*, with each character having one or more possible *'states'* (such as 'yes', 'no' or 'perhaps').

Contents

- A brief description of how SIFT will work.
- A table of characters (and states) suggested for SIFT.

Mechanics of SIFT

<u>Data</u>

One of the Search project's aims is to develop a tool that sifts out taxa with commercial prospects from the 10,000+ current WA taxa, with the minimum amount of superfluous data collection. To meet this aim, the SIFT database will be rich in data for only some characters, especially those:

- that apply to most taxa,
- that are powerful discriminators, and
- for which data is already available or is easy to find.

Conversely, it will have little data for characters that apply to few taxa, are weak discriminators, and for which data is unavailable or hard to get.

It will also contain some data relevant to specific products or uses, but often only for those taxa most likely to be suited for those products or uses.

In summary:

- Only for the most powerful, useful and widely applicable characters will data be sought for all taxa.
- For characters that are specific to a particular industry or product, data collection will be restricted to groups of taxa most likely to have potential for that use.

<u>Queries</u>

The SIFT database will allow several levels of query – each producing a reduced list of taxa, about which further data will be sought to allow the next query to be run.

At least three levels of query may be needed (in practice the process is likely to be more complex and iterative than described here):

- 'primary query ' – to restrict the taxa list to current, native, perennial taxa within one or more IBRA regions of interest. There are seven regions within the South-west botanical province, of which four cover the 'wheat and sheep' zone – Geraldton Sandplains (GS), Avon Wheatbelt (AW), Mallee (MAL) and Esperance Plains (ESP). The primary query in the WA Search project will be restricted to these four regions.

- 'secondary query' – to restrict the search further to one or more IBRA regions, and to apply general filters such as weed risk, growth rate, plant height and form, availability of propagules, genetic variation, and toxicity to stock.
- 'tertiary query' – apply specific filters appropriate to a particular product (such as timber colour, termite resistance) or a particular farming system (such as regeneration characteristics, tolerance to herbicides).

What next?

Time for a reality check. After using SIFT to produce some short lists of taxa, we will seek expert opinion on the results so far, to ensure that the taxa which have made it through SIFT conform reasonably well to expert expectation, given the selection criteria used (or if they don't - an acceptable, logical reason can be found). Some refining of the lists of species is expected at this stage, to take into account expert knowledge not captured in the selection criteria.

Beyond the reality check, the selected taxa will move into an industry development phase. They will be tested for their suitability as raw materials (laboratory testing of plant components and test products) and their performance in the field (propagation, establishment, growing, harvesting, yields). Since much of the data produced in this phase will be detailed, specific to provenances, and (in some cases) commercially sensitive, most of it will be stored outside SIFT.

Why SIFT contains very little bioclimatic data

SIFT is not designed to assess taxa for their potential to be introduced elsewhere. Rather, its aim is to identify suitable taxa for commercial use *within* their own natural distribution. Therefore, much of the bioclimatic information usually collected in this type of database is not needed by SIFT and has been left out.

A more elaborate selection system would be needed to predict the success of introduced species, but that task (apart from being beyond Search's immediate brief) is probably better done using other more appropriate tools - such as the spatial bioclimatic approach used by CSIRO, and specialist growth estimation tools such as 'Plantgro'.

Limiting the size of SIFT

Our aim is to make the smallest database which can efficiently sift through the flora to find taxa with commercial potential.

SIFT cannot include all the characters which are needed to select suitable feedstocks for each potential commercial use – there are too many of them. Rather, its job is to use a few powerfully discriminating characters to produce short lists of prospective species for further consideration and testing 'post-SIFT'.

It is difficult to decide how many characters (and which characters) are needed for this task. An attempt is made in the following tables, but this list could be cut back even further. Some candidates for deletion are shown with 'XXX' in their 'Level' column.

List of characters

In the following tables, characters are sorted into two categories – plant attributes and product attributes. Sub-groupings within each category are as follows:

- Plant attributes
  - Plant names
  - Natural distribution
  - Plant growth
  - Response to coppicing
  - Propagation
  - Biological interactions (include wildlife support)
  - Biological threats
  - Weed risk
  - Native habitat
  - Physical threats
  - Wildlife support
- Product attributes
  - Wood properties
  - Wood uses
  - Wood decay
  - Bark properties
  - Bark uses
  - Foliage properties
  - Foliage uses
  - Seed properties
  - Seed uses
  - Exudate properties
  - Exudate uses

Level

Each character has been assigned a 'level' in the following tables, to indicate what stage in the SIFT process the character will be used, and how wide data collection for that character will be. For example, Level 1 characters will have data for all taxa (if possible), and will be used as primary sifts. Lower level characters (levels 2, 3 and 4) will be used for later sifts, and will have data for progressively fewer taxa.

Comments

Some character fields will have a comments field linked to them, to allow extra information about those characters, or related to those characters to be recorded for each taxa. This ploy will enable the number of character fields to be kept to a minimum, and the number of states for each character to be kept small, while allowing extra useful information to be retained for later retrieval or analysis. For example, the growth rate for a species could be recorded against the character 'Growth rate on farm' as 'fast', with details recorded in a linked comments field (such as "Kulin, 12 green tonnes per hectare pa, 400mm rainfall, sandy soil, upper slope, two row belts at 2m spacing, assumed stocking 2667 sph").

Published references

Doran JC and Turnbull JW eds. (1997)
Australian Trees and Shrubs: species for land rehabilitation and farm planting in the tropics.
ACIAR Monograph No 24, viii + 384p.

Thackway R and Cresswell ID eds. (1995)
An interim biogeographic regionalisation for Australia: a framework for establishing the national system of reserves, version 4.0.
Australian Nature Conservation Agency, Canberra

McDonald RC, Isbell RF, Speight JG, Walker J, Hopkins MS (1984)
Australian Soil and Land Survey Field Handbook
Inkata Press, Melbourne

REX'96 Revegetation Expert System (1996)
PCWARE Australia

Unpublished sources

McDonald Maurice (pers. comm.)
List of characters and states for plant descriptions in LucID
CSIRO, Canberra

Vercoe Tim (pers. comm.)
List of data fields for Tredat
Australian Tree Seed Centre, CSIRO Canberra

Proposed SIFT characters (draft)

Plant Attributes

Plant names

Only those taxa found in WA will be included in this first version.

All fields in the ‘plant names’ section are drawn from the WA Herbarium database WACENSUS, and are updated regularly.

Level	Character	States	Format	Comments
	Taxon code number		num	<TaxonID>......... Unique code number used by WA Herbarium. This number will be used in SIFT to link all (taxa level) information in all tables.
	Taxon code name		txt	<SpCode> .... Non-unique alpha code used by WA Herbarium as shorthand identifier for field notes and for data entry.
	Family name		txt	<Family>............ Family name.
	Family code		num	<Fcode> .... Unique family number.
1	Plant group	*D (Dicots)* *G (Gymnosp.)* *M (Monocots)* *etc.*	txt	<Scode> .... Codes for fungi, moss, fern, algae, gymnosperm, monocot, dicot etc. Useful for selecting higher plants.
	Genus name		txt	<Genus>
	Genus code		num	<GenID>............ Unique number for each genus.
	Species name		txt	<Species>
	Authority for species		txt	<SpAuthority>
	Type of infraspecies		txt	<InfraspRank>... Subspecies or variety.
	Name of infraspecies		txt	>InfraspName>
	Authority for infraspecies		txt	<InfraspAuth>
1	In current use	*Yes* *No*	*	<Curnt> .... Use to sift out superseded names.

