An Australian Government Initiative

Joint Venture Agroforestry Program

Rural Industries Research & Development Corporation

Forest & Wood Products Australia

Land & Water Australia

Review of wood products, tannins and exotic species for agroforestry in lower rainfall regions of southern Australia

FLORASEARCH 1C

FUTURE FARM INDUSTRIES CRC

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

Trevor J. Hobbs (ed.)

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

Foreword

The FloraSearch project was initiated in 2002 to provide a focus to the development of broad scale woody crops for southern Australia. The project focuses on selecting species that can be developed to supply feedstock for the large-scale markets of wood and energy products. The first phase of the project has produced three reports:

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

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

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

This report provides background information and methods from three supporting studies undertaken by project partner Ensis/CSIRO Forestry and Forest Products. The first study is an assessment of wood testing protocols and results. The second study evaluates tannin as a product and its potential market. The third study addresses the possibility that species from around the world, in similar climatic regions, could be useful crop species and presents a review of this option. The rationale for this last study was that although the FloraSearch project has focused on an evaluation of native species, it recognised that there is a vast pool of unexploited genetic material overseas of unknown commercial value and which is potentially well suited to domestication in Australia.

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

This report, a new addition to RIRDC's diverse range of 1800 research publications, forms part of our Agroforestry and Farm Forestry R&D program, which aims to integrate sustainable and productive agroforestry within Australian farming systems.

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Peter O'Brien
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[1] Now Forest & Wood Products Australia (FWPA)

[2] Now Future Farm Industries CRC (FFI CRC)

Acknowledgements

The authors acknowledge the Joint Venture Agroforestry Program and Murray-Darling Basin Commission for funding this project, and the support of the Cooperative Research Centre for Plant-based Management of Dryland Salinity and SA Department of Water, Land and Biodiversity Conservation.

The reviews reported here were commissioned as part of the FloraSearch project. Mark Ellis and Mike Bennell initiated and administered the contracts through FloraSearch.

The input and helpful advice of project collaborators and members of the FloraSearch Steering Committee is gratefully acknowledged. This includes John Bartle, Graham Olsen, Ian Nuberg, Peter Milthorpe, George Frieschmidt, Des Stackpole and John Doran.

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Executive summary

What the report is about

This report provides results from three studies commissioned by the FloraSearch project to provide more detailed information on wood fibre products, tannins and overseas farm forestry species with potential for development in Australian agroforestry industries. These commissioned studies include:

- Assessment of Australian Native Woody Perennials for Potential Use in Wood Products
- Review of Tannin Product and Market Potential
- Identification of Exotic Woody Perennial Species for Low-Medium Rainfall Zones in Southern Australia.

Who is the report targeted at?

This report is intended to provide large scale biomass industries, agroforestry scientists, government agencies and rural landholders with technical documentation of methods and results from reviews of potential wood fibre and tannin products derived from Australian native species, and an exploration of the potential for exotic species to be used for farm forestry in lower rainfall regions of southern Australia.

Background

FloraSearch was initiated in 2002 with financial support from the Joint Venture Agroforestry Program and the Murray-Darling Basin Commission to provide a focus to the development of broad scale woody crops in short-cycle agroforestry systems for the wheat-sheep zone of southern Australia.

The FloraSearch study area contains the dryland wheat-sheep zone of southeastern Australia bounded by the low rainfall limit of cropping and the 650 mm rainfall isohyet, and extending north to the upper extent of annual, winter dominated rainfall region.

To complement and advance the broader species and industry selection and prioritisation work of the FloraSearch project it was decided to commission additional studies and expertise to explore the more specialised topics of wood products, tannin products and potential overseas species.

Aims and Objectives

The key objects of these studies were to:

- Investigate a range of Australian native woody perennials for their potential use in wood products, particulary for their paper making and fibreboard making properties
- Review the literature to determine the potential uses and market for tannins derived from low rainfall tree crops
- Identify exotic woody perennial species with the potential to be developed as large-scale economic crops in the 250-650 mm winter-dominated or uniform rainfall zone, and review their product potential, availability, suitability and any limiting factors.

Methods Used

Staff from CSIRO Forestry and Forest Products (now part of Ensis, a joint venture between CSIRO and SCION New Zealand) were engaged to undertake three separate studies. CSIRO selected scientific teams and individuals with specialist expertise in each topic area and they conducted a range of laboratory tests, literature reviews, database searches and analyses. Each section of this report details the specific methods used in each study.

Results / Key findings

The "Wood Products" study identified species being worthy of further investigation for pulp including *Acacia leucoclada, Acacia retinodes* (swamp form), *Acacia salicina, Eucalyptus cladocalyx, Eucalyptus aromaphloia* ssp. *sabulosa, Eucalyptus globulus* ssp. *bicostata, Eucalyptus goniocalyx, Eucalyptus incrassata, Eucalyptus ovata, Eucalyptus petiolaris, Eucalyptus polybractea, Eucalyptus porosa, Eucalyptus viminalis* ssp.*cygnetensis* and *Myoporum platycarpum.* They also identified species being worthy of further investigation for medium density fibreboard (MDF) included *Acacia leucoclada, Acacia retinodes* (swamp form), *Casuarina cunninghamiana, Eucalyptus baxteri, Eucalyptus blakelyi, Eucalyptus ovata, Eucalyptus rubida, Eucalyptus viminalis* ssp.*cygnetensis, Melaleuca armillaris* and *Petalostylis labicheoides.*

The "Tannins" study revealed that the most suitable species for tannin production appears to be black wattle (*Acacia mearnsii*). The majority of the world's tannin production is derived from this species. Several reports have concluded that a stand alone Australian tannin industry is not viable due to the low production costs of overseas tannin producers. There may, however, be some possibility of producing tannin extract as an adjunct to other processes such as timber processing.

The "Exotic Species" study identified that there are a number of exotic species potentially suited to the FloraSearch climatic zone, but there are many limitations to growing these commercial timber species in an area with a mean annual rainfall of less than 500 mm without irrigation. Success is only likely on deep soils, or where the trees have access to supplementary water. Weediness potential is a major consideration for the introduction of any species.

Overview

FloraSearch Phase 1 is a collaborative project within the CRC for Plant-based Management of Dryland Salinity (CRC PBMDS), funded by the Joint Venture Agroforestry Program and Murray-Darling Basin Comission and led by the South Australian Department of Water, Land and Biodiversity Conservation (DWLBC) and the Western Australian Department of Environment and Conservation. It is a long term project leading to the development of new woody perennial crops that will replace or be integrated into more traditional annual based farming systems in the sheep-wheat zone of southern Australia. It intends to develop short-cycle woody perennial crops for lower rainfall regions to aid the reduction of salinity contamination whilst at the same time providing valuable marketable woody resources. The first stage of the project involves identification of broad scale product and market opportunities for which new industries using woody perennial plants can be developed. This work is detailed in Bennell *et al.* (2008) and Hobbs and Bennell (2008). A later phase of FloraSearch work is presented in Hobbs *et al.* (2008) where they provide updated product testing results, productivity evaluations and regional industry analyses for a greater range of species and an expanded study area to include Western Australia.

To complement and advance the broader species and industry selection and prioritisation work of the FloraSearch project, it was decided to commission additional studies and expertise to explore the more specialised topics of wood products, tannin products and potential overseas species. CSIRO Forestry and Forest Products (now part of Ensis, a joint venture between CSIRO and SCION New Zealand) was commissioned by FloraSearch in 2003 to undertake wood product testing and evaluations of FloraSearch samples and species, and provide reviews of tannin products and exotic species with potential use in the FloraSearch region (Figure 1).

The results from these three studies have been edited and compiled into this one report with the following sections:

- *Assessment of Australian Native Woody Perennials for Potential Use in Forest Products.*
  By G Freischmidt, A Pereira, M Reilly, S Terrill, A Farrington, F Catela, J Hague, J Ramamurthy, R Wearne and V Dusting. CSIRO Forestry and Forest Products, Clayton, Victoria.
- *Review of Tannin Product and Market Potential.*
  By K Van Langenberg. CSIRO Forestry and Forest Products, Clayton, Victoria.
- *Identification of Exotic Woody Perennial Species for Low-Medium Rainfall Zones in Southern Australia.*
  By PF Macdonell. CSIRO Forestry and Forest Products, Clayton, Victoria.

Figure 1. The FloraSearch study area (shaded) contains the low rainfall winter cereal growing areas of southeastern Australia. Bounded by the low rainfall limit of cropping, summer dominated rainfall areas, and the 650 mm annual rainfall isohyet.

References

Bennell M, Hobbs TJ, Ellis M (2008) Evaluating agroforestry species and industries for lower rainfall regions of southeastern Australia: FloraSearch 1a. Report to the Joint Venture Agroforestry Program (JVAP) and the Future Farm industries CRC. RIRDC Publication No. 07/079; RIRDC, Canberra.

Hobbs TJ, Bennell M (2008) Agroforestry species profiles for lower rainfall regions of southeastern Australia: FloraSearch 1b. Report to the Joint Venture Agroforestry Program (JVAP) and the Future Farm Industries CRC. RIRDC Publication No. 07/080; RIRDC, Canberra.

Hobbs TJ, Bennell M, Huxtable D, Bartle J, Neumann C, George N, O'Sullivan W, McKenna D (2008) Potential agroforestry species and regional industries for lower rainfall southern Australia: FloraSearch 2. Report to the Joint Venture Agroforestry Program (JVAP) and the Future Farm Industries CRC. RIRDC Publication No. 07/082; RIRDC, Canberra.

1. Assessment of Australian native woody perennials for potential use in forest products

By G Freischmidt, A Pereira, M Reilly, S Terrill, A Farrington, F Catela, J Hague, J Ramamurthy, R Wearne and V Dusting.

CSIRO Forestry and Forest Products, Clayton, Victoria. November 2003

1.1 Introduction

The objective of this study was to investigate a range of Australian native woody perennials for their potential use in wood products. In future FloraSearch research, successful species will then be further evaluated, with the ultimate aim of widespread planting in marginal rainfall regions to combat salinity and in turn providing a cash crop for landowners. In future the FloraSearch Project will likely encompass a large range of end products. However, in this analysis, paper and reconstituted wood-based products were the principal products investigated (specifically – medium density fibreboard - MDF). Two typical commercial plantation woods were used for comparison: *Eucalyptus nitens* (14 years old) and *Pinus radiata* (25-30 years old).

The following physical and chemical analyses were carried out for this study:

- Whole Wood Basic Density
- Extractives Content (hot water and dichloromethane)
- Cellulose Content
- pH and Buffering Capacity
- Fibre Length

Refinements were made to some analysis methods as they lacked sensitivity when specific species were required to be named for their suitability in forest products. To this end the following assaying methods were halted: solvent extraction content, cellulose content, buffering capacity and fibre length.

Two industries identified as potential users of novel woody biomass are pulp and paper and reconstituted wood-based products, principally medium density fibreboard (MDF). To rapidly evaluate a broad range of wood samples, a protocol was established to identify the more promising opportunities.

Two controls, or base-line species, were used as references for the work. They represent typical examples of commercial hardwood and softwood species used by the forest products industry in Australia.

They were 14 year old plantation *Eucalyptus nitens* from northern Tasmania and 25-30 year old *Pinus radiata* from north eastern Victoria.

The following test methods were employed to identify promising wood species:

- ***Whole wood basic density***: Obtain wood density ranges to correlate species with suitable products.
- ***Extractives content (hot water and dichloromethane)***: Results from this test indicate likely yields for products such as pulp and fibreboard, and the potential magnitude (and hence treatment costs) of process effluent. Hot water soluble extractives include tannins, sugars and free acids. Solvent extraction using dichloromethane will remove resin and oxidised resin from softwoods, and fats (fatty acids) and waxes from hardwoods.
- ***Cellulose content***: This is a possible indicator of the suitability (in terms of product yield) of a potential feedstock for chemical pulp production.
- ***pH and buffering capacity:*** The results of this test provide good indications of any difficulties that may arise from the gluing of timber members or particles or fibres in panel boards. Extremes in pH can either inhibit resin cure or accelerate it too quickly. Similarly, some weak acids and bases present in wood can resist changes to pH and consequently influence resin curing.
- ***Fibre length and width:*** The mean fibre length and fibre width distribution of a potential feedstock is a good indicator of its suitability for pulp and panel boards. In broad terms short fibre length (~1 mm) pulps provide quality printing papers and long fibre (~2 mm) pulp provide sacking papers for packaging.
- ***Pulp yield:*** The amount (by weight) of usable pulp fibres produced by chemical Kraft cooking. Pulp yields of greater than 45% would be considered as favourable results for any of the species investigated, warranting further detailed investigation into both pulp yield and paper properties.

1.2 Methods

1.2.1 Wood sample preparation

Wood samples received at CSIRO FFP Clayton were in 1 or 20 kilogram lots. Early Acacia samples and 1 kg samples were first debarked (manually – the bark being retained for possible later evaluation of tannin content) and three 2.5 cm thick discs were cut from the base end of the wood stem. The first two discs were used for basic density measurements. The third disc had a 5 mm wide segment removed running across its diameter. This was used for fibre length determination. The remainder of the third disc was combined with discs from the other trees for each species into a composite sample which was then milled (Willy Mill) through a 1-2 mm diameter mesh screen. The milled wood was in turn used for the chemical analysis work – extractives content, cellulose content, pH and buffering capacities.

The screening procedure for 20 kg lots involved chipping the woody material in a pilot scale chipper followed by screening for acceptable chip sizes (>6 mm and < 29 mm diameter screen holes). Chipped material was then stored in sealed plastic bags for pulping studies. Pulp fibres were taken for fibre length and width determinations. Approximately 250 g of green chips were air dried and milled (as above) for the remaining chemical assays.

1.2.2 Whole wood basic density

Two discs from each billet of wood were used for basic density determination. Basic density is defined as the oven-dry weight divided by the green (maximum swollen) volume[3]. The discs were first vacuum soaked in water overnight to provide the "green swollen volume" and then oven dried.

Where 20 kg of material were supplied, basic density was determined on composite samples of wood chips and the same displacement method was used determine swollen volume.