Natural distribution

Level	Character	States	Format	Comments
1	Naturalised	*Yes* *No*	memo	<Naturalised> .... From WA Herbarium database (WACENSUS). Use to sift out introduced taxa.
1	IBRA regions (WA Herb)	*GS, AW, MAL, ESP*	txt	Only WA regions covering the wheat and sheep zone are included in the pilot scale system.
1	IBRA regions (other sources)	*GS, AW, MAL, ESP*	txt	Additional information from other sources (likely to be minor or unreliable compared to WA Herbarium data). Or add to a comments field for the above character?

1	Conservation status	*X* *R* *P1* *P2* *P3* *P4*	txt	<ConsvCode>....From WA Herbarium (WACENSUS). X ..... Presumed extinct R ..... Declared rare flora P1 ... Priority 1 P2 ... Priority 2 P3 ... Priority 3 *P4 ... Priority 4* *(P1 to P4 classifications are based on the adequacy of surveying, likely taxa rarity and likely severity of threat)* *(eg. P4 = adequate survey, rare, not currently threatened)*
2	Natural habitat (WA Herb)	*TBA*	txt	From WA Herbarium specimen records. States will match those used by the Herbarium – perhaps with some modification or amalgamation if appropriate. May help select taxa with wide applicability.
2	Natural habitat (other sources)	*TBA*	txt	Additional information from other sources. Or add in a comments field to the character above?

Plant growth

Level	Character	States	Format	Comments
3	Genetic variation	*Small* *Moderate* *Large* *Unknown*	txt	Large genetic variation may indicate need for taxonomic work before embarking on industry development (or at least caution in selecting material to test). Doran and Turnbull (1997) list both 'variation between provenances' and 'variation within provenances'.
3	Morphological variation	*As above*	txt	Similar to McDonald (2000) & Doran and Turnbull (1997) Large variations indicate that care is needed when selecting test material.
1	Plant life cycle	*Ephemeral* *Annual* *Biennial* *Perennial* *Unknown*	txt	Useful for initial sorting of taxa.
XXX	Longevity of perennials	*Long* *Medium* *Short* *Unknown*	txt	May not be relevant for short rotation crops. Data may be unreliable and hard to get. Doran and Turnbull (1997) used >50 years (long-lived), 20 – 50 (moderate), and 5 – 20 (short-lived). Suggested definitions for states are: Long *(> 30 years)* Medium *(10 – 30 years)* *Short* (< 10 years)
2	Mature height in nature	*… metres*	num	From WA Herbarium specimen records.
2	Form in nature	*Tree* *Mallee* *Shrub* *Vine, etc.*	txt	From WA Herbarium specimen records.
2	Growth rate in nature - estimated	*Fast* *Medium* *Slow* *Unknown*	txt	Subjective. Use only as a coarse filter. Field trials of the most promising taxa will provide better growth data later.

2	Growth rate on farms - estimated	*Fast* *Medium* *Slow* *Unknown*	txt	Subjective. Use only as a coarse filter. Where measured data is available, record in a comments field, and include details of location, site and design (single rows, multi-row belts, blocks, planting density). Doran and Turnbull (1997) classified 0.5 metres per year as 'moderate' growth, anything more as 'fast' and anything less as 'slow'.
3	Expected bole form	*Excellent* *Good* *Poor* *Variable*	txt	For long rotation timber trees. Based on experts' assessments of sawlog potential, rather than being derived from characters such as number of stems, straightness of stems, prevalence of forks, number of branches, size of branches, etc. Suggested definitions for states are: *Excellent (reliably produces a clear bole)* *Good (often produces a clear bole)* *Poor (rarely produces a clear bole)* *Variable (strong provenance differences)*
XXX	Rooting depth	*Deep* *Medium* *Shallow*	txt	May be of limited usefulness due to difficulty in getting adequate or useful data. Root depth depends on site conditions as well as plant behaviour. Suggested definitions for states are: Deep *(roots penetrate deep into subsoil)* Medium *(roots penetrate some distance into subsoil)* Shallow *(most roots near surface)*

Response to coppicing

Level	Character	States	Format	Comments
3	Coppicing ability	*Strong* *Weak* *Variable* *None* *Unknown*	txt	Similar to Doran and Turnbull (1997)
3	Root suckering ability	*As above*	txt	Similar to Doran and Turnbull (1997) Root suckering may be correlated with coppicing ability.

Propagation

Level	Character	States	Format	Comments
2	Availability of propagules	*Yes* *Perhaps* *No* *Unknown*	txt	Requires expert opinion. Suggested definitions for states are: Yes .... (readily available) Perhaps ... (low availability – improvement likely)) No .... (low availability – improvement unlikely)
2	Propagation by seed	*Strong* *Weak* *Variable* *None* *Unknown*	txt	Record special needs (such as cold treatment, smoke, or scarification for seeds) in a comments field.
2	Propagation from stem cuttings	*As above*	txt	Record special needs in a comments field.
2	Propagation from root cuttings	*As above*	txt	Record special needs in a comments field.

Biological interactions

Level	Character	States	Format	Comments
3	Nitrogen fixing	*Yes – rapidly* *Yes – slowly* *No* *Unknown*	txt	Need to differentiate between taxa that fix N rapidly, and those that do so slowly?
3	Rhizobial inoculation needed	*Yes – essential* *Yes - beneficial* *No* *Unknown*	txt	Similar to Doran and Turnbull (1997) and MacDonald (2000)
2	Allelopathic effects	*As above*	txt	Differentiate between severe and mild allelopathic effects, and between broad and narrow spectrum allelopathy? Record this information in a comments field?
3	Parasitic	*As above*	txt	Record major host species in a comments field.
3	Host to parasites	*Yes* *No* *Unknown*	txt	Record major parasites where important, in a comments field.
2	Toxicity to stock	*High toxicity* *Low toxicity* *Not toxic* *Unknown*	txt	Record plant parts which are toxic, in a comments field.

Biological threats

Level	Character	States	Format	Comments
3	Known susceptibilities	*Termites* *Insects* *Nematodes* *Fungi* *Diseases* *Animals*	txt	Specify major susceptibilities in a comments field. Note: This section refers to biological threats to the growing plant, not to harvested products (see 'Wood decay' under Product attributes, later)
XXX	Resistance to termites	*High* *Medium* *Low* *Variable* *Unknown*	txt	
XXX	Resistance to other insects	*As above*	txt	Specify major insect risks in a comments field.
XXX	Resistance to fungi	*As above*	txt	Specify major fungal risks in a comments field.
XXX	Resistance to diseases	*As above*	txt	Specify major fungal risks in a comments field.

Weed risk

Level	Character	States	Format	Comments
2	Risk to nature conservation - own IBRA region(s)	*High* *Moderate* *Low* *Unknown*	txt	Likely to be low for most taxa. In practice, if this information is hard to get, weed risk may be checked *after* level 3, to focus data gathering on taxa with apparent commercial potential.
2	Risk to nature conserv. - other IBRA region(s)	*As above*	txt	Could be significant for some taxa.
2	Risk to agriculture	*As above*	txt	

Native habitat

This is a rudimentary list of physical factors. Because the main thrust of *Search* is to find species with commercial potential when grown *within* their own natural distribution, there is no need to define climate factors in detail. IBRA boundaries adequately define many biophysical factors.

Soil characters may be the most relevant biophysical factors, as soils vary greatly within IBRA regions.

Level	Character	States	Format	Comments
3	Minimum rainfall	*… mm*	num	Suggestion: Minimum rainfall could be determined only for taxa that survive the first two iterations, to minimise the work collecting this data. Rainfall varies greatly within IBRA regions.
XXX	Maximum rainfall	*… mm*	num	Unlikely to be a limiting character for most taxa, and could be ignored, at least in early iterations.
3	Temperature	*Northern (< 30^o Lat.)* *Central (30^o – 32^o Lat.)* *Southern (> 32^o Lat.)*	txt	These states are easy to collect, and could act as surrogates for temperature. The IBRA regions fall as follows: *Northern* = GS and northern AW. *Central* = central AW. *Southern* = southern AW, MAL, ESP.
3	Soil type - WA Herbarium records	*Clay* *Sandy clay* *Clay loam* *Loam* *Sandy loam* *Sand* *Gravel* *Skeletal (stones)* *Peat*	txt	Will be taken from specimen records held by WA Herbarium (states will be determined by Herbarium data). May be unreliable, as many specimen collectors are not skilled in soil description. Many descriptions will be for surface soil only. Consider simplifying first six states to the four major soil types: Clay, Clay loam, Loam, Sand.
3	Soil type – other sources	*As above*		Soil data from sources other than WA Herbarium records. Or add to a comments field to the character above?
3	Surface soil - summary	*Light* *Medium* *Heavy*	txt	Summarised soil types to reflect farmers description of soil (where more detailed data is lacking).
3	Sub-surface soil - summary	*Light* *Medium* *Heavy*	txt	As above.
XXX	Soil depth	*Shallow (to hard layer)* *Shallow (to water)* *Deep* *Unknown*	txt	Doran and Turnbull (1997) used: Skeletal (< 20 cm), Shallow (20-50 cm), Moderate (50-100 cm) and Deep (> 1 metre). May be difficult to get accurate data.
3	Soil pH	*Acid* *Neutral* *Alkaline* *Unknown*	txt	Doran and Turnbull (1997) and REX'96 used: Highly. acidic (<4.5), Acidic (4.5 – 6.0), Neutral (6.0 - 7.5), Alkaline (7.5 – 9.0) and Highly alkaline (>9.0). (REX'96 used 8.5 between alkaline and highly alkaline)
3	Soil drainage	*Free draining* *Moderate* *Poor*	txt	Same as Doran and Turnbull (1997)
3	Site drainage	*Well drained* *Seas. waterlogged* *Perm. waterlogged*	txt	Similar to Doran and Turnbull (1997)

Physical threats

Level	Character	States	Format	Comments
3	Critical intolerances	*Acid soils* *Alkaline soils* *Saline soils* *Fire* *Frost* *Prolonged drought* *Waterlogging* *Poorly drained soil* *Sandy soil* *P fertiliser* *Pesticides*	txt	Rationale for this character: For many taxa, only one or two pieces of information will be known about its tolerances to site factors, and these will be critical intolerances. Therefore, rather than trying to collect information on a wide range of characters for which data is lacking or difficult to find, it is easier and more effective to record these critical pieces of information which are widely known.
3	Tolerance to seasonal waterlogging	*High* *Medium* *Low* *Unknown*	txt	Needs a quantifiable definition? Doran and Turnbull (1997) used: High (> one month), Moderate (about one month), Low (brief inundation) Nil.
3	Tolerance to permanent waterlogging	*As above*	txt	Needs a quantifiable definition?
3	Tolerance to salt	*As above*	txt	Needs a quantifiable definition? Doran and Turnbull (1997) used: Extremely high (> 16 dS m-1), High (9-16), Moderate (5-8), Slight (2-4) Nil (< 2).
3	Tolerance to frost at establishment	*High* *Medium* *Low* *Variable* *Unknown*	txt	Doran and Turnbull (1997) classified 'frost tolerance' as follows (not necessarily at establishment): High (survives <-5^{o}C), Moderate (tolerates down to -5^{o}C), Low (tolerates down to –1^{o}C), Nil (killed by light frosts). Differentiate between frost death and frost damage? McDonald also included frost frequency. Data may be hard to get for the wide range of species which have not previously been cultivated in the open. May be more useful in later iterations for a reduced number of species.
3	Tolerance to agricultural pesticides	*High* *Medium* *Low* *Variable* *Unknown*	txt	Tolerance to common pesticides is an advantage for new crops being introduced into agricultural systems. But high tolerance to most herbicides could also be risky (weed potential).

Wildlife support

Information available for 'wildlife support' characters may be subjective or incomplete.

Level	Character	States	Format	Comments
XXX	Value as food source	*High* *Medium* *Low* *Unknown*	txt	Worth including? Varies with plant age, location.
XXX	Value for nest material or site	*As above*	txt	Worth including? Depends on plant age.
XXX	Value as habitat	*As above*	txt	Worth including? Varies with plant age. More relevant to plant assemblage than to a single species grown as a crop. Is habitat value too hard to assign to a single species?

Product attributes

Wood properties

Level	Character	States	Format	Comments
4	Heartwood colour	*Yellow* *Brown* *Pink* *Red*	txt	Also include grey, black and purple?
4	Heartwood shade	*Pale* *Medium* *Dark*	txt	Note: colour and shade separated to simplify wood description and avoid confusion.
4	Sapwood colour	*Yellow* *Brown* *Pink* *Red*	txt	
4	Sapwood shade	*Pale* *Medium* *Dark*	txt	
XXX	Sapwood thickness - estimated	*Thin (< 10%)* *Medium (10 – 30%)* *Thick (>30%)*	txt	Estimated as a percentage of the radius (not the cross-sectional area) Is this necessary? useful?, too variable with age?
XXX	Sapwood percentage - measured	*…%*	num	As a percentage of the radius (not the cross-sectional area)
4	Extractive content - estimated	*High* *Medium* *Low* *Unknown*	txt	Type of extractive recorded in a comments field.
4	Extractive content - measured	*…%*	num	Type of extractive recorded in a comments field.
4	Combustion properties	*TBA*		More work needed on how best to describe this character.
4	Suitability for conversion to liquid fuel	*TBA*		More thought needed on how best to describe this character. Cellulose and hemicellulose % will be useful.
XXX	Basic density - estimated	*High* *Medium* *Low* *Unknown*	txt	
XXX	Basic density - measured	*… kg/m^3*	num	Record in comments field whether natural or in cultivation.

4	Durability - estimated	*High* *Medium* *Low* *Unknown*	txt	
4	Durability – measured (CSIRO 'in ground' durability ratings)	*1* *2* *3* *4*	num	Class 1 (> 25 years) Class 2 (15 – 25 years) Class 3 (8 – 15 years) Class 4 (< 8 years)
XXX	Modulus of rupture - estimated	*High* *Medium* *Low* *Unknown*	txt	Useful only for solid timber products. Delete?
XXX	Modulus of rupture - measured	*…*	num	Record in comments field whether natural or in cultivation.
XXX	Modulus of elasticity - estimated	*High* *Medium* *Low* *Unknown*	txt	Useful only for solid timber products. Delete?
XXX	Modulus of elasticity - measured	*…*	num	Record in comments field whether natural or in cultivation.
4	Pulp density	*…*	num	Record in comments field whether natural or in cultivation.

Wood uses

Level	Character	States	Format	Comments
4	Known wood uses	*Solid timber – appearance* *Solid timber – joinery* *Solid timber – construction* *Veneers and laminates* *Particle boards* *Fibreboards* *Pulp and paper* *Carbon products* *Solid fuel – industrial* *Solid fuel - domestic* *Liquid fuel*	txt	Comments field could include more details of use. For example: 'Used for particle board manufacture in Tunisia'.
4	Suggested wood uses	*As above*		Record source and details in comments field
4	Known wood unsuitabilities	*As above*	txt	Rationale: An opportunity to record directly the unsuitability of some species for particular uses.

Wood decay

Level	Character	States	Format	Comments
4	Known susceptibilities	*Termites* *Other insects* *Fungi*	txt	This character refers to decay in wood products, not in the growing tree (covered in 'Biological threats', above)
4	Resistance to termites	*High* *Medium* *Low* *Variable* *Unknown*	txt	
4	Resistance to other insects	*As above*	txt	
4	Resistance to fungi	*As above*	txt	

Bark properties

Level	Character	States	Format	Comments
XXX	Bark colour	*Yellow* *Brown* *Pink* *Red*	txt	
XXX	Bark shade	*Pale* *Medium* *Dark*	txt	
4	Extractive content - estimated	*High* *Medium* *Low* *Unknown*	txt	Type of extractive recorded in a comments field.
4	Extractive content - measured	*… %*	num	Type of extractive recorded in a comments field.