[3] TAPPI (1989) Density determinations defined and described in "Basic density and moisture content of pulpwood". TAPPI Standard T 258 om-89.

1.2.3 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.

1.2.4 Dichloromethane extractives

The method is based on the Australian Standard[4], but with the following modifications. Wood was Wiley milled to pass through a screen with 1mm holes and 5 g of milled wood was used for extraction instead of the 2 g specified in the Standard (with unknown, and possibly low, levels of extractives 5 g lowers the likely error in the determination).

Milled wood (5 g) was continuously extracted with dichloromethane (150 mL) for 6 hours in a Soxhlet extractor. Dichloromethane was removed on a rotary evaporator and the residue dried for 1h at 105°C. Extractives were calculated as a percentage of OD wood. Results were a mean of duplicate extractions.

1.2.5 Cellulose content

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 were a mean of duplicate determinations.

1.2.6 pH and wood meal buffering capacity

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

The buffering capacities and pH of wood meals were determined using a modified method described by Johns and Niazi[5]. 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 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.

1.2.7 Fibre length

Fibre length and width were determined on fibres prepared by chemical digestion of randomly selected midsections from the discs described in ***Wood sample preparation*** above. Matchstick sized wood specimens were first immersed in a solution containing 100 mL glacial acetic acid, 100 mL hydrogen peroxide (100 vol) and 50 g sodium acetate (buffer) and then heated in water bath at 80°C for 48 h. At the end of the time the pulp was washed thoroughly and dispersed in a high-speed mixer to separate individual fibres.

Where 20 kg lots of material were supplied, fibre length and width were determined on fibres from chemical cooks obtained from the pulp yield evaluations.

Fibre length was determined using a Galai CIS-100 image analysis system coupled with video-still software.

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4 Organic solvent extractive in wood, pulp and paper. AS/NZS 1301.012s:1994.

5 Johns, WE and Niazi, KA (1980) Effect of pH and buffering capacity of wood on the gelation time of urea-formaldehyde resin. *Wood and Fibre* 12(4), 255-263.

1.2.8 Chemical pulping

Alkaline Kraft cooking of wood chips was carried out on a laboratory scale of 400 g of wood chips per 3 L bomb in which the alkaline liquor to wood ratio was 4:1. Bombs were heated to 165°C in 100 minutes and held for 90 minutes at this temperature. After cooking, the bombs were cooled rapidly and the pulp washed, screened (removal of coarse fibres), dewatered and crumbed.

Pulp yield was determined as the oven dry equivalent of pulp on the oven dry equivalent of wood starting material for a pulp having a Kappa number of 18. The Kappa number of the pulps was determined as described in AS/NZS 1301.201s:2002.

1.3 Results and Discussion

1.3.1 Basic density, water solubles, pH and pulp yield

Species investigated are listed in ascending basic density in Table 1, along with results for hot water soluble extractives content, pH and pulping yield. An alphabetical listing of the same table is shown in Appendix 1.

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

Extractives in wood can have detrimental effects on various forest products and their associated manufacturing processes for example, adhesive bonding may be impaired, the level of effluent produced in processes may be excessive, and yields of product may be markedly reduced.

Hot water soluble extractives include tannins, sugars and free acids. Solvent extraction using dichloromethane will remove resin and oxidised resin from softwoods, and fats (fatty acids) and waxes from hardwoods.

The cellulose content gives a reasonable indication of likely pulp yield resulting from chemical digestion of wood. Table 2 shows the level of extractives and cellulose content found in earlier trials when the testing protocol included solvent extractives and cellulose content. Although similar cellulose and solvent extractives contents were found between the native species and the commercial reference species, very high levels of hot water extractives were found in the Acacias. This is in general agreement with the known naturally high levels of water-soluble tannins found in many Acacias.

1.3.3 pH and buffering capacity

The pH and buffering capacity of wood materials is particularly important in reconstituted products, because the cure characteristics of resins can be significantly affected. Extremes in pH can either inhibit resin cure or accelerate it too quickly. Similarly, some weak acids and bases present in wood can resist changes to pH and consequently influence resin curing. Results from early tests to determine wood buffering capacity are shown in Table 3 along with pH.

Very little difference in pH and buffering capacities was found between the acacias studied and the commercial reference species. There also appeared to be reasonable correlation between pH and buffering capacities. Accordingly, only pH was determined in subsequent evaluations of species.

1.3.4 Fibre length

Results for fibre length and width are presented in Table 4. These analyses were discontinued as the results did not significantly aid the selection process.

1.3.5 Pulp yield

Wood species supplied in 20 kg lots were assessed for pulp yield using the Kraft cooking method (see Materials and Methods). Yields higher than ~45% (wt./wt.) were considered to be sufficiently interesting to warrant further investigation of the species, in particular, pulp properties.

Table 1. Basic density, hot water solubles content, pH and pulp yield of species investigated, listed in ascending basic density.

Species	Density [kg/m^3]	Water Soluble Extractives [%dm]	pH	Pulp Yield [%dm@ Kappa 18]
Commercial species				
Pinus radiata	~350	2.8	4.1	~50*
Eucalyptus nitens	~550	3.6	4.2	~50[a]
FloraSearch Species				
Brachychiton populneus	368	15.0	5.5	
Callitris gracilis	487	0.7	5.5	<37
Eucalyptus camaldulensis	489	4.1	5.7	
Eucalyptus baxteri	490	8.0	4.6	
Casuarina cunninghamiana	491	13.4	5.6	
Eucalyptus ovata	504	8.2	4.5	49.2
Eucalyptus rubida (DSE)	524	8.7	3.9	
Alstonia constricta	529	11.0	5.3	<36
Eucalyptus viminalis	532	11.2	5.0	
Eucalyptus bridgesiana	539	8.8	4.4	46.5
Eucalyptus aromaphloia ssp. *sabulosa*	541	7.7	4.5	43.5
Eucalyptus blakelyi	543	3.4	5.2	
Eucalyptus cosmophylla	549	10.9	4.6	
Hakea sericea (DSE)	566	11.7	4.6	
Eucalyptus largiflorens (DSE)	568	11.1	5.0	
Petalostylis labicheoides	568	7.7	5.6	
Melaleuca armillaris	576	12.5	4.8	43.0
Acacia retinodes (swamp)	585	5.0	4.6	54.8
Callitris endlicheri	590	3.7	5.7	
Callitris glaucophylla	595	1.3	5.7	
Eucalyptus porosa	606	7.7	5.1	49.9
Acacia leucoclada	616	13.4	5.0	48.4
Eremophila longifolia (DSE)	617	9.4	5.5	
Eremophila longifolia	621	8.8	5.2	

Table 1. Basic density, hot water solubles content, pH and pulp yield of species investigated, listed in ascending basic density continued…

Species	Density [kg/m^3]	Water Soluble Extractives [%dm]	pH	Pulp Yield [%dm@ Kappa 18]
Eucalyptus chlorocada	621	14.0	4.0	39.9
Myoporum platycarpum	631	5.0	4.8	49.6
Leptospermun continentale	635	9.1	4.7	
Melaleuca uncinata	642	4.6	5.7	39.5
Eucalyptus fasciculosa	644	10.2	4.8	
Melaleuca lanceolata	653	5.8	5.5	39.4
Eucalyptus globulus ssp. *bicostata*	656	9.0	4.6	
Melaleuca halmaturorum	656	8.6	4.7	
Callitris verrucosa	657	6.5	4.1	
Eucalyptus goniocalyx	660	9.0	3.8	46.8
Eucalyptus leucoxylon	663	9.5	5.5	43.0
Melaleuca brevifolia	663	9.0	4.7	
Eucalyptus petiolaris	664	10.1	4.3	
Eucalyptus macrorhyncha	668	10.6	3.5	
Acacia retinodes x uncifolia	677	13.0	4.8	
Acacia hakeoides	678	12.6	4.4	
Acacia linearnifolia	679	12.5	4.4	
Eucalyptus conica	679	8.5	4.3	
Acacia retinodes (dryland)	682	11.6	5.7	43.4
Acacia decurrens	684	13.4	4.3	
Eucalyptus sideroxylon	686	11.0	4.8	
Acacia parramattensis	693	13.7	4.9	
Capparis mitchellii	695	19.1	5.6	38.0
Leptospermum coriaceum	701	8.7	4.9	
Callistemon sieberi	702	11.3	4.7	
Acacia victoriae	706	15.0	4.1	
Casuarina pauper	707	10.0	4.6	
Acacia penninervis	710	14.4	4.5	
Acacia deanei	711	16.4	4.9	
Myoporum insulare	713	10.4	4.9	

Table 1. Basic density, hot water solubles content, pH and pulp yield of species investigated, listed in ascending basic density continued…

Species	Density [kg/m^3]	Water Soluble Extractives [%dm]	pH	Pulp Yield [%dm@ Kappa 18]
Eucalyptus melliodora	719	9.7	4.9	
Acacia verniciflua	720	10.5	4.7	
Eucalyptus socialis	720	4.9	4.9	
Acacia pycnantha (Alligator Gorge)	724	16.5	4.4	
Eucalyptus leptophylla	725	3.6	5.4	
Allocasuarina verticillata	726	13.4	5.7	41.5
Acacia calamifolia	729	9.9	4.1	
Acacia vestita	730	9.7	4.1	
Casuarina cristata	732	7.2	5.6	<37
Acacia pycnantha (Kaiser Stuhl)	733	13.3	4.2	
Eucalyptus odorata	733	6.2	3.9	
Eucalyptus polybratea (DSE)	733	7.4	4.4	
Allocasuarina muelleriana	737	10.8	4.3	
Allocasuarina luehmannii	738	10.1	4.7	
Leptospermum laevigatum	741	6.7	4.6	
Eucalyptus incrassata	746	4.6	5.9	48.6
Atalaya hemiglauca	751	14.6	5.8	<39
Eucalyptus cladocalyx	753	8.4	4.3	
Eremophila mitchellii	754	13.2	4.8	
Dodonaea viscosa	756	8.8	5.2	
Acacia notabilis	762	17.0	3.9	
Eucalyptus viridis	762	5.2	5.2	
Grevillea striata	769	13.4	4.2	
Eucalyptus polybractea (WA)	770	5.6	5.5	53.8
Eucalyptus microcarpa	775	7.7	4.7	
Canthium oleofolium	780	13.1	4.3	
Eucalyptus cnearorifolia	781	8.5	4.5	
Eucalyptus polyanthemos	783	15.3	4.0	
Apophyllum anomalum	785	10.5	5.8	

Table 1. Basic density, hot water solubles content, pH and pulp yield of species investigated, listed in ascending basic density continued…

Species	Density [kg/m^3]	Water Soluble Extractives [%dm]	pH	Pulp Yield [%dm@ Kappa 18]
Callistemon rugulosus	788	11.7	5.0	
Eucalyptus populnea	788	9.5	5.1	
Acacia decora	789	11.0	5.9	
Acacia rivalis	800	13.3	4.3	
Eucalyptus fibrosa	801	12.8	3.2	
Owenia acidula	801	11.6	4.6	<40
Geijera parviflora	803	9.3	5.1	
Myoporum montanum	803	8.9	4.5	
Eremophila bignoniiflora	813	12.0	4.7	
Eucalyptus dumosa	815	3.3	4.8	
Acacia pendula	819	17.5	5.9	
Eucalyptus viridis ssp. *wimmerensis*	819	9.2	3.9	
Flindersia maculosa	821	6.4	4.5	<40
Ventilago viminalis	843	10.0	5.6	<39
Eucalyptus melanophloia	844	11.9	3.6	
Eucalyptus albens	850	8.7	3.8	
Acacia homalophylla	864	26.6	4.2	
Acacia aneura	875	10.1	5.0	
Acacia argyrophylla	891	13.2	3.8	
Eucalyptus pilligaensis	896	11.9	3.2	

* Typical value. '<' result would be less than figure given due to high fines content.

[a] Pulpwood quality of 13 eucalypt species with potential for farm forestry. CC Hicks and NB Clark. RIRDC Report No. 01/164 CSF-56A.

Table 2. Hot water and solvent (dichloromethane) extractives contents and cellulose content.

Species	Hot Water Extractives [%dm]	Solvent Extractives [%dm]	Cellulose Content [%dm]
Acacia parramattensis	13.7	0.4	38.1
Acacia decurrens	13.4	0.4	39.0
Acacia leucoclada	13.4	0.4	39.4
Acacia hakeoides	12.6	0.3	38.9
Acacia linearnifolia	12.5	0.4	37.3
Acacia retinodes × uncifolia	13.0	0.5	39.8
Acacia retinodes (swamp form)	5.0	0.3	43.0
Acacia pycnantha (A.G.)	16.5	0.3	38.3
Acacia rivalis	13.3	0.4	41.2
Acacia pycnantha (K.S.)	13.3	0.2	40.0
Acacia victoriae	15.0	0.3	38.3
Acacia decora	11.0	0.2	42.1
Acacia pendula	17.5	0.8	35.7
Acacia retinodes (hill form)	11.6	0.4	40.1
Allocasuarina verticillata	13.4	0.4	41.9
Apophyllum anomalum	10.5	0.7	35.8
Callitris endlicheri	3.7	0.4	46.4
Callitris glaucophylla	1.3	0.7	43.4
Callitris gracillis	0.7	1.0	46.0
Casuarina cristata	7.2	0.3	35.8
Eucalyptus camaldulensis	4.1	0.3	41.1
Eucalyptus incrassata	4.6	0.3	39.6
Eucalyptus leucoxylon	9.5	0.5	37.7
Eucalyptus populnea	9.5	0.5	37.8
Melaleuca lanceolata	5.8	0.3	38.7
Melaleuca uncinata	4.6	0.5	39.0
Commercial Species			
Pinus radiata	2.8	1.1	~40[#]
Eucalyptus nitens	3.6	0.3	40.4

[#] Estimate, method not reliable for *P. radiata*

Table 3. pH and buffering capacities.

BBC: Base Buffering Capacity; ABC: Acid Buffering Capacity, WBC: Wood Buffering Capacity. The pH figures (and #Standard Deviations) are from two or four readings and the buffering capacities are the average of duplicate runs.