Bark uses

Level	Character	States	Format	Comments
4	Known bark uses	*Particle boards* *Extractives* *Solid fuel* *Liquid fuel*	txt	
4	Suggested bark uses	*As above*		Record source and details in comments field
4	Known bark unsuitabilities	*As above*	txt	

Foliage properties

Level	Character	States	Format	Comments
4	Extractive content - estimated	*High* *Medium* *Low* *Unknown*	txt	Type of extractive recorded in a comments field.
4	Extractive content - measured	*… %*	num	Type of extractive recorded in a comments field.
4	Palatability to stock	*High* *Medium* *Low* *Unknown*	txt	Subjective assessment?
4	Protein content - estimated	*As above*	num	
4	Protein content - measured	*… %*	num	
4	Digestibility - estimated	*High (>50%)* *Medium (30-50%)* *Low (<30%)* *Unknown*	txt	
4	Digestibility - measured	*… %*	num	Refer to D Bicknell memo for suggested methods.
2	Foliage toxicity	*High* *Medium* *Low* *Unknown*	txt	

Foliage uses

Level	Character	States	Format	Comments
4	Known foliage uses	*Extractives* *Fodder* *Fibre* *Solid fuel* *Liquid fuel*	txt	
4	Suggested foliage uses	*As above*		Record source and details in comments field
4	Known foliage unsuitabilities	*As above*	txt	

Seed properties

Level	Character	States	Format	Comments
4	Extractive content - estimated	*High* *Medium* *Low* *Unknown*	txt	Type of extractive recorded in a comments field.
4	Extractive content - measured	*… %*	num	Type of extractive recorded in a comments field.
4	Palatability to stock	*High* *Medium* *Low* *Unknown*	txt	Subjective assessment?
4	Protein content - estimated	*As above*	num	
4	Protein content - measured	*… %*	num	
4	Digestibility - estimated	*High (>50%)* *Medium (30-50%)* *Low (<30%)* *Unknown*	txt	
4	Digestibility - measured	*… %*	num	Refer to D Bicknell memo for suggested methods.
2	Seed toxicity	*High* *Medium* *Low* *Unknown*	txt	

Seed uses

Level	Character	States	Format	Comments
4	Known seed uses	*Extractives* *Food* *Fodder* *Fibre* *Solid fuel* *Liquid fuel*	txt	
4	Suggested seed uses	*As above*		Record source and details in comments field
4	Known seed unsuitabilities	*As above*	txt	

Exudate properties

Level	Character	States	Format	Comments
4	Gum production – estimated	*High* *Medium* *Low* *Unknown*	txt	Type of gum recorded in a comments field.
4	Gum production – measured	*… %*	num	Type of gum recorded in a comments field.
4	Gum quality	*High* *Medium* *Low* *Unknown*		Record potential uses in a comments field.
4	Resin production – estimated	*As above*	txt	Type of resin recorded in a comments field.
4	Resin production – measured	*… %*	num	Type of resin recorded in a comments field.
4	Resin quality	*High* *Medium* *Low* *Unknown*		Record potential uses in a comments field.
4	Latex production – estimated	*As above*	txt	
4	Latex production – measured	*… %*	num	
4	Latex quality	*High* *Medium* *Low* *Unknown*		Record potential uses in a comments field.

Exudate uses

Level	Character	States	Format	Comments
4	Known exudate uses	*Gum* *Resin* *Latex*	txt	
4	Known exudate unsuitabilities	*As above*	txt	

Other data

Notes

Level	Character	States	Format	Comments
	Other plant attributes		memo	
	Other product attributes		memo	
	Other comments		memo	
	Sources		memo	List of sources of data in the database. Link to each piece of data.

Search Report

Appendix 21

Preferred timber species

Gary Brennan

Draft List

Potential Timber Species for the low rainfall < 450 mm areas

Goldfields Timbers

Currently the two most popular Goldfields timber's are :

Goldfields blackbutt – *Eucalyptus lesouefii*

and

Gimlet – *E. salubris*

Timber cut from these two trees show a large amount of interest in furniture manufacturing and craftwood/specialty timbers

Other Goldfields timbers that are currently harvested but are more widespread in the Goldfields are :

Redwood – *E. transcontinentalis*
Salmon gum *E. salmonophloia*
Black morrel –*E. melanoxylon*
Giant mallee – *E. oleosa*
Dundas blackbutt – *E. dundasii*

Other smaller and less available species with commercial potential include :

mulga	(*Acacia aneura*)
gidgee	(*A. pruinocarpa*)
Western Myall	*(A. papyrocarpa)*
miniritchie	(*A. grasbyi*)
black oak	(*Casuarina pauper*) formerly *C. cristata*
Cleland's blackbutt	(*Eucalyptus clelandii*)
merrit	(*E. flocktoniae*)
salt gum	(*E. salicola*)
pixie bush	(*Eremophila oldfieldii*)
turpentine bush	(*E. fraseri*)
beefwood	(*Grevillea striata*)
corkwood	(*Hakea suberea*)
native willow	(*Pittosporum phylliraeoides*)

Some are showing good potential for timber and craftwood. They are :

Native willow (wide distribution and some salt tolerance)
Beefwood
Corkwood
Western myall
Sandalwood
Gidgee

Other minor species with potential timber values are :

Jam – *Acacia acuminata* – by far the best host for establishing sandalwood and you can use the timber for specialty timber, fence posts and turnery.
Native currant – *Canthium latifolium* - hard tree to establish.
Native box – *Bursaria occidentalis* - grows well on deep sandy soils (good form) and excellent carving and turning timber.
Emu tree – *Hakea francisiana* –
Quandong – *Santalum acuminatum* – similar to sandalwood but the timber is better.
Berrigan – *Eremophila longifolia* - small shrubs, to small for commercial milling, but suitable for carving, wood turning. Other Eremophilas are similar to Berrigan e.g. pixie bush and turpentine
Eucalyptus salicola – very salt tolerate, good form.
Desert oak – *Allocasuarina decaisneana* – grows near the WA/SA border.

White cypress pine – *Callitris glaucophylla* – a large wide spread resource already exists
Yorrel – *E. yilgarnensis* – produces excellent burls, possibly not as good as some of the other Goldfields eucs
Snap and rattle – *E. celastroides* –a small hollow tree suitable for didgeridoo manufacture.

Wheatbelt trees

York gum – *E loxophleba* subsp *loxophleba*
Brown mallet – *E. astringens*
Wandoo – difficult to establish a good formed trees, when raised from seedling stock. It may be possible to establish a from good formed wandoo by direct seeding
Rock Sheoak – *Allocasuarina huegeliana* - the timber is similar to WA sheoak growing in the forest areas.
Swamp sheoak – *Casuarina obesa* - salt and waterlogging tolerant – timber very pale and feature less compare to the other sheoaks.
Kondinin blackbutt – *E. kondininensis* – Very salt tolerant.
Flat top yate/ swamp yate – *E. occidentalis*

Exotic trees

Spotted gum and lemon *scented gum – Corymbia maculata and C. citriodora*
Sugar gum – *E. cladocalyx* – excellent timber
Maritime pine – *Pinus pinaster*
River red gum – *E. camaldulensis* – Lake Albacutya variety has the best form
Murray River sheoak – *C. cunninghamiana* ?? – Possibly suited to the higher rainfall areas in the Western Wheatbelt of North of Perth near Moora or Dandaragan/Badgingara

Oil mallees

E. horistes, *E. kochii kochii*, *E. kochii plenissima*, *E. loxophleba lissophloia*, *E. angustissima* and *E. polybractea* (NSW, Vic). E. angustissima is more suited to the south coast near Esperance. E. polybractea is most suited to the higher rainfall area, in particular the south Wheatbelt – Woodinilling and Katanning areas.

Melaleuca uncinata – tea-tree oil and thatch for fencing.

Peter White has suggested including :

Dundas mahogany - E. brockwayi
Mallee wandoo - E. capillosa subsp. capillosa
Dundas blackbutt - E. dundasii
Kondinin blackbutt - E. kondininensis
Red morrel - E. longicornis
Black morrel - E. melanoxylon
Salmon gum - E. salmonophloia
Gimlet - E. salubris
E. urna (the mallet form of *E. flocktoniae*)

Craftwood timber list from Grant Pronk and others

Native willow *Pittosporum phylliraeoides*

Beefwood *Grevillea striata*

Corkwood - *Hakea suberea*

Western Myall, - *Acacia papyrocarpa*

Snakewood – *Acacia xiphophylla*

Native box – *Bursaria occidentalis*

Native current – *Canthium latifolium*

Emu tree (not sure of botanical name)

Search Report

Appendix 22

Wood densities

Gary Brennan

WOOD DENSITY ASSESSMENTS BY CALM (1985 TO 1995)

G.K. Brennan

Density is the major physical property of wood because of its link with most mechanical properties, including those of structural importance. There is a strong correlation between density and strength, based on test data from small defect-free specimens. Other mechanical properties like toughness, hardness and resistance to cleavage also increase with increased density. Strength is related to the thickness of cell walls, but in practice the correlation between density and strength is complicated by factors such as grain variations and defects.

The density of wood (or any other substance) is defined as its mass divided by its volume, usually expressed in kilograms per cubic metre (kg/m^3). Although the proportions may vary, the combined density of cellulose, hemicellulose, lignin and extractives which make up the cell walls of wood is approximately the same for all species at about 1500 kg/m^3. No timber species has a density as high as this, because the cellular structure includes air and water as well as cell walls. The density of the wood of different species will depend on the proportions of cell wall material, air space and moisture content. The content of cell wall material in wood and density varies not only between species but also within species and individual trees. Thus, wood density is affected by factors such as heartwood and sapwood, rate of growth and the proportion of earlywood to latewood.

Young trees have a significant volume of juvenile wood in their central core which is of lower density than mature wood of the same species, and considerable variation in density occurs both between and within trees. Density increases more with increasing cambial age or distance from the pith, at a given height in the tree, than it does with increasing height in wood of the same age from the pith. The mean wood density for a tree may sometimes be influenced by growth, but the wood density in a particular tree is controlled more by a combination of environmental and genetic factors than it is by growth rate.

Moisture content of wood has a large effect on wood density, therefore it is usual to compare densities of different species of wood on an oven-dried basis or at a particular moisture content e.g. 12 per cent.

There are four density measurements (all expressed in kg/m^3) which are particularly relevant to forest products:

Green density is the ratio of the mass of green or unseasoned wood to green volume (kg/m^3). It is useful when determining log transport costs by relating tonnes to cubic metres, the basis of weight-scaling. However, the moisture content of the logs varies during the year.

Air-dry density is the weight of a piece of wood divided by its volume after seasoning (generally to 12 per cent moisture content). This condition relates to wood in use and is the usual figure used when comparing densities of different species in practical situations.

Basic density is oven-dry mass divided by green volume. This measure has the advantage that moisture content variations during the year are avoided.

Bone-dry density is a measure of the density of woodchips when the maximum amount of water possible under normal drying conditions has been removed. Note: woodchips are sold as bone-dry units of 1088 kg, an international measure based on the weight of 2400 lb for one cord of Douglas fir pulpwood.

Research data on a range of species were collected at the Wood Utilisation Research Centre (WURC) since its establishment in 1984. The WURC is now known as CALM Timber Technology. The data were required for seasoning, preservation, gluing and sawmilling trials and wood properties of a range of species, generally regrowth and plantation grown eucalypts, but including others such as Goldfields eucalypts, pine and various sheoaks.

This information sheet lists density data collected at the W.U.R.C. from 1985 to mid-1995. Table 1 provides a comprehensive summary of basic, air-dry and green density by species, age and sometimes origin. Values are given for mean, standard deviation (S.D.), range, and number of specimens tested. The numbers in the last column refer to the published or unpublished references on the wood density data, as listed below. Further information on wood density can be obtained from the general references.

REFERENCES

(1) Bishop, D. Unpublished data. Department of Conservation and Land Management, Wood Utilisation Research Centre, Harvey, Western Australia.

(2) Brennan, G.K. (1991). Basis and air-dried density and log moisture content survey of regrowth jarrah and karri. Department of Conservation and Land Management. Wood Utilisation Research Centre Technical Report No. 28.

(3) Brennan, G.K. (1992). Processing eucalypts grown on a rehabilitated bauxite minesite. Wood Utilisation Research Centre Technical Report - Prepared for ALCOA Australia Ltd. February 1992.

(4) Brennan, G.K., Hanks, W.R. and Ward, S.L. (1992). Processing plantation-grown Tasmanian blue gum. Department of Conservation and Land Management. Wood Utilisation Research Centre Technical Report No. 41.

(5) Brennan, G.K. and Newby P. (1992). Potential of Western Australian eastern Goldfields timbers for high quality wood products. Australian Forestry 55 (74-79).

(6) Brennan, G.K. and Pitcher, J.A. (1993). Preserving two-year-old Tasmanian blue gum fence posts with high temperature creosote. Wood Utilisation Research Centre. Internal Report.

(7) Brennan, G.K. and Pitcher, J.A. (1993). Creosote treatment of pine fence posts cut from the crowns of 33-year-old maritime pine or 26-year-old radiata pine trees. Wood Utilisation Research Centre. Internal Report.

(8) Brennan, G.K. and Pitcher, J.A. (1993). Preserving pine fence posts from six-year-old farm shelterbelts. Wood Utilisation Research Centre. Internal Report.

(9) Brennan, G.K. and Pitcher, J.A. (1994). Treating swamp and rock sheoak posts with high temperature creosote. Wood Utilisation Research Centre. Internal Report.

(10) Brennan, G.K. and Pitcher, J.A. (1994). Preservation of regrowth marri fence posts using non-pressure techniques. Department of Agriculture Western Australia, Miscellaneous Publication 35/94. August 1994.

(11) Brennan, G.K. and Ainsworth, G. (1994). ALCOA natural durability trial - initial assessment of Pinjarra and Marrinup sites. Wood Utilisation Research Centre. Progress Report, November 1994.

(12) Brennan, G.K. and Pitcher, J.A. (1995). Equilibrium moisture content variations of timbers commonly used in Western Australia. CALMScience 2(1): 25-50.

(13) Brennan, G.K., Pitcher, J.A. and Watkins, J.B. (1995). Treating four-year-old Tasmanian blue gum posts with pigment emulsified creosote. Accepted by CALMScience.

(14) Greep, D.A. (1992). Processing eastern states eucalypts and cypress pine into VALWOOD®. Wood Utilisation Research Centre. Internal Report.

(15) Greep, D.A. (1992). Processing of regrowth marri and karri into VALWOOD®. Wood Utilisation Research Centre. Internal Report.

(16) Johnson, G.C. and Thornton, J.D. (1990). AFS study of the natural durability of heartwood from mature and regrowth trees. CSIRO Division of Forestry and Forest Products. Internal Report - June 1990.

(17) Pitcher, J.A. Unpublished data. Department of Conservation and Land Management. Wood Utilisation Research Centre, Harvey, Western Australia.