Species	pH	Buffering Capacities		
		BBC [mmol/g]	ABC [mmol/g]	WBC [mmol/g]
Acacia decurrens	4.3 (0.1)	0.04	0.04	0.08
Acacia hakeoides	4.4 (0.1)	0.05	0.04	0.10
Acacia leucoclada	5.0 (0.1)	0.03	0.03	0.06
Acacia linearnifolia	4.4 (0.03)	0.06	0.06	0.13
Acacia parramattensis	4.9 (0.5#)	0.06	0.03	0.09
Acacia pycnantha (A.G.)	4.4 (0.1)	0.06	0.04	0.10
Acacia pycnantha (K.S.)	4.2 (0.1)	0.05	0.04	0.09
Acacia retinodes (swamp form)	4.6 (0.01)	0.07	0.03	0.10
Acacia retinodes x uncifolia	4.8 (0.1)	0.07	0.03	0.10
Acacia rivalis	4.3 (0.3)	0.14	0.05	0.19
Acacia victoriae	4.1 (0.01)	0.06	0.07	0.12
Commercial Species				
Pinus radiata	4.1 (0.1)	0.04	0.03	0.08
Eucalyptus nitens	4.2 (0.03)	0.05	0.04	0.09

Table 4. Mean weighted fibre length and width.

Species	Mean Weighted Fibre Length [µm]	Mean Weighted Fibre Width [µm]
Acacia decora	496 (181)	19.5 (4.5)
Acacia decurrens	423 (158)	19.0 (4.7)
Acacia hakeoides	589 (231)	20.8 (5.5)
Acacia leucoclada	495 (190)	19.0 (4.6)
Acacia linearnifolia	472 (246)	19.5 (4.9)
Acacia parramattensis	449 (168[#])	19.0 (4.6)
Acacia pendula	443 (177)	17.4 (4.0)
Acacia pycnantha (A.G.)	509 (195)	18.6 (4.9)
Acacia pycnantha (K.S.)	524 (192)	19.5 (4.8)
Acacia retinodes (swamp)	481 (180)	18.8 (4.5)
Acacia retinodes x *uncifolia*	453 (171)	17.5 (4.5)
Acacia rivalis	514 (214)	18.2 (4.1)
Acacia victoriae	484 (187)	18.2 (4.6)
Apophyllum anomalum	334 (116)	18.3 (4.8)
Callitris endlicheri	1220 (692)	24.7 (7.1)
Callitris glaucophylla	898 (449)	22.4 (5.6)
Eucalyptus camaldulensis	515 (195)	17.6 (4.3)
Eucalyptus populnea	430 (138)	17.1 (4.6)
Commercial species		
Pinus radiata	2000[b]	30
Eucalyptus nitens	630[c]	-

[#] (Weighted Standard Deviation)

[b] Properties and uses of New Zealand radiata pine. Volume 1 - Wood Properties. JA Kininmonth and LJ Whitehouse. Forest Research Institute, Rotarua New Zealand 1991.

[c] Pulpwood quality of 13 eucalypt species with potential for farm forestry. CC Hicks and NB Clark. RIRDC Report No. 01/164 CSF-56A.

Table 5. Pulp yields from the Kraft process.

Species	Pulp Yield [%dm@ Kappa 18]
Acacia retinodes (swamp)	54.8
Eucalyptus polybractea (WA)	53.8
Eucalyptus porosa	49.9
Eucalyptus goniocalyx	49.8
Myoporum platicarpum	49.6
Eucalyptus ovata	49.2
Eucalyptus incrassata	48.6
Acacia leucoclada	48.4
Eucalyptus bridgesiana	46.5
Eucalyptus aromaphloia ssp. *sabulosa*	43.5
Acacia retinodes (dryland)	43.4
Melaleuca armillaris	43.0
Eucalyptus leucoxylon	43.0
Allocasuarina verticillata	41.5
Eucalyptus chloroclada	39.9
Melaleuca uncinata	39.5
Melaleuca lanceolata	39.4
Capparis mitchellii	38.0
Flindersia maculosa	<40
Owenia acidula	<40
Ventilago viminalis	<39
Atalaya hemiglauca	<39
Callitris gracilis	<37
Casuarinas cristata	<37
Alstonia constricta	<36
Commercial Species	
Pinus radiata	~50[#]
Eucalyptus nitens	~52[d]

[#] Typical value. '<' result would be less than figure given due to high fines content.

[d] Pulpwood quality of 13 eucalypt species with potential for farm forestry. CC Hicks and NB Clark. RIRDC Report No. 01/164 CSF-56A.

1.4 Summary

1.4.1 Key results

Wood density, in this work referred to as "basic density", was regarded as the most important indicator of wood suitability. The selection criteria used to identify promising species were as follows:

- Basic density as low as possible for hardwoods (500 - 700 kg/m^3 for pulp and 350 - 600 kg/m^3 for reconstituted wood-based composites eg MDF).
- Species with pulp yields greater than 45%.
- For composites, pH values in the range ~4 to 6 and water soluble extractives of less than 15%.

The above criteria were used in conjunction with knowledge of growth rates and stem form to make the final selections.

A number of promising species have been identified for potential use as pulp feedstock – these are:

Acacia leucoclada

Acacia retinodes (swamp form)

Eucalyptus goniocalyx

Eucalyptus incrassata

Eucalyptus ovata

Eucalyptus porosa

Eucalyptus globulus ssp. *bicostata*

Myoporum platicarpum

Species suitable for wood-based composites include those of an acceptable density range from the pulp species along with the following:

Acacia leucoclada

Acacia retinodes (swamp form)

Casuarina cunninghamiana

Eucalyptus baxteri

Eucalyptus blakelyi

Eucalyptus ovata

Eucalyptus viminalis

Melaleuca armillaris

Petalostylis labicheoides

1.4.2 Application of results and further work

Additional species, not listed but offering potential opportunities for commercial use, exist in the botanical data bases held by Western Australian Department of Environment and Conservation (Crawley WA 6009) as well as South Australian Department of Water, Land & Biodiversity Conservation (FloraSearch, Urrbrae SA 5064).

Species with high pulp yields should now be investigated for pulp properties and those species identified as suitable for wood-based composites, namely MDF, can be trialed on a pilot-plant level at FFP CSIRO Clayton.

1.5 Recommendations and Conclusions

Many of the species investigated in this work were deemed to be unsuitable as feed-stocks for the pulp and wood composites industries owing to their high density. However, some species were identified which appeared to have potential commercial applications.

During the course of the investigations, it became apparent that some of the analyses were not sufficiently sensitive or useful in aiding selection of species. These included solvent extractives, cellulose content, buffering capacity and fibre length. Accordingly, these tests were discontinued, and the following abbreviated test protocol was adopted:

- Basic density – acceptable densities being up to 700 kg/m^3 for pulp and up to 600 kg/m^3 for reconstituted wood-based composites eg MDF.
- Pulp yield – species with yields greater than 45% being considered worthy of further study.
- pH range of approximately 4 to 5.
- Total hot water extractives content – less than approximately 15%.

Other factors such as growth rates and species "form" are of course necessary considerations for the long term success of any plantings of new native species. These factors are addressed by South Australian department of Water, Land & Biodiversity Conservation data.

Species identified as being worthy of further investigation for pulp were:

Acacia leucoclada

Acacia retinodes (swamp)

Eucalyptus globulus ssp. *bicostata*

Eucalyptus goniocalyx

Eucalyptus incrassata

Eucalyptus ovata

Eucalyptus porosa

Myoporum platicarpum

Species identified as being worthy of further investigation for MDF were:

Acacia leucoclada

Acacia retinodes (swamp)

Casuarina cunninghamiana

Eucalyptus baxteri

Eucalyptus blakelyi

Eucalyptus ovata

Eucalyptus viminalis

Melaleuca armillaris

Petalostylis labicheoides

Species from the WA Search[6] project – CALM along with CSIRO FFP in-house pulp and wood-based composites expertise will, in future, further contribute to this species list.

See Appendix 2 – Paper Testing and Pulp Yields Supplementary Report – June 2004 for further testing results and commentary on pulp and paper properties.

6 WA CALM Search Project – J Bartle and G Olsen, CALM Australia II Drive, Crawley 6009.

1.6 Appendix 1 – Results of Analyses in Alphabetical Order

Species	Density [kg/m^3]	Water Soluble Extractives [%dm]	pH	Pulp Yield [%dm@ Kappa 18]
Commercial species				
Pinus radiata	~350	2.8	4.1	~50[#]
Eucalyptus nitens	~550	3.6	4.2	~52[e]
FloraSearch Species				
Acacia aneura	875	10.1	5.0	
Acacia argyrophylla	891	13.2	3.8	
Acacia calamifolia	729	9.9	4.1	
Acacia deanei	711	16.4	4.9	
Acacia decora	789	11.0	5.9	
Acacia decurrens	684	13.4	4.3	
Acacia hakeoides	678	12.6	4.4	
Acacia homalophylla	864	26.6	4.2	
Acacia leucoclada	616	13.4	5.0	48.4
Acacia linearnifolia	679	12.5	4.4	
Acacia notabilis	762	17.0	3.9	
Acacia parramattensis	693	13.7	4.9	

1.6 Appendix 1 – Results of Analyses in Alphabetical Order

Species	Density [kg/m^3]	Water Soluble Extractives [%dm]	pH	Pulp Yield [%dm@ Kappa 18]
Acacia pendula	819	17.5	5.9	
Acacia penninervis	710	14.4	4.5	
Acacia pycnantha (Alligator Gorge)	724	16.5	4.4	
Acacia pycnantha (Kaiser Stuhl)	733	13.3	4.2	
Acacia retinodes (dryland)	682	11.6	5.7	43.4
Acacia retinodes (swamp)	585	5.0	4.6	54.8
Acacia retinodes x uncifolia	677	13.0	4.8	
Acacia rivalis	800	13.3	4.3	
Acacia verniciflua	720	10.5	4.7	
Acacia vestita	730	9.7	4.1	
Acacia victoriae	706	15.0	4.1	
Allocasuarina luehmannii	738	10.1	4.7	
Allocasuarina muelleriana	737	10.8	4.3	
Allocasuarina verticillata	726	13.4	5.7	41.5
Alstonia constricta	529	11.0	5.3	<36
Apophyllum anomalum	785	10.5	5.8	
Atalaya hemiglauca	751	14.6	5.8	<39
Brachychiton populneus	368	15.0	5.5	
Callistemon rugulosus	788	11.7	5.0	
Callistemon sieberi	702	11.3	4.7	
Callitris endlicheri	590	3.7	5.7	
Callitris glaucophylla	595	1.3	5.7	
Callitris gracilis	487	0.7	5.5	<37
Callitris verrucosa	657	6.5	4.1	
Canthium oleofolium	780	13.1	4.3	
Capparis mitchellii	695	19.1	5.6	38.0
Casuarina cristata	732	7.2	5.6	<37
Casuarina cunninghamiana	491	13.4	5.6	
Casuarina pauper	707	10.0	4.6	
Dodonaea viscosa	756	8.8	5.2	
Eremophila bignoniiflora	813	12.0	4.7	
Eremophila longifolia	621	8.8	5.2	

1.6 Appendix 1 – Results of Analyses in Alphabetical Order

Species	Density [kg/m^3]	Water Soluble Extractives [%dm]	pH	Pulp Yield [%dm@ Kappa 18]
Eremophila longifolia (DSE)	617	9.4	5.5	
Eremophila mitchellii	754	13.2	4.8	
Eucalyptus albens	850	8.7	3.8	
Eucalyptus aromaphloia ssp. *sabulosa*	541	7.7	4.5	43.6
Eucalyptus baxteri	490	8.0	4.6	
Eucalyptus blakelyi	543	3.4	5.2	
Eucalyptus bridgesiana	539	8.8	4.4	46.5
Eucalyptus camaldulensis	489	4.1	5.7	
Eucalyptus chlorocada	621	14.0	4.0	39.9
Eucalyptus cladocalyx	753	8.4	4.3	
Eucalyptus cnearorifolia	781	8.5	4.5	
Eucalyptus conica	679	8.5	4.3	
Eucalyptus cosmophylla	549	10.9	4.6	
Eucalyptus dumosa	815	3.3	4.8	
Eucalyptus fasciculosa	644	10.2	4.8	
Eucalyptus fibrosa	801	12.8	3.2	
Eucalyptus globulus ssp. *bicostata*	656	9.0	4.6	
Eucalyptus goniocalyx	660	9.0	3.8	46.8
Eucalyptus incrassata	746	4.6	5.9	48.6
Eucalyptus largiflorens (DSE)	568	11.1	5.0	
Eucalyptus leptophylla	725	3.6	5.4	
Eucalyptus leucoxylon	663	9.5	5.5	43.0
Eucalyptus macrorhyncha	668	10.6	3.5	
Eucalyptus melanophloia	844	11.9	3.6	
Eucalyptus melliodora	719	9.7	4.9	
Eucalyptus microcarpa	775	7.7	4.7	
Eucalyptus odorata	733	6.2	3.9	
Eucalyptus petiolaris	664	10.1	4.3	
Eucalyptus ovata	504	8.2	4.5	49.2
Eucalyptus pilligaensis	896	11.9	3.2	
Eucalyptus polyanthemos	783	15.3	4.0	
Eucalyptus polybractea (WA)	770	5.6	5.5	53.8

1.6 Appendix 1 – Results of Analyses in Alphabetical Order

Species	Density [kg/m^3]	Water Soluble Extractives [%dm]	pH	Pulp Yield [%dm@ Kappa 18]
Eucalyptus polybratea (DSE)	733	7.4	4.4	
Eucalyptus populnea	788	9.5	5.1	
Eucalyptus porosa	606	7.7	5.1	49.9
Eucalyptus rubida (DSE)	524	8.7	3.9	
Eucalyptus sideroxylon	686	11.0	4.8	
Eucalyptus socialis	720	4.9	4.9	
Eucalyptus viminalis	532	11.2	5.0	
Eucalyptus viridis	762	5.2	5.2	
Eucalyptus viridis ssp. *wimmerensis*	819	9.2	3.9	
Flindersia maculosa	821	6.4	4.5	<40
Geijera parviflora	803	9.3	5.1	
Grevillea striata	769	13.4	4.2	
Hakea sericea (DSE)	566	11.7	4.6	
Petalostylis labicheoides	568	7.7	5.6	
Leptospermum coriaceum	701	8.7	4.9	
Leptospermum laevigatum	741	6.7	4.6	
Leptospermun continentale	635	9.1	4.7	
Melaleuca armillaris	576	12.5	4.8	43.0
Melaleuca brevifolia	663	9.0	4.7	
Melaleuca halmaturorum	656	8.6	4.7	
Melaleuca lanceolata	653	5.8	5.5	39.4
Melaleuca uncinata	642	4.6	5.7	39.5
Myoporum insulare	713	10.4	4.9	
Myoporum montanum	803	8.9	4.5	
Myoporum platycarpum	631	5.0	4.8	49.6
Owenia acidula	801	11.6	4.6	<40
Ventilago viminalis	843	10.0	5.6	<39

[#] Typical value. '<' result would be less than figure given due to high fines content.

[e] Pulpwood quality of 13 eucalypt species with potential for farm forestry. CC Hicks and NB. Clark. RIRDC Report No. 01/164 CSF-56A.

1.7 Appendix 2 – Paper Testing and Pulp Yields Supplementary Report – June 2004

Paper Testing

Wood species found to have approximately 45% pulp yields and greater were selected to test their paper properties. Specific mechanical and physical paper properties are described in the following tables along with a ranked analysis for the more important paper properties. The ranked table allows a quick guide to the best performing species thus targeting further work.

Laboratory prepared hand-sheets were 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 – 23 ±1°C and 50 ±2% Relative Humidity. Paper testing was carried out in accordance with AS/NZS 1301.208s:1997 – Methods of test for pulp and paper – Physical testing of pulp hand-sheets.

The highlights of the paper testing results are:

- Unexpected poor "tear index" for all species including the better performing species.
- *Eucalyptus globulus* ssp. *bicostata* and *Acacia leucoclada* have the best papermaking potential, paper densities of less the 700 kg/m^3 and high freeness values (good water drainage).
- *Eucalyptus polybractea* and *Eucalyptus goniocalyx* were the next best performing species having slightly lower tear indices.
- General poor performance of species in paper testing may not be indicative of the species. Further trials will be required with information on the age and provenance of trees in which we would expect a better performance from many of the eucalypt species.
- High fines content found for *Myoporum platycarpum*.

Pulp Yield

Further pulp yields were carried out on a range of species shown in the last table. Those species with pulp yield higher than approximately 45% will have their paper properties examined. The results will appear in the next report.

1.7.1 Ranking of paper properties

		Paper properties			
Species	Pulp Yield	Freeness	Density	Tear index	Tensile index
Acacia leucoclada ssp. *leucoclada*	v.good	Excellent	Excellent	v.poor	v.poor
Acacia retinodes var. *retinodes* (swamp form)	Excellent	v.good	poor	v.poor	good
Casuarina cunninghamiana ssp. *cunninghamiana*	v.poor (<40%)	No Further Action			
Eucalyptus aromaphloia ssp. *sabulosa*	good	v.good	Excellent	v.poor	v.poor
Eucalyptus bridgesiana	good	good	poor	v.poor	poor
Eucalyptus globulus ssp. *bicostata*	good	Excellent	Excellent	v.poor	poor
Eucalyptus goniocalyx	good	v.good	v.good	v.poor	v.poor
Eucalyptus ovata	v.good	v.good	v.poor	v.poor	good
Eucalyptus polybractea	Excellent	v.good	Excellent	v.poor	poor
Eucalyptus porosa	v.good	v.good	good	v.poor	poor
Eucalyptus viminalis ssp. *cygnetensis*	poor	v.good	poor	v.poor	poor
Myoporum platycarpum	v.good	v.good	good	v.poor	v.poor
Ranking					
Nominal	**Values compared with paper properties table**				
Excellent	>50	>500	<620	>9	>90
v.good	48-50	450-500	620-650	8.5-9	80-90
good	45-48	400-450	650-680	8-8.5	70-80
poor	41-45	350-400	680-710	7.5-8	60-70
v.poor	<41	<350	>710	<7	<60
		unbeaten	unbeaten	at 70 tensile	at 350csf

1.7.2 Mechanical and physical paper properties

Species	Pulp Yield [%dm] @ [Kappa No]	Beat revs	Freeness [csf*]	Drainage [s]	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 [s]
Acacia leucoclada ssp. *leucoclada*	14.8 [17.6]	0	508	4.2	609	2.1	29	1.1	5.3	0.2	1.0	2.0
		250	460	4.4	625	2.9	34	1.5	5.8	0.4	1.4	3.0
		950	350	5.1	680	4.8	50	2.3	6.7	0.9	3.0	10
		2050	260	6.2	770	5.7	70	3.4	7.2	1.7	4.3	29
		3000	200	8.1	820	6.0	80	3.8	7.4	2.7	5.0	54
Acacia retinodes var. *retinodes* (swamp form)	55.7 [18.9]	0	460	4.4	699	4.0	43	1.6	6.4	0.5	2.0	4.9
		250	410	4.8	730	4.8	56	2.1	6.8	0.8	3.0	10
		725	350	6.0	780	5.6	71	2.9	7.4	1.5	4.3	21
		700	355	5.9	780	5.6	70	2.9	7.3	1.4	4.3	20
		1100	305	6.2	815	6.2	80	3.4	7.8	1.9	5.0	35
Eucalyptus aromaphloia ssp. *sabulosa*	45.4 [18.5]	0	473	4.6	597	4.7	39	2.0	5.4	0.6	1.9	4.0
		250	430	5.0	670	5.1	50	2.8	6.0	1.1	2.6	12
		900	350	6.1	775	5.9	70	3.8	6.9	1.9	4.4	31
		900	350	6.1	775	5.9	70	3.8	6.9	1.9	4.4	31
		1050	295	7.0	830	6.4	80	4.2	7.3	2.4	5.3	48
Eucalyptus bridgesiana	45.9 [18.7]	0	445	4.6	688	3.6	40	2.0	5.2	0.6	1.9	5.5
		250	386	5.2	730	4.5	52	2.6	5.7	1.0	2.6	13
		500	350	5.8	755	5.1	61	3.2	6.3	1.4	3.2	26
		850	315	6.5	790	5.7	70	3.8	6.8	1.9	3.8	45
		1475	280	8.1	845	6.1	80	4.2	7.3	2.4	4.2	80
Eucalyptus globulus ssp. *bicostata*	46.7 [20.3]	0	506	4.4	600	3.7	42	1.2	7.2	0.3	1.6	1.9
		250	455	4.7	630	5.1	52	1.7	7.4	0.6	2.3	2.8
		850	350	5.5	690	6.6	67	2.6	7.9	1.2	3.7	6.1
		1000	330	5.6	702	6.8	70	2.7	7.9	1.3	4.0	7.7
		1750	260	6.4	740	7.4	80	3.0	7.9	1.7	5.1	18

1.7.2 Mechanical and physical paper properties continued…

Species	Pulp Yield [%dm] @ [Kappa No]	Beat revs	Freeness [csf*]	Drainage [s]	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 [s]
Eucalyptus goniocalyx	46.0 [19.8]	0	473	4.4	624	3.5	38	1.8	5.3	0.5	1.7	2.5
		250	400	4.8	660	4.2	48	2.2	5.8	0.8	2.4	5.0
		500	350	5.9	690	4.8	56	2.7	6.2	1.1	3.0	8.0
		1200	255	6.5	740	6.0	70	3.7	6.8	1.8	4.6	16
		1950	235	7.6	758	6.7	80	4.2	7.0	2.3	5.5	33
Eucalyptus ovata	49.8 [19.0]	0	474	4.7	765	4.9	52	2.3	6.5	0.9	2.7	16
		250	410	5.1	780	5.3	63	2.8	6.7	1.3	3.5	23
		600	350	5.8	815	5.6	73	3.3	7.0	1.7	4.5	45
		450	370	5.5	800	5.4	70	3.1	6.9	1.6	4.3	38
		900	320	6.6	830	5.8	80	3.7	7.3	2.1	5.2	60
Eucalyptus polybractea	54.2 [18.4]	0	483	4.3	537	2.3	29	0.9	5.5	0.2	0.9	0.6
		250	460	4.9	575	2.8	38	1.2	5.9	0.3	1.4	1.0
		1450	350	6.0	670	5.4	65	2.3	7.4	1.1	3.6	4.8
		1750	325	6.2	685	5.9	70	2.6	7.6	1.3	4.1	6.5
		2550	270	8.0	720	6.8	80	3.2	7.8	1.8	5.1	17
Eucalyptus porosa	49.8 [19.5]	0	465	4.4	680	2.8	37	1.6	5.5	0.4	1.6	2.6
		250	420	4.7	705	3.4	46	2.1	5.8	0.8	2.3	5.0
		900	350	5.5	760	4.8	61	3.3	6.4	1.5	3.8	15
		1450	320	6.2	800	5.5	70	3.8	6.8	1.9	4.5	27
		2400	290	7.8	840	6.0	80	4.2	7.2	2.3	5.4	67
Eucalyptus viminalis ssp. *cygnetensis*	44.3 [17.2]	0	459	4.6	698	3.6	42	2.0	6.1	0.6	2.1	9.8
		250	415	4.9	745	4.5	52	2.4	6.5	0.9	3.2	27
		700	350	5.8	805	5.2	66	3.1	7.1	1.5	4.4	59
		900	325	6.2	825	5.4	70	3.4	7.3	1.7	4.7	74
		1750	290	8.9	870	5.4	80	4.2	7.4	2.4	5.4	170
Myoporum platycarpum	49.9 [17.7]	0	494	4.1	658	1.5	23	0.9	4.7	0.1	0.8	1.5
		250	460	4.4	685	2.0	29	1.2	5.0	0.3	1.2	3.0
		1050	350	5.5	770	3.4	44	2.2	5.8	0.7	2.2	12
		3950	440	21.0	880	4.9	70	3.7	7.2	1.9	4.3	850

* Canadian Standard Freeness, # Total Energy Absorbed

1.7.3 Pulp yields

Species	Basic Density [kg/m^3]	Pulp Yield [%dm@ Kappa 18]	Paper Testing
Acacia salicina	581	45.3	Yes
Callitris verrucosa	657	<38	No
Casuarina pauper	707	<39	No
Eremophila longifolia (DSE)	617	<38	No
Eucalyptus baxteri	490	46.0	Yes
Eucalyptus blakelyi	543	44.7	Yes
Eucalyptus cladocalyx	753	49.6	Yes
Eucalyptus conica	679	44.5	Yes
Eucalyptus cosmophylla	549	42.9	No
Eucalyptus fasciculosa	644	43.7	Yes
Eucalyptus macrorhyncha ssp. *macrorhyncha*	668	40.4	No
Eucalyptus nortonii	639	<39	No
Eucalyptus petiolaris	664	47.1	Yes
Eucalyptus rubida	524	46.5	Yes
Melaleuca halmaturorum ssp. *halmaturorum*	656	40.4	No
Myoporum insulare	713	44.2	Yes

2. Review of tannin product and market potential

By K Van Langenberg.

CSIRO Forestry and Forest Products, Clayton, Victoria. October 2003.

2.1 Introduction

The FloraSearch project is currently in the process of methodically selecting tree species to supply new product industries. One aspect of this program is to review products and markets, to focus species selection and development.

This study reviewed the literature to determine the potential market for tannins derived from low rainfall tree crops.

2.2. Methods

The information from this review has been sourced from a number of documents. The documents were found by searching the primary literature, such as patents, books and scientific papers, as well as collecting information from the Internet. No attempt has been made to document the authenticity of this information and the reader is warned that CSIRO shall not be responsible in any way whatsoever to any person who relies in whole or in part on the contents of this report.

2.3 Results and Discussion

2.3.1 Definition of tannin

Tannins are a class of polyphenolic materials produced as plant secondary metabolites.[5] Tannins have been defined by Bate-Smith as "water soluble phenolic compounds having a molecular weight in the order of 500 and 3000 that, besides giving the usual phenolic reactions, have special properties such as the ability to precipitate alkaloids, gelatin and other proteins."[7,8] The term "tannin" has recently been replaced by Haslam with the term "polyphenol" to emphasise the multiplicity of phenol groups that characterize these compounds.[5,9,10]

7 AE Hagerman, "*Tannin Chemistry Handbook*" at http://www.users.muohio.edu/hagermae/tannin.pdf

8 EC Bate-Smith, T Swain (1962) "*Comparative Biochemistry*" Volume 3A, Eds. Mason and Florkin, Academic Press, 705.

9 E Haslam (1989) "*Plant Polyphenols. Vegetable tannins revisited*", Cambridge University Press.

10 E Halam (1998) "*Practical polyphenolics: from structure to molecular recognition and physiological function*", Cambridge University Press.

Haslam has noted that molecular weights as high as 20,000 have been reported and that tannins have been shown to complex with certain polysaccharides.[5,7,8]

The traditional role of tannins have been as agents for the conversion of animal hides into leather (tanning).[5] This is due to the principle property of tannins, their ability to interact and precipitate proteins, including those proteins found on animal skins.[5] The word "tannin" was introduced by Seguin in 1796 to describe extractable matter in certain plant tissues able to convert hide to leather.[7]

Tannins can be further classified into condensed and hydrolysable tannins.[11] Condensed tannins consist predominately of flavolans or polymers of flavan-3-ols (catechins) and/or flavan 3:4-diols (leucoanthocyanidins).[11] The molecular weight of condensed tannins can range from 500 to over 20,000. Condensed tannins can be polymerized to generate phlobaphene, a water insoluble product. Condensed tannins are reactive to aldehydes to form polymeric materials.[12] The hydrolysable tannins are usually compounds containing a central core of glucose or other polyhydric alcohols esterified with gallic acid (gallotannins) or hexahydroxydiphenic acid (ellagitannins).[13] They are hydrolyzed by heating with dilute acid to generate gallic acid, ellagic acid or other similar species.[10] The condensed tannins are characteristic of most of the important tanning materials, such as wattle or "mimosa", quebracho, mangrove and hemlock.[11] Chestnut wood (*Castanea sativa* and *C. dentata*) and dry myrobalan fruits (*Terminalia chebula*) are the most important tanning material for the hydrolysable group.[11] The hydrolysable tannins were formerly of great importance to the tanning industry but have been replaced by condensed tannins due to their greater availability The chemistry of tannins is a complex subject. Further information regarding the chemistry of tannins can be found in the excellent review by Hillis.[9]

2.3.2 Potential products derived from tannin

A search of the scientific, patent and commercial literature has found several potential applications for tannin-based products. These are reviewed in the following.