(18) Siemon, G.R and Pitcher, J.A. (1996). Timber properties and market potential of selected Wheatbelt species. 1. Rock sheoak and swamp sheoak. Department of Conservation and Land Management. CALM Timber Technology. Unpublished Report.

GENERAL REFERENCES

Bootle, K.R. (1983). *Wood in Australia - Types, properties and uses*. McGraw-Hill Book Company, Sydney.

Kingston, R.S.T. and Risdon, C. June E. (1961). Shrinkage and density of Australian and other South-west Pacific woods. CSIRO Division of Forests Products. Technological Paper No.13.

Shedley, P.N. and Challis, P.J. (1984). Mechanical properties of timbers commonly used in Western Australia. Forests Department of Western Australia. Technical Paper No.7.

October 1996.

Table 1.
Summary of wood density data of species assessed at the WURC between 1985 and 1995

Scientific Name	Common Name	Age	Origin	Basic Density (kg/m3)				Air-dry Density (kg/m3				Green Density (kg/m3)				Ref
				Mean	S.D.	Range	n	Mean	S.D.	Range	n	Mean	S.D.	Range	n	
Acacia																
Acacia acuminata	Jam		Narrogin	**940**	42	827 - 1017	20	**1077**	53	966 -1196	20	**1258**	24	1196 -1311	20	**17**
A. aneura	Mulga		W.A.Goldfields	**991**	14	981 - 1000	2	**1166**	5	1163 - 1170	2					**12**
A. aneura	Mulga		North Kalgoorlie	**959**	62			**1185**	24			**1265**	89			**5**
Sheoak																
Allocasuarina decussata	Karri oak		Pemberton	**634**	24	601 - 669	22	**845**	54	773 - 967	22	**1188**	19	1152 - 1228	22	**17**
A. fraserana	W.A. sheoak (regrowth)	25 - 50	Collie, Harvey					**717**	41	651 - 763	5					**16**
A. fraserana	W.A. sheoak (mature)	100 - 125	Collie, Harvey , Jarrahdale					**737**	32	708 - 798	5					**16**
A. fraserana	W.A. sheoak		Unknown	**611**	18	598 - 623	2	**718**	21	704 - 733	2					**12**
A. huegeliana	Rock sheoak	24	Narrogin					**985**	50	920 - 1115						**9**
A. huegeliana	Rock sheoak	40 - 90	Katanning	**722**	41			**894**	32							**18**
A. huegeliana	Rock sheoak		Katanning	**720**	40							**1130**	65			**17**
Casuarina obesa	Swamp sheoak	20	Katanning	**649**	30			**822**	31							**18**
C. obesa	Swamp sheoak	27	Narrogin					**1005**	25	955 - 1045						**9**
C. obesa	Swamp sheoak		Katanning	**650**	30							**1115**	45			**17**
Cypress pine																
Callitris columellaris	White cypress pine	100	Buckingbong State Forest NSW					**780**	70	670 - 920	24					**14**
C. glaucophylla	Northern cypress pine	\ I	Paynes Find - W.A.	**654**	36			**773**	50			**858**	50			**5**
Eucalypts																
Eucalyptus astringens	Brown mallet		Narrogin	**867**	39	816 - 940	20	**1094**	49	1017 - 1183	20	**1128**	46	1064 - 1212	20	**17**
E. calophylla	Marri	14	Jarrahdale	**592**	67	728 -995	20									**11**
E. calophylla	Marri	30	Unknown	**570**	73	429 - 669	17									**18**
E. calophylla	Marri (mature)	150 - 300	Harvey, Manjimup, Kirup, Jarrahdale					**835**	103	705 - 1000	5					**16**
E. calophylla	Marri		Unknown	**582**	3	579 - 585	3	**748**	3	746 - 752	3					**12**
E. calophylla	Marri		Manjimup (ex-pasture site)					**696**	30	662 - 752	8					**1**

Scientific Name	Common Name	Age	Origin	Basic Density (kg/m3)				Air-dry Density (kg/m3				Green Density (kg/m3)				Ref
				Mean	S.D.	Range	n	Mean	S.D.	Range	n	Mean	S.D.	Range	n	
E. calophylla	Marri		Manjimup, Pemberton					**885**	49	796 - 944	8					**1**
E. calophylla	Marri		Unknown					**830**	76	746 - 928	8					**1**
E. diversicolor	Karri	12	Jarrahdale (Gordon Block)	**541**	21	520 - 576		**769**	54	649 - 872						**3**
E. diversicolor	Karri (regrowth) brownwood	15 - 20	Manjimup, Pemberton					**780**	68	659 - 867	5					**16**
E. diversicolor	Karri (regrowth)	15 - 20	Manjimup, Pemberton					**883**	15	858 - 900	5					**16**
E. diversicolor	Karri (regrowth)	30	Nairn Block Pemberton	**680**	37	587 - 772	20					**1054**	59	1149	20	**17**
E. diversicolor	Karri (regrowth)	52	Treen Block Pemberton	**641**	46	549 - 777	21	**872**	70	746 - 1047	42					**2**
E. diversicolor	Karri (regrowth)		Mack Block Manjimup	**646**	64	544 - 763		**813**	51	727 - 892						**15**
E. diversicolor	Karri (regrowth)		Unknown	**697**	36	639 - 747	8	**948**	57	843 - 998	8					**1**
E. diversicolor	Karri (regrowth)		Unknown	**688**	10	671 - 700		**943**	13	926 - 966	8					**1**
E. diversicolor	Karri (mature)	~100	Treen Block Pemberton	**632**	44	528 - 729	21	**824**	50	717 - 933	44					**2**
E. diversicolor	Karri (mature)	100 - 500	Manjimup, Pemberton					**880**	42	806 - 919	5					**16**
E. diversicolor	Karri (mature)		Unknown	**733**	19	676 - 756	25	**967**	26	909 - 1004	25					**12**
E. dundasii	Dundas blackbutt		Norseman	**852**	60			**1183**	30			**1114**	91			**5**
E. globulus ssp globulus	Tasmanian blue gum	2	Mundijong	**411**	36	346 - 468		**475**	43	399 - 544						**6**
E. globulus ssp globulus	Tas blue gum	4	Middlesex - W.A.					**640**	70	550 - 790						**13**
E. globulus ssp globulus	Tasmanian blue gum	8	Manjimup (ex-pasture site)	**527**			3									**4**
E. globulus ssp globulus	Tasmanian blue gum	10	Manjimup	**470**												**4**
E. globulus ssp globulus	Tasmanian blue gum	13	Vasse plantation (high pruned)	**518**	14	498 - 534	8	**664**	37	611 - 710	8					**1**
E. globulus ssp globulus	Tasmanian blue gum	14	Jarrahdale	**510**	31		20									**11**
E. globulus ssp globulus	Tasmanian blue gum	14	Vasse plantation (high pruned)	**538**	20	501 - 561	20	**734**	30	672 - 795	20	**1041**	26	991 - 1084	20	**18**
E. gomphocephala	Tuart		Unknown	**895**			2	**1082**	11	1092 - 1071	2					**12**
E. grandis	Rose gum		Queensland					**640**	132	471 - 901						**14**
E. loxophleba	York gum		North Kalgoorlie	**785**	30			**1129**	45			**1104**	73			**5**
E. loxophleba	York gum		Narrogin	**884**	59	768 - 973	20	**1067**	53	991 - 1155	20	**1185**	26	1137-1231	20	**18**
E. maculata	Spotted gum	12	Jarrahdale	**630**	43	551 - 715		**785**	64	666 - 891						**3**

Scientific Name	Common Name	Age	Origin	Basic Density (kg/m3)				Air-dry Density (kg/m3				Green Density (kg/m3)				Ref
				Mean	S.D.	Range	n	Mean	S.D.	Range	n	Mean	S.D.	Range	n	
E. maculata	Spotted gum	19	Jarrahdale	**682**	36		16									**11**
E. maculata	Spotted gum	29	Conondale - Qld					**1040**	54	942 - 1149						**14**
E. maculata	Spotted gum	21 - 45	Dwellingup, Collie, Busselton,Nannup, Jarrahdale					**812**	96	704 - 967	5					**16**
E. marginata	Jarrah (regrowth)	30 - 50	Dwellingup, Harvey, Jarrahdale,Kirup					**816**	93	696 - 980	5					**16**
E. marginata	Jarrah (regrowth)	48 - 58	Collie (Arklow Block)	**633**	60	438 - 789	21	**801**	65	552 - 901	43					**2**
E. marginata	Jarrah (regrowth)		Jarrahdale	**617**	17*	530 - 710										**11**
E. marginata	Jarrah (mature)	~300	Arklow Block Collie	**624**	61	536 - 885	21	**777**	59	674 - 899	42					**2**
E. marginata	Jarrah (mature)	200 - 300	Harvey, Jarrahdale, Manjimup,Nannup					**858**	99	772 - 1050	5					**16**
E. marginata	Jarrah (mature)		Unknown	**647**	22	602 - 682	24	**841**	35	775 - 902	24					**12**
E. marginata	Jarrah (Fistulina attack)		Harvey					**803**	48	734 - 856	5					**16**
E. microcorys	Tallowwood	17	Jarrahdale	**686**	54		20									**11**
E. microcorys	Tallowwood	19	Jarrahdale					**891**	38	833 - 941						**3**
E. microcorys	Tallowwood	21 -52	Pemberton, Harvey, Mundaring, Busselton, Nannup					**907**	80	764 -980	5					**16**
E. muellerana	Yellow stringybark	16	Pemberton (Dombakup Block)	**629**	65	510 - 737		**750**	105	610 - 978						**14**
E. muellerana	Yellow stringybark	21	Jarrahdale	**610**	49		24									**11**
E. muellerana	Yellow stringybark	19 -28	Walpole, Collie, Jarrahdale, Busselton					**684**	34	649 -739	5					**16**
E. obliqua	Tasmanian oak		Unknown					**770**	10	759 - 775	3					**12**
E. patens	W.A. blackbutt (regrowth)	40 - 60	Harvey, Kirup, Nannup, Manjimup					**903**	126	687 - 1070	5					**16**
E. patens	W.A. blackbutt (mature)	150 - 300	Harvey, Kirup, Nannup, Manjimup					**915**	53	877 - 1020	5					**16**
E. pilularis	Blackbutt		Queensland					**770**	84	655 - 886						**14**
E. regnans	Mountain ash	52	Toolangi State Forest Victoria	**497**	62	419 - 633		**620**	75	481 - 721						**14**
E. resinifera	Red mahogany	12	Jarrahdale	**570**	71	394 - 737		**829**	75	745 - 913						**3**
E. resinifera	Red mahogany	17	Jarrahdale	**603**	50		18									**11**
E. resinifera	Red mahogany	21 - 52	Harvey, Walpole, Dwellingup, Jarrahdale, Nannup					**733**	84	631 - 883	5					**16**
E. saligna	Sydney blue gum	19	Jarrahdale	**470**	42		22									**11**
E. saligna	Sydney blue gum	22	Dwellingup (Amphion Block)	**476**	64	412 - 642		**700**	71	593 - 855						**14**
E. salubris	Gimlet		W.A.Goldfields	**922**	105			**1162**	40			**1194**	96			**5**
E. transcontinentalis	Redwood		W.A.Goldfields	**958**	27	934 - 997	4	**1147**	21	1128-1167	4					**12**
E. transcontinentalis	Redwood		Kalgoorlie	**865**	49			**1152**	13			**1196**	55			**5**

E. wandoo	Wandoo (regrowth)	50 - 70	Katanning, Bannister, Narrogin, Mundaring	**1068**	38	1010-1110	5					**16**

Scientific Name	Common Name	Age	Origin	Basic Density (kg/m3)				Air-dry Density (kg/m3				Green Density (kg/m3)				Ref
				Mean	**S.D.**	**Range**	**n**	**Mean**	**S.D.**	**Range**	**n**	**Mean**	**S.D.**	**Range**	**n**	
E. wandoo	Wandoo (mature)	150 - 300	Katanning, Bannister, Narrogin,Mundaring, Kelmscott					**1096**	19	1080-1130	5					**16**
E. wandoo	Wandoo		Unknown	**865**			2	**1094**	0	1097- 1094	2					**5**
Pines																
Pinus pinaster	Maritime pine	6	Geraldton					**425**	28	383 - 488						**8**
P. pinaster	Maritime pine (crown logs)	33	Harvey (McLarty plantation)					**505**	65	420 - 650						**7**
P. pinaster	Maritime pine	28 - 57	Harvey, Gnangara					**659**	52	609 - 747	5					
P. pinaster	Maritime pine		Unknown	**454**	25	426 - 487	4	**573**	24	551 - 606	4					**12**
P. radiata	Radiata pine	6	Geraldton					**380**	30	332 - 421						**8**
P. radiata	Radiata pine (crown logs)	26	Harvey (McLarty plantation)					**500**	30	435 - 535						**7**
P. radiata	Radiata pine	14 - 34	Harvey plantations					**576**	128	421 - 779	5					
P. radiata	Radiata pine		Unknown	**451**	88		4									**11**
P. radiata	Radiata pine		Unknown	**436**	35	377 - 523	25	**520**	33	468 - 600	25					**12**
Other timbers																
Payena spp	Nyatoh		Unknown					**777**	18	575 - 924	3					**12**
Pseudotsuga menziesii	Douglas fir		Unknown					**532**	42	465 - 642	24					**12**
Shorea pauciflora	Dark red meranti		Unknown					**798**	1	797 - 799	2					**12**
Thuja plicata	Western red cedar		Unknown					**351**	2	349 - 354	3					**12**