2.3.2.1 Tanning agents

The original use of plant tannins were as tanning agents for the conversion of animal hides and skins into leather. Today, the majority (70-85%) of the leather produced is made using inorganic salts, particularly chrome salts.[14,15] There is a European research program currently investigating the replacement of these toxic chrome salts with copolymers of tannins and other synthetic materials to produce less toxic, more environmentally friendly tanning agents.[13] This work is still in the research stage with results not expected until 2004.

2.3.2.2 Wood adhesives

The use of tannins for the production of adhesives for wood gluing is not a new concept. McCoy first suggested the use of tannin in adhesives in a 1918 patent.[16] Most of the basic and fundamental work on wattle tannin adhesives, as well as the early commercialization, was carried out in Australia by the CSIRO.[14] Wattle tannin adhesives have been

11 WE Hillis, "*Tannin Chemistry*" in "*Black Wattle and its utilization-Abridged English Edition*". Edited by AG Brown and Ho Chin Ki. RIRDC publication, 106.

12 European patent application EP1245613A2.

13 F Ximenes, "*Tannins*" at http://sres.anu.edu.au/associated/fpt/nwfp/tannins/tannins.html

14 See the website http://www.usd.edu/~jfallan/weinachtb407sp2001/fibers.htm

15 See the website http://europa.eu.int/comm/research/quality-of-life/ka5/en/00913.html

16 Y Yazaki, P Collins, "*Uses of wattle extract: Tannin based adhesives*" in "*Black Wattle and its utilization-Abridged English Edition*". Edited by AG. Brown and Ho Chin Ki. RIRDC publication, 127.

commercially produced and used in South Africa for many years.[14] There are a number of research groups currently studying the use of tannins extracted from various species for use in wood adhesives.
One large research effort was recently completed in Europe investigating the use of tannin derived from pine species.[17] A number of patents also describe the use of different tannin materials for use as wood adhesives. Pizzi has published an excellent review on tannin adhesives.[29] Tannins are often used as a replacement for the phenol and resorcinol found in these adhesives. Phenol and resorcinol are manufactured from petrochemical feed stocks and their cost is associated with the price of crude oil. To substitute these materials, tannin extracts must be very cost competitive with these chemicals. One drawback of tannins is the potential variability of the extract. Any tannin extract for use as a replacement for phenol or resorcinol must have a high level of consistency.

2.3.2.3 Water flocculants

Tannin derived products have been used as flocculants for water.[21] One commercial product, Floccotan, has been used to remove suspended colloidal matter (such as clay and organic matter) in municipal water supplies.[21] Tannin can also be used to remove metallic ions from water due to its strong chelating ability. Wastewater contaminated with Cr, Ni, Zn or Cd can be clarified with tannin.[21] Tannin can also be used in the hydro metallurgical leaching of zinc to reduce the deposition of sulfur.[18]

2.3.2.4 Anticorrosives and protective coatings

Tannins have been reported as being effective inhibitors of corrosion of iron (mild steel and cast iron).[17] Since 1976, there has been much attention given to the chemistry and application of mimosa tannin for the treatment of rusted steel. The African Territories Wattle Industry Fund Ltd has funded this work.[19] Tannin has been used as a corrosion inhibitor in circulated cooling systems and steam boiler systems. Sulfonated tannins have been shown to have excellent properties for removing scale-forming minerals from boilers and cooling water pipes.[20] A Chinese company markets several such products.[21] They have also been used in the protective coatings industry as a primer/undercoat/topcoat in protecting metal surfaces.[17] An anti-corrosive primer marketed as Nox-Primer has been developed in Chile from pine tannin.[22] Applications using black wattle extract as a polyurethane type coating for wood have also been described.[21]

2.3.2.5 Conditioning agent for drilling mud

Tannin derived from wattle extracts has been used as conditioning agents for drilling mud.[18,23,24] The hydrophilic groups on the tannin molecules can be hydrated, which results in a weakening of the network of the clay particles and the liberation of water. The effect increases the fluidity of the mud and decreases the shear strength and viscosity.

[17] See the executive summary for the project "Natural tannin-based adhesives for wood composite products of low or no formaldehyde emission" at http://www.nf-2000.org/secure/Fair/F340.htm

[18] See the product description for ORFOM Grade 2 Tannin at the website http://www.cpchem.com/specialtychem/products/mining/OrfomGrade2Tannin.asp

[19] J Moresby, "Uses of wattle extracts: Anticorrosion of metals" in *Black Wattle and its utilization-Abridged English Edition*. Edited by AG Brown and Ho Chin Ki. RIRDC publication, 144.

[20] P Steiner (1988) "*Tannins as specialty chemicals: an overview*" in *Chemistry and Significance of Condensed Tannins*, Ed R Hemingway and J Karchesy, Plenum Press.

[21] See the Chengdu Chuanfeng Chemical Engineering Company product list at the website http://www.chuanfeng.com/eproduction-1.htm

[22] See "*Tannin produced from pine bark in Chile*" at http://www.idrc.ca/nayudamma/tannin_47e.html

[23] W Zaisong, "*Other uses of wattle extract*", in *Black Wattle and its utilization-Abridged English Edition*. Edited by AG Brown and Ho Chin Ki. RIRDC publication, 154.

[24] "Inquiry into the utilization of Victorian native flora and fauna" available at the website http://www.parliament.vic.gov.au/enrc/unff/report/default.htm - TopOfPage

A commercial mud-fluidizing agent (Kr 6D) has been made from black wattle extract and a chromium salt and used in wells to 1820m in depth.[21] A Chinese company markets several tannin products for this application.[19] A related application is as a viscosity modifier for the production of residential and architectural bricks.[25]

2.3.2.6 Biocides and wood preservatives

Condensed tannins are natural preservatives of lignocellulosic materials and, as such, have been studied as potential biocides and wood preservatives.[18,26,27] Much of this work is still experimental and appears not to have been commercialized to date.

2.3.2.7 Pharmaceuticals

There are references to the potential for deriving medicinal products from tannin.[18,25] Tannins have been shown to have antiviral, anticancer, antibacterial, antiflammatory and anti-oxidant properties and there is currently a large amount of research being undertaken.[28] This work is still very much in the research stage and potential products will likely be dependent on the species of tree the tannins are derived from.

In summary, there are a number of potential products that can be made from tannin extracts. The largest potential market in Australia at the current time appears to be the wood adhesives industry.

Other specialty (and small volume) markets such as biocides and wood preservatives, anti-corrosives and protective coatings, conditioning agents for drilling mud and pharmaceuticals, require much more fundamental scientific research to develop products from tannin.

2.3.3 Extraction technology

The extraction of tannins from bark is typically achieved by water extraction of the ground bark, and spray drying of the solution to give a solid tannin extract. There are a number of patents describing different extraction procedures using water and other solvents (such as alcohols). Examples of relevant patents describing include US5417888, US5238680, US5968517, JP2000086686, WO9744407 and EP1245613A2. The final properties of the tannin extract can be influenced by the extraction process. The most economic solvent to use would likely be water. Dr Yazaki of Monash University has been very active in studying the extraction of tannins from bark for a number of years. He could offer valuable insights into the relative merits of establishing an extraction facility in Australia.

Bunnings Timbachem conducted an economic viability study of a tannin extraction plant in 1988.[33] The results of this study indicated that there was an attractive opportunity to supply a liquid tannin concentrate instead of the imported powdered extract. A liquid extract would eliminate the spray-drying equipment required to produce a powdered extract and reduce the capital investment. The cost of such a plant was estimated to be in the order of A$200-500,000 (in 1988 dollars) with the plant being ancillary to an existing operation.[33] Several other authors have expressed the opinion that, to be economically viable, any tannin extraction plant must be located next to a primary processing plant (such as a timber mill or pulp mill).[18,25]

[25] See the product description for ORFOM D-3 Tannin at the website http://www.cpchem.com/specialtychem/products/mining/OrfomD3.asp

[26] P Laks (1988) "*Condensed Tannins as a source of novel biocides*", in *Chemistry and Significance of Condensed Tannins*, Ed R Hemingway and J Karchesy, Plenum Press.

[27] R Hemingway, "Opportunities to use bark polyphenols in specialty chemical markets" at http://www.srs.fs.usda.gov/pubs/rpc/1999-03/rpc_99mar_17.pdf

[28] See for instance the papers in *Plant Polyphenols 2: Chemistry, Biology, Pharmacology, Ecology* Ed by G Gross, R Hemingway and T Yoshida

2.3.4 Testing procedures for tannin

There are a number of different test procedures which can be used for the determination of tannin extractives from plant materials. A number of these methods have been reviewed by Professor Ann Hagerman.[5] It should be noted that the methods have often been developed for the determination of individual components in a tannin mixture, and Hagerman has pointed out that a major limitation of these methods is the different responses that different phenolics can give as well as the difficulty in obtaining appropriate standards.[5] These different responses mean that the tannin level or phenolic level of a sample cannot be expressed as a single value. To overcome these limitations, it has been suggested that several different methods be used to obtain an evaluation of the tannins present in the mixture.[5]

Stiasny developed a method of evaluating tannin levels in 1905.[29] The method has since been further refined by Hillis and Yazaki.[27] It involves the reaction of the tannin extract with formaldehyde in an acidic environment to produce an insoluble precipitate. The yield of the precipitate is expressed as a percentage of the weight of the original dried sample of extractives (Stiasny value). This value can be further used to determine the polyflavanoid content of the resulting bark by multiplying the hot water extractives yield of the bark by the Stiasny value and dividing by 100.[30] This test, whilst not giving an exact value, is advantageous in that it gives a comparative measure of the amount of tannin being capable of reacting with formaldehyde under the conditions of a thermosetting phenolic-type adhesive.[31] This test has been used to determine the tannin level of a number of Acacia species.[33]

Several other spectroscopic methods have also been described in the analysis of phenolic materials in tannin extracts.[29]

2.3.5 Tannin markets

The market for tannin is currently dominated by the tannin extracted from Black wattle (*Acacia mearnsii*).[32,33,34,35] Black wattle is grown commercially for tannin and wood products in a number of countries including South Africa, Brazil, China, Kenya, India, Zimbabwe and Tanzania. It has been estimated that there are approximately 500,000 ha currently being grown.[33] There are 131,679 ha of wattle currently being grown in South Africa.[36] The bark of black wattle has been noted for its high tannin content, 36-44%, depending on site quality.[22,31] The tannin from *A. mearnsii* appears to be preferred for wood adhesives due to its bond strength and water repellency.[33] Other species are continuously being investigated in other parts of the world, including the Philippines, Kenya and South Africa.[33] Tannin extracted from the bark of the Green wattle tree (*Acacia decurrens*) has also been used overseas, particularly in Indonesia, where it has been used as a sizing agent in fibreboard.[32]

Australia currently imports all its tannin. The majority of the tannin extract imported is used for the production of wood adhesives for particleboard, plywood and fingerjointing.[30] A small amount of tannin (*ca* 600 tonnes) is used in the leather industry.[30] The importation of wattle tannin extracts from all countries into Australia

29 N Saito, M Reilly, Y Yazaki (2001) *Holzforschung*, **55(2)**, 205.

30 Y Yazaki, Z Guancheng, S Searle (1990) *Aust. For.*, **53(3)**, 148.

31 A Pizzi (1983) "*Tannin-based wood adhesives*", in "*Wood Adhesives: Chemsistry and Technology*" Ed A Pizzi (Marcel Dekker), Chapter 4, 177.

32 J Doran, in "*Report of the international expert consultation on non-wood forest products*". This report can be viewed at the FAO website, http://www.fao.org/DOCREP/V7540e//V7540e32.htm

33 T Kevin, "Black wattle farm forestry" at the website http://www.nre.vic.gov.au/4A2568B2008332A3/BCView/4E45E368553F86D9CA256BCF000BBDE3?OpenDocument

34 See the article "Australian Acacia Biodiversity" at http://www.ea.gov.au/biodiversity/abrs/online-resources/acacia/tannin.html

35 L Barbour, "Tannin and fuel wood from plantation grown bipinnate acacias", RIRDC Publication No 00/47. Can be accessed at the website http://www.rirdc.gov.au/reports/AFT/00-47.pdf

36 See the website http://www.forestry.co.za/forestry.nsf/links36668DDEBD659C19422569940048DEF4?opendocument

Table 6. Australian import of wattle tannin extract.

Year	Quantity (tonnes)	Value ($A'000)	Cost ($A/kg)
2002	6341	$3,807	$0.60
2001	5985	$3,950	$0.66
2000	1809	$2,394	$1.32
1999	1669	$2,530	$1.52
95/96	7100	$7,291	$1.03
94/95	8631	$10,190	$1.18
93/94	6723	$8,695	$1.29
92/93	6520	$8,065	$1.24
91/92	5525	$5,999	$1.09
90/91	5485	$5,579	$1.02

The import data for 1999-2002 were obtained from the Australian Bureau of Statistics and are for the calendar year. The 1990-1996 data are for financial years and are taken from reference 38. The cost was determined by dividing the value by the quantity and converted to $A/kg

(derived from Australian Bureau of Statistics data) is given in Table 6. Data for 1997 and 1998 were not obtained.