Search Report

Appendix 23

Details of logs harvested for FPC timber trials

Log	Photo	Genus	species	Date	Site	Location	voucher #	age	accuracy	Comments	Number
1	Yes	Melaleuca	preissiana	20/02/2003	St Johns Road	NW of Nannup	WOS 1958	40	estimate		
2	Yes	Melaleuca	preissiana	20/02/2003	St Johns Road	NW of Nannup	WOS 1959	40	estimate		
3		Melaleuca	preissiana	20/02/2003	Blackwood Road	NE of Augusta	WOS 1960	30	estimate		
4		Melaleuca	preissiana	20/02/2003	Blackwood Road	NE of Augusta	WOS 1961	40	estimate		
5	Yes	Melaleuca	preissiana	20/02/2003	Stewart Road	NW of Pemberton	WOS 1962	50	estimate		
6A	Yes	Melaleuca	preissiana	20/02/2003	Stewart Road	NW of Pemberton	WOS 1963	40	estimate	two logs	
6B	Yes	Melaleuca	preissiana	20/02/2003	Stewart Road	NW of Pemberton	WOS 1963	40	estimate	two logs	7
7	Yes	Taxandria	juniperina	24/02/2003	Donnelly River	Peerabeelup	WOS 1964	35	estimate		
8	Yes	Taxandria	juniperina	24/02/2003	Donnelly River	Peerabeelup	WOS 1965	35	estimate		
9	Yes	Taxandria	juniperina	24/02/2003	Loverock Road	S of Northcliffe	WOS 1966	35	estimate		
10	Yes	Taxandria	juniperina	24/02/2003	Loverock Road	S of Northcliffe	WOS 1967	35	estimate		
11		Taxandria	juniperina	24/02/2003	Big Brook	W of Pemberton	WOS 1968	35	estimate		
12		Taxandria	juniperina	24/02/2003	Big Brook	W of Pemberton	WOS 1969	35	estimate		6
13	Yes	Eucalyptus	accedens	25/02/2003	Dryandra	NE of Narrogin	WOS 1970	64	known age		
14	Yes	Eucalyptus	accedens	25/02/2003	Dryandra	NE of Narrogin	WOS 1971	64	known age		
15	Yes	Eucalyptus	accedens	28/02/2003	Robinson's	S of Bowelling	WOS 1984	22	known age	Storm damaged top	
16	Yes	Eucalyptus	accedens	28/02/2003	Robinson's	S of Bowelling	WOS 1985	22	known age		
17	Yes	Eucalyptus	accedens	4/03/2003	Sullivan Block	NW of West Dale	WOS 1986	45	estimate		
18	Yes	Eucalyptus	accedens	4/03/2003	Sullivan Block	NW of West Dale	WOS 1987	45	estimate		6
19	Yes	Eucalyptus	argyphea	25/02/2003	Dryandra	NE of Narrogin	WOS 1972	64	known age		
20	Yes	Eucalyptus	argyphea	25/02/2003	Dryandra	NE of Narrogin	WOS 1973	64	known age		
21	Yes	Eucalyptus	argyphea	27/02/2003	McDougall's	N of Tincurrin	WOS 1976	65	estimate		
22	Yes	Eucalyptus	argyphea	27/02/2003	McDougall's	N of Tincurrin	WOS 1977	65	estimate		
23	Yes	Eucalyptus	argyphea	27/02/2003	Kukerin	NE of Kukerin	WOS 1980	70	estimate		
24	Yes	Eucalyptus	argyphea	27/02/2003	Kukerin	NE of Kukerin	WOS 1981	70	estimate		6
25	Yes	Melaleuca	rhaphiophylla	25/02/2003	Tumlo	E of Harvey	WOS 1974	40	estimate		
26	Yes	Melaleuca	rhaphiophylla	25/02/2003	Tumlo	E of Harvey	WOS 1975	30	estimate		
27	Yes	Melaleuca	rhaphiophylla	21/03/2003	Fewster's	NE of Muchea	WOS 2025	35	estimate		
28	Yes	Melaleuca	rhaphiophylla	21/03/2003	Fewster's	NE of Muchea	WOS 2026	35	estimate		
29	Yes	Melaleuca	rhaphiophylla	26/03/2003	Pollard's, Bannister	NE of Boddington	WOS 2027	50	estimate		
30	Yes	Melaleuca	rhaphiophylla	26/03/2003	Pollard's, Bannister	NE of Boddington	WOS 2028	50	estimate		6
31	Yes	Eucalyptus	kondininensis	27/02/2003	Lake Grace	E side of Lake Grace	WOS 1978	45	estimate		
32	Yes	Eucalyptus	kondininensis	27/02/2003	Lake Grace	E side of Lake Grace	WOS 1979	45	estimate		
33		Eucalyptus	kondininensis	5/03/2003	Kondinin	W of Kondinin	WOS 1990	45	estimate		
34		Eucalyptus	kondininensis	5/03/2003	Kondinin	W of Kondinin	WOS 1991	45	estimate		
35	Yes	Eucalyptus	kondininensis	6/03/2003	Lake Biddy	NW of Newdegate	WOS 1999	65	estimate		
36	Yes	Eucalyptus	kondininensis	6/03/2003	Lake Biddy	NW of Newdegate	WOS 2000	60	estimate		6

Log	Photo	Genus	species	Date	Site	Location	voucher #	age	accuracy	Comments	Number
37	Yes	Eucalyptus	occidentalis	28/02/2003	McFall's	NE of Kojonup	WOS 1982	60	estimate		
38	Yes	Eucalyptus	occidentalis	28/02/2003	McFall's	NE of Kojonup	WOS 1983	60	estimate	Recent windfall	
39	Yes	Eucalyptus	occidentalis	12/03/2003	Smith's	W of Buntine	WOS 2009	20	known age		
40	Yes	Eucalyptus	occidentalis	18/03/2003	Nepowie	E of Narrogin	WOS 2013	16	known age		
41	Yes	Eucalyptus	occidentalis	18/03/2003	Nepowie	E of Narrogin	WOS 2014	16	known age		
42	Yes	Eucalyptus	occidentalis	20/03/2003	Magenta	NE of Jerramungup	WOS 2024	35	estimate		6
43		Eucalyptus	ornata	5/03/2003	Notting Hill	NE of Kondinin	WOS 1992	60	estimate		
44		Eucalyptus	ornata	5/03/2003	Notting Hill	NE of Kondinin	WOS 1993	60	estimate		
45	Yes	Eucalyptus	ornata	6/03/2003	Buettners Road	SE of Hyden	WOS 1997	60	estimate		
46	Yes	Eucalyptus	ornata	6/03/2003	Buettners Road	SE of Hyden	WOS 1998	65	estimate		
47	Yes	Eucalyptus	ornata	6/03/2003	Trevenen Road	NE of Lake Grace	WOS 2001	50	estimate		
48	Yes	Eucalyptus	ornata	6/03/2003	Trevenen Road	NE of Lake Grace	WOS 2002	50	estimate		6
55	Yes	Eucalyptus	clivicola	19/03/2003	Moir Road	S of Ravensthorpe	WOS 2020	45	estimate		
56		Eucalyptus	clivicola	20/03/2003	Bandalup Hill	E of Ravensthorpe	WOS 2021	50	estimate		
57	Yes	Eucalyptus	clivicola	20/03/2003	Bandalup Hill	E of Ravensthorpe	WOS 2022	50	estimate		3
61	Yes	Acacia	subfalcata	13/03/2003	Brooks'	N of Dandaragan	WOS 2010	18	estimate		
62	Yes	Acacia	subfalcata	13/03/2003	Brooks'	N of Dandaragan	WOS 2011	16	estimate		
63	Yes	Acacia	subfalcata	13/03/2003	Chelsea Road	NE of Dandaragan	WOS 2012	22	estimate		3
66A	Yes	Acacia	aff. redolens	29/09/2002		NE of Esperance	WOS 1894	?		Forked, cut into two	
66B	Yes	Acacia	aff. redolens	29/09/2002		NE of Esperance	WOS 1894	?		Forked, cut into two	
67	Yes	Acacia	aff. redolens	19/03/2003	Burdett Road	NE of Esperance	WOS 2015	15	estimate		3
73	Yes	Eucalyptus	semivestita	11/03/2003	Bonza's	N of Doodlakine	WOS 2003	50	estimate		
74A	Yes	Eucalyptus	semivestita	11/03/2003	Bonza's	N of Doodlakine	WOS 2004	50	estimate	two logs	
74B	Yes	Eucalyptus	semivestita	11/03/2003	Bonza's	N of Doodlakine	WOS 2004	50	estimate	two logs	
75	Yes	Eucalyptus	semivestita	12/03/2003	N-S fence	NE of Mukinbudin	WOS 2005	45	estimate		
76	Yes	Eucalyptus	semivestita	12/03/2003	N-S fence	NE of Mukinbudin	WOS 2006	45	estimate		
77	Yes	Eucalyptus	semivestita	12/03/2003	E-W fence	NE of Bonnie Rock	WOS 2007	40	estimate		
78	Yes	Eucalyptus	semivestita	12/03/2003	E-W fence	NE of Bonnie Rock	WOS 2008	45	estimate		7
										Number of species	12
										Number of logs	65

Note: Estimates of dates made from sequence of voucher numbers

Note: Some logs with a second log length were also sawn to give more timber for panels (butt log = A, upper log = B)