Two key points concerning the tannin usage in Australia over the last 4 years standout. There has been a large variation in the quantity of tannin imported. It is unclear whether the import levels of 1999-2000 were abnormal or a demonstration of the potential volatility of the market. The second key point of the import statistics is the dramatic decrease in the cost of the wattle extract to $0.60/kg ($600/tonne). This is half the value of the tannin extract in 1999-2000. This data indicates that tannin demand in Australia could be subjected to large fluctuations in both quantity and price.

2.3.5.1 Previous investigations of tannin products

There have been several studies that have investigated the potential for establishing an Australian tannin production industry.

The aim of the project "*Tannin and fuel wood from plantation grown bipinnate acacias*" was to study the suitability of plantation bipinnate acacias to produce tannin and fuel wood. The project investigated 12 different species and found that *A. mearnsii* was the most suitable species for tannin production in South-west Australia. The report also referenced other studies investigating the suitability and measurement of tannin from various acacia species. This report quoted a figure by Thomas that estimated that approximately 7,400kg/ha of wattle tannin could be produced on a 10-year rotation, assuming that the tannin yield of the bark was 40% (on a dry weight basis).[38,37]

A report from the Australian Greenhouse Office found that the market for tannins is modest, and that the market was unlikely to increase significantly. It was concluded that the production of tannin in Australia from mid to low rainfall areas was identified to be a high risk venture.[38] Kevin also made similar observations.[36]

37 S Thomas (1993) *"Black wattle (Acacia mearnsii): a re-vitalised industry for Australia"* in Australian Forest Grower, Special Liftout Section No. 24, Autumn, Vol 16, No 1.

38 See "*The contribution of low to mid rainfall forestry and agroforestry to greenhouse and natural resource management outcomes: Overview and analysis of opportunities.*" at the website http://www.greenhouse.gov.au/land/lowrainfall/pubs/lowrainfall.pdf

2.3.5.2 Potential Risks

There are several existing products that any tannin produced in Australia must compete with. In wood adhesives, the tannin must compete with imported tannin from overseas. The production of tannins is a well-established industry in South Africa and South America. Owing to the low labour costs, tannin can be produced very economically.[36] There is also potential competition from other sources of tannin, especially those derived from pine species in softwood plantations. The largest competitor to any tannin product, at least in the short term, is likely to be chemicals produced by the petrochemical industry. Tannin is seen as a replacement for phenol and resorcinol in wood adhesives. Any tannin product must be able to compete on price with phenol. The spot price of phenol in the Asia Pacific region was around $US680-780 per tonne in October 2002.[39] The price of phenol over the last five years has been fluctuating between $US350-680 per tonne.[40]

Since the Barbour study, there has been significant consolidation of the Australian wood composites industry. Two large multinational companies, Carter Holt Harvey (CHH) and Fletcher Building, now dominate the market. These companies can exert considerable market pressure on any potential new products in the Australian adhesives market. Any increased penetration of tannin adhesives into the Australian market would only be achievable after consultation and buy-in with these organizations.

There have been many attempts to commercially utilize tannins; most have failed.[23] This has been attributed to a number of factors. Failure to be cost competitive with synthetic chemicals (such as phenol), the inherent variability and limited stability of many tannin extracts and the failure to recognize industrial application and performance requirements have all been cited.[23] It has been suggested that tannin producers must determine which market they will target and be certain that they can achieve cost and quality criteria consistently.[23]

An example of a failed tannin processing venture can be found in Chile. Chile imports approximately 4000 tonnes of plant tannin a year, predominately from Argentina.[25] A pine tannin extraction facility was set up by DITECO that had the capacity to produce 600 tonnes of tannin extract a year. However, the cost of producing the tannin extract was twice the price of the imported product (which was approximately $US1/kg). As a result, the extraction plant is currently not operating.[41]

2.4 Summary

2.4.1 Key results

The major results of the study were:

- There are a number of reports that have previously investigated the potential of tannin products derived from low rainfall areas.
- Black wattle (*Acacia mearnsii*) is regarded as the best species for producing tannin. Tannin extracted from black wattle dominates the world market.
- Australia imports all of its tannin. The quantity of tannin coming into Australia has varied dramatically over the last 4 years. The price of the tannin extract has more than halved in price to currently costing $A0.60/kg.
- The creation of a stand-alone tannin industry in Australia would appear to be a high-risk proposition. The risk could be reduced if it was part of a production process manufacturing multiple products.
- A number of potential tannin-based products were identified. The largest volume use of tannin in Australia is for adhesives for the wood composites industry. However, to be competitive

[39] See the website http://www.icislor.com/il_free/il_sitesamp/rpt_view_sample_reports.asp?ReportDestination=1&BlankRetIDs=ON&UserMapIds=10147330

[40] See the December addition of "The Oricle" at Orica Adhesives and Resins website at http://www.orica.com/Business/CHE/A&R/WCHE00015.nsf/webnav2/A&R+News?OpenDocument

[41] See "Non-wood forest products from conifers" at the FAO website http://www.fao.org/docrep/X0453E/X0453e00.htm

in this industry, tannin must be more cost effective than phenol. Furthermore, two international companies (which determine market direction) dominate the wood composites industry. Buy-in from these companies would be essential for any tannin adhesive to succeed.

- Other potential uses for tannins are biocides and wood preservatives, anti-corrosives and protective coatings, conditioning agents for drilling mud and pharmaceuticals. However, these products are small volume niche products that are still in the development stage.
- A number of analytical techniques for determining tannin levels in bark have been identified. The Stiasny test is commonly used to test for tannin compounds reactive with formaldehyde, and is thus best suited for determining the tannin levels in bark suitable for use in wood adhesives. This test has been used to determine the tannin level in a number of Acacia species.
- Water is the most economic solvent for extracting tannin from the bark. The extraction process has a significant effect on the properties of the tannin extract.

2.5 Recommendations and Conclusions

There have been several studies previously undertaken to investigate the potential of tannin extracted from mid to low rainfall species in Australia. The most suitable species for tannin production appears to be black wattle (*Acacia mearnsii*). The majority of the world's tannin production is derived from this species. Several reports have concluded that a stand alone Australian tannin industry is not viable due to the low production costs of other overseas tannin producers. There may, however, be some possibility of producing tannin extract as an adjunct to other processes such as timber processing.

The importation of wattle tannin extracts into Australia has been variable over the last four years. Less than 2000 tonnes of tannin was imported in 1999-2000 while in 2001-2002 tannin imports were approximately 6000 tonnes. The price of the tannin has more than halved from a high of $A1.52/kg in 1999 to $A0.60 in 2002.

The largest potential market for a tannin extract in Australia would be the wood adhesives market. Tannin would be a replacement for phenol and resorcinol, which are derived from petrochemicals. To be competitive, any tannin extract would have to have a high level of consistency. Australian produced tannin would be competing with imported tannin and also phenol and resorcinol.

To be economic, any tannin product would have to be more cost effective than phenol as a replacement. Phenol prices have fluctuated between $US350-680 over the last 5 years. Two international companies that dictate market requirements currently dominate the Australian wood composites industry. Any potential entry into the adhesive industry would require the active participation of these companies.

Other potential niche markets for tanin were identified as being biocides and wood preservatives, anti-corrosives and protective coatings, conditioning agents for drilling mud and pharmaceuticals. These markets are likely to be very small with many of the applications found still in the research and development stage. There is a European project investigating the potential for natural tannins to replace the toxic chromium salts in the manufacture of leather. Any commercial outcome to this work is likely to be a number of years into the future.

A number of analytical procedures for the testing of tannin levels in extracts have been identified. The most suitable technique for testing tannin levels appears to be the Stiasny test. This test is used to determine the level of tannins that are reactive with formaldehyde, to give an indication of its potential use as a wood adhesive.

The most economical way to extract tannins from bark is by using water as a solvent. Other solvents, such as alcohols, have also been investigated. The extraction process has a large effect on the final properties of the extract.

3. Identification of exotic woody perennial species for low-medium rainfall zones in southern Australia

By PF Macdonell.
CSIRO Forestry and Forest Products, Clayton, Victoria. April 2003.

3.1 Introduction

The Australian Tree Seed Centre, a part of CSIRO Forestry and Forest Products was contracted to identify exotic woody perennial plant species from similar climatic zones to the low-medium rainfall areas of southern Australia, with the potential to be developed as economic crops for the FloraSearch project.

The overall aim of FloraSearch is to identify a number of species worthy of further consideration in species trials and ultimately for crop development research. The initial focus is on species native to the study area, but it is considered important to review the potential of exotic germplasm that may form the basis of later stages of the project.

It should be noted that it is very difficult to grow timber species commercially in areas with a mean annual rainfall of less than 500 mm per year without irrigation. Otherwise success is only likely on deep soils or where the trees can access other sources of water (watercourses, groundwater, etc).

3.2 Terms of reference

- Identify exotic woody perennial species with the potential to be developed as large-scale economic crops in the 250 to 650 mm winter or uniform rainfall zone. These species will either come from a Mediterranean climate or have been shown to grow successfully under cultivation in this climatic zone.
- Identify institutions/researchers with knowledge of these species and/or have access to sources of genetic material.
- Provide basic information (in table form) on the species identified. Including botanical family, life form, country of origin and product potential.
- Identify (where known) if short listed species are already in collections in Australia, and (where possible) comment on the suitability of these collections for genotype selection.
- The above results to be presented in report format giving details of the rationale, methods and results of the survey, including discussion of the potential/limitations of the species to be developed as broad scale crops in low-medium rainfall Mediterranean climate zones of Australia.

3.3 Methods

3.3.1 Study area

The study area for this project is the zone lying between the 250 and 650 mm rainfall isohyets in Victoria, New South Wales, South Australia and Western Australia, with a winter peak or uniform rainfall distribution. The Australian Low Rainfall Tree Improvement Group (ALRTIG) target zone is between the 400-600 mm rainfall isohyets and is completely encompassed within the study area of FloraSearch. Harwood and Bush (2002) describe the soils of the ALRTIG area as poor, infertile, easily degraded, with widespread sodic and saline areas. In addition, large areas are alkaline (pH >7.5) partly due to denudation, degradation, rising water tables or from the underlying limestone parent material.

3.3.2 Climatic indicators

Climatic factors are particularly useful to indicate broad regions where particular species are worth considering for cultivation (Jovanovic & Booth 2002). Climatic factors were generated for the study area using the AUSGRD mapping program. Rainfall ranges and seasons were entered and then the dry season duration and temperature factors were determined.

Figure 2. Australia – Green areas indicate parts of the winter and uniform rainfall zone receiving mean annual rainfall between 150 and 650 mm. (150 mm lower limit was used rather than 250 mm to extend the scope of this survey to highly drought tolerant species.)

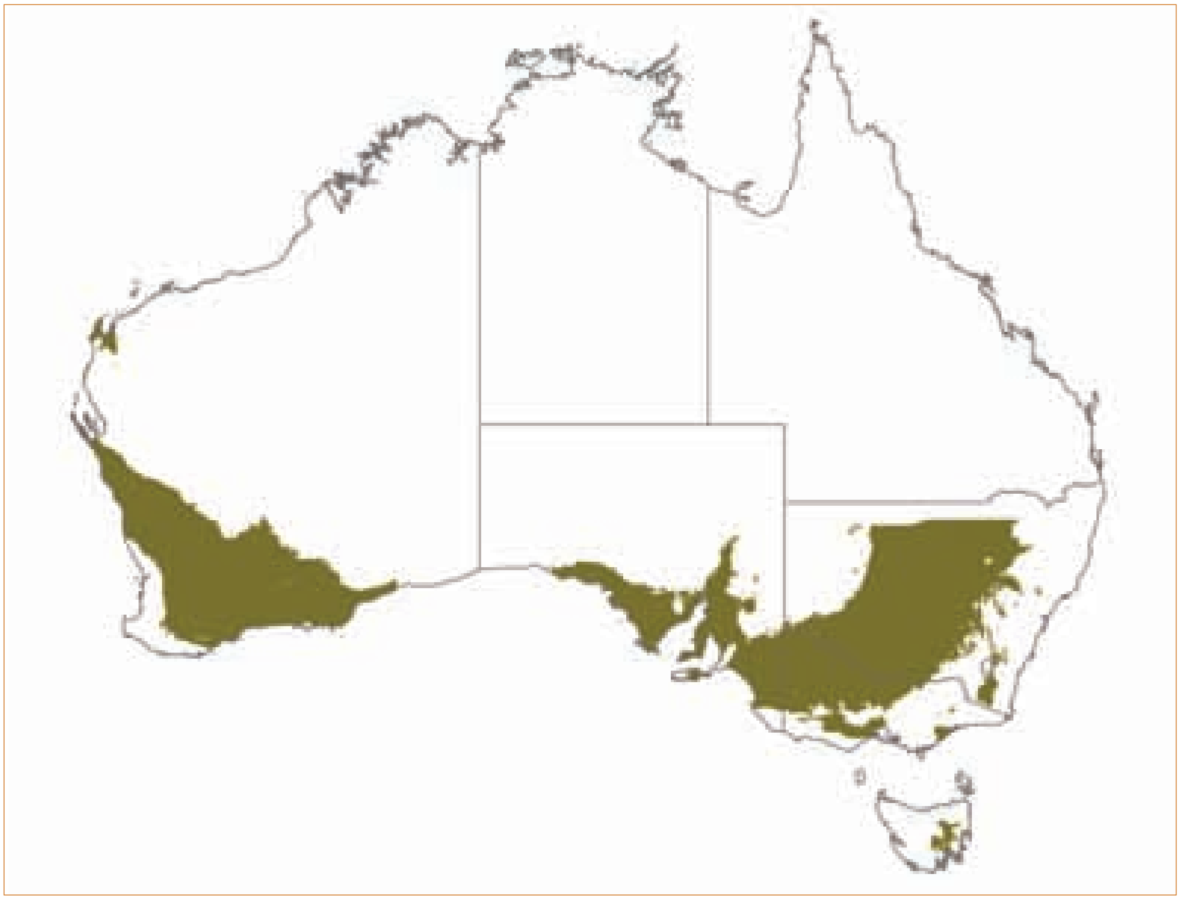
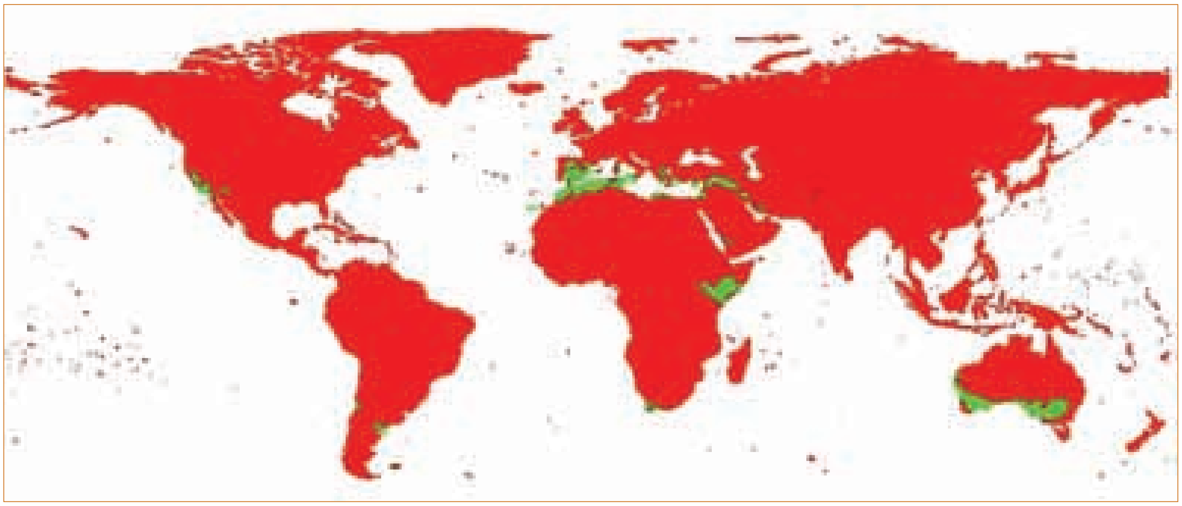


Figure 3. World – Green areas indicate parts of the winter and uniform rainfall zone receiving mean annual rainfall between 150 and 650 mm.



In consultation with Mark Ellis of DLWBC, these climatic indicators were modified to enable the inclusion of species which grow in less favourable conditions. For example the lower rainfall limit was dropped from 250 mm to 150 mm, and the minimum temperature of the coldest month was reduced from 2°C to 0°C.

Figure 2 illustrates the region of Australia which fits the agreed climatic indicators (see Table 7). From these indicators a list of countries that either fully or partially matched the climate criteria were determined (Figure 3). The countries are:

Afghanistan	Algeria	Argentina
Belgium	Chile	Egypt
Ethiopia	France	Greece
Iran	Iraq	Israel
Italy	Kenya	Libya
Mexico	Morocco	Portugal
Somalia	South Africa	Spain
Syria	Tunisia	Turkey
United Kingdom	USA – California	USA – Nevada

By using the criteria in Table 7 a list of species was generated using available databases, a variety of printed references, and seeking out suggestions from international networks.

3.3.3 Information sources

3.3.3.1 Databases

The Forestry Compendium Global Module (CABI 2003), International Centre for Research in Agroforestry (ICRAF) Multipurpose Tree and Shrub (von Carlowitz *et al.* 1992), and the Tree and Shrub Selection Guide (for South Africa) (von Malitz *et al.* 1996) databases were used to produce a broad species list. The Forestry Compendium was searched using all the climatic indictors listed in Table 7 to generate a list of species that either fitted or approximately fitted each criteria. The ICRAF Multipurpose Tree and Shrub Database could not be searched with as much precision, allowing only mean annual rainfall and mean annual temperature as search criteria. The Tree and Shrub Selection Guide (for South Africa) database could only be searched using specific climatic indicators, rather than ranges for the various criteria. A location with a mean annual temperature of 17°C, mean maximum temperature of the hottest month 26°C, mean minimum temperature of the coldest month 7°C and a mean annual rainfall of 348 mm was chosen.

Table 7. Agreed climatic indicators for the study area of Australia.

Constraint	Value
Annual rainfall (winter or uniform regimes)	150-650 mm
Mean maximum temperature of the hottest month	23-35°C
Mean minimum temperature of the coldest month	0-8°C
Mean annual temperature	12-18°C
Absolute minimum	> -6°C
Dry season duration (<40mm per month)	3-12 months

These searches generated a list of 65 species that approximately fitted the climate of the target area, however additional information was required to determine their suitability for cultivation.

3.3.3.2 Printed references

Hall *et al.* (1972), Simpfendorfer (1981) and Cremer (1990) provide information on exotic plant species in Australia. Tables within these texts contain some information on climatic requirements of exotic species. From these references a list of 23 species was formed, and then further references were consulted to determine their suitability for the study area and product potential.

3.3.3.3 International networks

Fifty-four letters were sent out to overseas networks in an attempt to determine the current species being researched/tested for low rainfall areas in various countries. The list of networks included: the Food and Agriculture Organisation (FAO) Panel of Experts on Forest Gene Resources, FAO's Silva Mediterranea Group, International Plant Genetic Resource Institute (IPGRI), and World Agroforestry Centre (ICRAF). The text of this letter is attached in 3.9 Appendix 1 – Text of Letter Sent to International Networks.

The letter defined the problem and how this project aims to help solve it. The recipients were asked to provide information on species that they are currently researching or know of that fit the criteria. Included was a map produced using the WORLD climatic mapping program (Booth *et al.* 2002), which highlighted the areas of interest in the world with a similar climate to the study area (Figure 3). This showed recipients which areas we were targeting, so no assumptions had to be made. Responses were then collated, their suitability determined and species recommendations integrated into the tables.

3.3.4 Selection criteria

It is not feasible to generate a list of species and expect that they all will provide suitable products, have desirable characteristics, and not have high weed potential. Therefore these lists were sorted using the characteristics listed in Table 8 to produce four tables. Species were not deleted from a table unless they were already native to Australia, were not a tree or shrub, or further investigation showed they didn't match the climatic indicators. The tables are: potentially suitable species (section 3.4.1); potentially suitable species from summer rainfall zones (section 3.4.2); less suitable species (section 3.4.3); and unsuitable species (section 3.4.4).

3.3.5 Genetic material

The ICRAF Tree Seed Suppliers Directory (http://www.worldagroforestrycentre.org/Sites/TreeDBS/TSSD/treessd.htm) provides a comprehensive list of seed suppliers and the species they stock. This database was used to compile a list of seed suppliers for each species listed in Table 9, and is presented in 3.10 Appendix 2 – Seed Suppliers, with the corresponding number referring to the numbers in Table 9 under "*seed suppliers*". There are three species for which no seed supplier could be found. Due to the large number of seed suppliers, no attempt was made to determine what provenances are available from these sources. This exercise could form part of a follow-up component of this research.

3.4 Results (Species Lists)

The entire list of species found to match the climatic indicators is presented in one of the following four tables. Species were only deleted if they were native to Australia, were not a tree or shrub, or did not match the climatic indicators.

The distribution of the species is presented under "*origin*". The continent(s) in which it occurs is underlined, following this are the countries in which the species naturally occurs and **also** have climatic conditions which match the study area. If it did not naturally occur in a country with matching climatic conditions, but was introduced into one, then this was highlighted. When known to be planted in Australia, the states were listed in abbreviated form.

The "*rainfall range*" presents the entire rainfall range of sites where the species either occurs naturally, or is planted. Some of these have a very large range, for example, *Albizia julibrissin* where the range is 100-2300 mm. This indicates the species grows over a very large area, and, as such, grows on many different site types. It generally indicates that careful selection of germplasm is required due to the potential of large genetic variation throughout the distribution. Although there is the exception, for example, *Pinus torreyana*, which has virtually no genetic variation, yet has shown adaptability across a range of sites, albeit in the Australian Capital Territory.

Where known the tolerances ("*tolerates*") of each species were recorded. Although this information should be used with caution, it does provide a useful insight into the properties of many species. For example, it would be expected that every species is drought tolerant given one of the climatic indicators is a dry season of 3-12 months, but this might not be the case. It may indicate that different authors have different opinions on what is drought tolerant. It may also indicate that while the species grows in a low rainfall zone with a long dry season, it could be sourcing its water through the water table. Alternatively the plant might be dormant during dry periods, therefore adapted to dry periods, but not drought resistant as such. Tolerance to wind (eg. does not fall over easily) indicates that the species has an extensive root system, but if "Wi" is absent from the table for a particular species it does not mean that it does not have a deep or extensive root system. Indication of frost tolerance should be carefully interpreted as well. All the species listed have an absolute minimum temperature limit of minus 6°C or colder, but this does not indicate their tolerance to out of season frosts. Particular care should be taken with species that exhibit dormancy. These species generally originate from areas that have a defined cold period, when the species is dormant, and a growing season, where frosts are absent or very minor in number and severity. Hence their sensitivity to out of season frosts.

Table 8. Characteristics used to rank the species that fitted or approximately fitted the climatic indicators given in Table 7.

Broad Characteristic	Specific Attributes
Biological	Moderate to fast growth rate, coppice/suckering ability, self pruning, low or no weed potential, rainfall requirements.
Plant Form	Habit, root structure, not bearing thorns.
Wood and/or Non-wood use	Major uses, multi-purpose potential.
Soil Preference	Broadness of preference, tolerances, intolerances.
Land Use Benefits	Soil improvement, erosion control, soil conservation.
Tolerances	Fire, drought, waterlogging.

"Site type" has been divided into two categories, '*soils*' and '*habitat*'. Where known, the soils of sites where a particular species occurs naturally or is planted are defined. Habitat contains any information found on the climate types and site conditions of natural and planted occurrences.

The "*wood*" qualities/characteristics have been presented in the terms used by the references cited. Many of these terms are unquantified except where density in kg m^{-3} or specific gravity in g cm^{-3} is provided.

The "*crop type*" is presented in the same format as Maslin & McDonald (*in press*). Short rotation coppice (SRC), are long lived species that readily coppice from the stump and can be harvested every two to five years. Short rotation phase (SRP), are short lived species used for locally lowering the water table, and can be harvested in three to six years. The species listed as suitable for SRP in this report are also nitrogen fixers. Long rotation (LR), are trees of erect form selected and managed over 10 to 100 years. Long cycle crops are grown for solid wood products, for example sawn timber and roundwood. Coppice and phase crops are grown for composite wood, chemical extracts and bioenergy (Maslin & McDonald *in press*).

Suitability of species for *"general use(s)"* such as land protection and soil stabilisation have been noted. Australian Standards (2001) have a list of important, or potentially important, timber species of commercial interest to Australia. Species noted in this list are marked with a "Y" under "*Standards Australia*". Similarly, the FAO (2000) publishes a list of species that the FAO Panel of Experts on Forest Gene Resources consider to be high priority forest tree species. This data can be accessed at http://www.fao.org/forestry/foris/webview/forestry2/index.jsp?siteId=1500&langId=1 and the species listed in this document are also marked with a "Y" under "*FAO Listed*".

"Seed suppliers" are given for the species where a supplier appears in various catalogues. Just because a supplier is listed does not mean they will have suitable germplasm for planting in the study area. Supplier details have been coded alphabetically by country from one to 37. The reference table to these numbers is provided in 3.10 Appendix 2 – Seed Suppliers.

The reference(s) of information used to prepare these tables are presented under *"source"*.

3.4.1 Potentially suitable species

Species that were reported to have moderate to fast growth rates are presented in Table 9. Within this table, species were subjectively ranked one to three, using available information, indicating how well they matched the characteristics in Table 8. With further research these rankings may change as new information is accessed/published.

3.4.2 Potentially suitable species from summer rainfall zones

The species that matched the climatic indicators, except for rainfall regime are presented in Table 10. They have been included as some species can be exchanged freely between rainfall zones with no apparent negative affect on their performance. An example of this is *Robinia pseudoacacia* which is native to the highlands of eastern United States of America. The majority of rainfall is in the summer, however, it has proven adaptable to winter rainfall regimes (Hall *et al.* 1972). The species have been ranked the same way as Table 9, with the assumption they are exchangeable between rainfall regimes.

3.4.3 Less suitable species

The species that were reported to have slow growth rates, or insufficient information was available to make an informed decision on their performance, are presented in Table 11. They have been ranked as either "four" or "five", respectively. Species ranked as 'four' are still potentially suitable as limited quantitative data is available on growth rates in dry zone areas. These species, although reported as having slow growth rates, may yet prove, with species/provenance testing to provide acceptable growth and biomass rates. Species ranked as "five" did not have sufficient information available to make a judgement on their expected performance.

3.4.4 Excluded species

The species listed in Table 12 have been deemed by the author to be unsatisfactory for the study area, although they were found to match the climatic indicators. They have certain characteristics which made them undesirable. For example, they may only grow on wet sites, bear thorns or prickles, or are Weeds of National Significance. The reason for exclusion is provided.

Table 9. Potentially suitable species.

Ranking	Botanical Family	Taxon Name	Habit	Origin	Rainfall Range	Tolerates	Site Type - Soils
1	*Cupressaceae*	*Cupressus arizonica*	Tree 20-25m, DBH (-75)cm, straight stem.	North America. Mexico, California.	300-600	Dr, Fr, Wi	*Texture:* m; *Drainage:* f; *Reaction:* ac, n, alk; *Tolerates:* sh; *Soils:* calcareous, clay, granite, limestone, sandstone. Doesn't tolerate humid or sandy soils, grows best on fertile soils. pH=5.5-8.3.
1	*Cupressaceae*	*Cupressus sempervirens*	Medium tree 30m, DBH 50-60cm, straight stem.	Europe, Asia, Africa. Greece, Italy, Portugal, Spain, Iran, Syria, Libya. Intro: ACT, WA.	300-900	Dr, Fr, Ter, We, Wi	*Texture:* h, *Drainage:* f, *Reaction:* ac, n, alk. *Tolerates:* sh, inf. *Soils:* arid, calcareous, clay. Requires certain amount of clay in soil. Tolerates rocky, clayey soils, which become very dry in summer.
1	*Cupressaceae*	*Cupressocyparis leylandii*	Hybrid tree 18-21(-40)m.	Intro: Europe, Africa, Asia, North America. Belgium, Italy, Spain, UK, Kenya, California, Australia - NSW, SA, Tas, Vic.	450-1800	Dr, Fr, Sh, WL	*Texture:* l, m, h; *Drainage:* f; *Reaction:* ac, n, alk; *Tolerates:* inf.
1	*Fabaceae*	*Albizia julibrissin*	Deciduous tree 6-12m. Straight stem, occasionally multi-stemmed.	Asia, Africa. Afghanistan, Iran, Ethiopia, Somalia.	100-2300	Dr, Fr, Wi	*Texture:* l, m, h; *Drainage:* f; *Reaction:* ac, n, alk; *Tolerates:* sal, high pH, inf; *Soils:* prefers fertile, well drained, sandy loam - medium loam soil.
1	*Fabaceae*	*Leucaena pallida*	Small multi-stemmed tree 3-7m, DBH 10-15cm.	North America. Mexico. Intro: Qld.	500-1500	Dr, Fr	*Texture:* l, m; *Drainage:* f; *Reaction:* n, alk; *Soils:* shallow calcareous.
1	*Fagaceae*	*Quercus coccifera*	Shrub 1-1.5(-4)m	Europe, Asia, Africa. France, Greece, Italy, Portugal, Spain, Syria, Libya, Morocco, Tunisia.	200-1500	Dr, Fi, Sh, Wi	*Texture:* l, m, h; *Drainage:* f; *Reaction:* ac, n, alk; *Tolerates:* sh, inf; *Soils:* loamy.
1	*Fagaceae*	*Quercus faginea*	Semi-deciduous tree 20-25m.	Europe, Africa. France, Portugal, Spain, Morocco, Tunisia.	350-2000	Dr, Fi, Fr, Sh	*Texture:* l, m, h; *Drainage:* f, sw; *Reaction:* ac, n, alk; *Tolerates:* sh; *Soils:* basic soils, mostly limestone.
1	*Oleaceae*	*Fraxinus ornus*	Small tree 10m, DBH 40-60cm.	Europe, Asia. France, Greece, Italy, Spain.	400-1200	Dr, Sh, Wi	*Texture:* l, m, h; *Drainage:* f, imp; *Reaction:* n, alk; *Tolerates:* sh, inf; *Soils:* calcareous, loam rock, prefers good soils.
1	*Pinaceae*	*Pinus pinea*	Tree 25-30m, DBH (-150cm), straight stem - no branches for 2/3 of height.	Europe. France, Greece, Italy, Portugal, Spain, Syria. Intro: NSW, SA, Vic, WA.	300-1500	Dr, Fr	*Texture:* l, m, h; *Drainage:* f, sw; *Reaction:* ac, n, alk; *Tolerates:* sh, inf; *Soils:* grows in most soils, including very poor, except marshy soils, or along the coast, pH 4-9. Moderately tolerant of salinity.

Table 9. Potentially suitable species continued…

Site Type - Habitat	Wood	Crop Type	Primary End Use(s)	General Uses	Comments	Standards Australia	FAO listed	Seed Suppliers	Source
Arid mountain regions, low humidity. Low elevation: canyon bottoms and ravines. High elevation: NE-NW exposed ridges and slopes.	Similar to *C. sempervirens*. Large knots which often spilt during drying, less durable than other Cupressus species.	LR	Sawn timber, round wood, fuel.	EC, LR, R, SC	Low economic importance. Susceptible to *Cinara cupressi*.	Y	Y	2, 3, 4, 5, 12, 16, 17, 18, 23, 24, 25, 27, 28, 34, 35, 36, 37, 38	Streets (1962), Rout & Doran (1974), CABI (2003)
Suitable in unfavourable conditions, hilly terrain.	High quality, very durable in water, fine grain, odour repels numerous harmful insects, easy to glue, easy to work. Colour: yellow-pink.	LR	Sawn timber, wood composites, round wood, tannin.	EC, R, SC	Pest - Cypress Canker, although resistant clones available. Dry season 0-3 months. Provenance selection important. Roots: well developed.	Y	Y	3, 4, 10, 12, 15, 16, 17, 18, 19, 23, 25, 27, 28, 29, 30, 31, 34, 35, 36, 37	Booth & Saunders (1984), CABI (2003), E-mail response.
Tolerates wide range of site conditions.	Softwood, good timber value.	LR, SRC	Round wood, pulp, fuel.	A, LR	Hybrid *Cupressus macrocarpa* x *Chamaecyparis nootkatensis*. Little use as plantation species although good wood.	Y			CABI (2003)
Southern exposure preferred, adapts well to arid conditions.	Dense and hard.	LR, SRC, SRP	Sawn timber, food, fodder.	A, EC, LR R, SI	Fungus a problem in USA - attacks roots. Toxic amino acids in seeds. Light demanding. Roots: extensive system.			2, 3, 4, 24, 25, 28, 31, 34, 35, 36, 37	CABI (2003), ICRAF (2003)
Mid interior highlands of south central Mexico, also tropics.		SRC, SRP	Tannins, food, fodder.	A, EC, LR, R, SC, SI	Imported seed must be grown in quarantine.			32, 33	Lefroy (2002), CABI (2003), ICRAF (2003)
Occurs on degraded land. Low elevation grasslands, Mediter-ranean climate.		SRC	Fuel, tannin.	EC, R, SC, SI	Abs. min - no data.			23, 28, 36	Ainalis & Tsiouvaras (1998), Ciesla (2002), CABI (2003)
		SRC	Fuel, fodder.	EC, SC, SI				28, 36	CABI (2003)
Arid regions, common on south facing slopes. In Victoria used as an ornamental in good soils on moist sites.	Hard, resilient, elastic, oily to touch when worked.	SRC	Fuel, fodder, resin.	EC, SC, SI	Light demanding.			3, 6, 12, 25, 28, 34, 35, 36, 37	Streets (1962), CABI (2003)
In semi-arid areas growth is dramastically reduced.	Mediocre quality, resinous and heavy, SG 0.5-0.7 g cm-3, coarse texture. Colour: sapwood large amount whitish-pink, heartwood yellow-reddish.	LR	Sawn timber, wood composites, pulp, food, tannin.	EC, LR, SC	Experimental plantings in early 20th century in Australia are almost gone. Light demanding. Roots: shallow taproot 60-180cm, but extensive root system.	Y	Y	2, 3, 4, 5, 12, 23, 24, 25, 26, 28, 30, 31, 34, 35, 36, 37	Booth & Saunders (1984), CABI (2003), E-mail response

Table 9. Potentially suitable species continued…

Ranking	Botanical Family	Taxon Name	Habit	Origin	Rainfall Range	Tolerates	Site Type - Soils
1	*Pinaceae*	*Pinus brutia and P. eldarica*	Tree 25m, straight stem.	Europe, Asia. Greece, Iraq, Syria. Intro: SA, ACT, WA.	400-1300	Dr, mod Fi, mod Fr	*Texture:* l, m; *Drainage:* f, imp; *Reaction:* n, alk; *Tolerates:* sh, inf; *Soils:* marls, limestone, dolomites, acid sands, volcanic rocks, sandstone.
1	*Ulmaceae*	*Ulmus hollandica*	Hybrid between *U. glabra* and *U. minor*. Single stem.	Europe: Belgium, France, Italy. Intro: Australia.	550-1000	Wi	*Texture:* l, *m, h; Drainage:* f, *sw; Reaction:* ac, n, alk; Tolerates: sodic, sal.
2	*Aceraceae*	*Acer rubrum*	Medium tree 18-27m.	North America. Canada, USA. Intro: WA.	600-1670	Dr, Sh, We, Wi, WL	*Texture:* l, m, h; *Drainage:* f, imp, sw; *Reaction:* ac, n; Tolerates: sh; *Soils:* well drained, moist, fertile.
2	*Fabaceae*	*Chamaecytisus proliferus*	Shrub or small tree 7-8m, if multi-stemmed 5-7m.	Europe. Canary Islands. Intro: Australia.	450-1000	Fi, Fr	Favours well drained loamy or sandy soils, but thrives on gravels, loams, limestones and laterites.
2	*Fagaceae*	*Quercus trojana*	Small to medium tree 5-16m, DBH 100cm.	Europe, Asia. Greece, Italy.	600-800	Dr	*Texture:* m; *Drainage:* f; *Reaction:* ac, n; *Soils:* prefers limestone to clay.
2	*Oleaceae*	*Fraxinus pennsylvanica*	Medium tree 15-18(-37)m, DBH 46-60 (-75)cm, good form.	North America. Canada, USA.	380-1500	WL	*Texture:* l, m, h; *Drainage:* f, imp, sw; *Reaction:* ac, n, alk ; *Soils:* wide ranging from clays subject to water-logging to sandy soils with limited moisture.
2	*Pinaceae*	*Pinus halepensis*	Tree 20-25m.	Europe, Asia, Africa. France, Greece, Italy, Spain, Israel, Algeria, Libya, Morocco, Tunisia. Intro: NSW, SA, WA.	150-900	Dr, Fi, Ter	*Texture:* l, m, h; *Drainage:* f; *Reaction:* ac, n, alk; *Tolerates:* sh, inf; *Soils:* marls, limestone, dolomites, luvisols, rendzinas, clay-loams, sandstones, heavy clays to poor sandy podsols.
2	*Pinaceae*	*Pinus jeffreyi*	Large tree 25-50(-60)m, DBH 120-230 (-300)cm.	North America. Mexico, California, Nevada. Intro: ACT, NSW, Vic, WA.	380-1500	Fi	*Texture:* l, m, h; *Drainage:* f; *Reaction:* n; *Tolerates:* sh, inf ; *Soils:* inceptisols, entisols, alfisols, ultramafic. Parent material - granite, igneous, metamorphic, sedimentary, volcanic, sandstone, serpentine.
3	*Pinaceae*	*Pinus muricata*	Tree 12-24 (-30)m, DBH 60-90(-100)cm. Stem form variable, influenced by site condition, usually straight and clean, although tends to fork.	North America. Mexico, California. Intro: Qld, SA, ACT, NSW, Tas, Vic, WA.	380-2000	Fr, Sh, Wi, WL	*Texture:* l, m, h; *Drainage:* f; *Reaction:* n, alk; *Tolerates:* inf; *Soils:* ideal site has porous sandy to sand-loam soils.

Table 9. Potentially suitable species continued…

Site Type - Habitat	Wood	Crop Type	Primary End Use(s)	General Uses	Comments	Standards Australia	FAO listed	Seed Suppliers	Source
Mediterranean climates, subhumid to semi-arid areas, less frequently arid.	Medium density 536-550 kg m-3, high resistance to compression, medium resistance to flexing, fibre suited for kraft pulping.	LR	Sawn timber, wood composites, round wood, pulp, resin.	R	Provenance of seed is critical. Resin tapping doesn't have adverse affect on wood *or seed production.*	Y	Y	1, 4, 5, 10, 12, 15, 24, 28, 31, 33, 32	Booth & Saunders (1984), Spencer (2001), CABI (2003)
	Excellent timber.	LR, SRC	Sawn timber, veneer, fuel, fodder.	A	Dutch Elm Disease has limited its use. Dry season - no data.				CABI (2003)
	Heavy SG 0.49-0.54 g cm-3, close grained.	LR	Sawn timber, wood composites, veneer, pulp.	EC, LR, R, SC	The wood is not high quality due to susceptibility of defects and diseases, and poor quality of coppice. Can be managed to produce good quality sawlogs.			2, 4, 7, 8, 9, 34, 35, 36, 37	Booth & Saunders (1984), Ciesla (2002), CABI (2003)
Dry climates.		SRC, SRP	Fuel, fodder.	EC	In some parts of temperate Australia can become a weed. Closely allied to brooms and gorses which are well known weeds. Only worthwhile planting on very deep, well drained soils, other sites *Atriplex nummularia* is a better performer.			1, 5, 6	Cremer (1990), Snook (1996), ICRAF (2003)
		LR, SRC	Fuel, food, woodware.	A, SI	Susceptible to fungi - *Botryosphaeria stevens* and *Armillaria mellea.*				CABI (2003)
Moist bottomlands, stream banks, intolerant of shade. Hardy to climatic extremes. Wetlands species.	Similar to other Ash species. Colour: white.	SRC	Fodder.	LR, R	Good resistance to disease and insects. Light demanding. Dry season, annual temp, abs. min - no data.			2, 4, 8, 36, 37	Conner et al. (1997), CABI (2003)
Dunes, coastal plant communities, coniferous forests, sclerophyllous forests and scrub.	Coarse grained, resinous, moderately dense, poor quality, high proportion of compression wood. Colour: yellowish brown.	LR	Sawn timber, round wood, fuel.	A, EC, R, SC, SI	Weed in Australia. Invaded disturbed mallee in SA, and spread into *E. marginata* forest in WA.Widely planted in South Australian 450-750mm yr-1 winter rainfall zones.			2, 4, 8, 12, 15, 23, 24, 28, 30, 31, 32, 34, 35, 36, 37	CABI (2003)

Table 9. Potentially suitable species continued…

Site Type - Habitat	Wood	Crop Type	Primary End Use(s)	General Uses	Comments	Standards Australia	FAO listed	Seed Suppliers	Source
Long cold winters, moderate summers. Montane habitats. Doesn't grow well with weeds.	Similar to *P. ponderosa*. General purpose.	LR	Sawn timber, wood composites, pulp.		Hasn't shown success as plantation tree outside natural range. Light demanding. Roots: deep taproot, extensive lateral roots.	Y	Y	13, 24, 28, 34, 35, 36, 37	Rout & Doran (1974), Booth & Saunders (1984), CABI (2003)
Mediterranean climate, heavy fogs during dry period are important for water. Grows best on swampy sites and peat bogs, also grows on good soil to dry sandy plains.	Light, moderately strong, coarse grained, conspicuous resin ducts, density to 540kg m^{-3}, in NSW trial - wood marginally stronger than *P. radiata*. Colour: sapwood creamy yellow, heartwood light brown or pinkish.	LR	Sawn timber, wood composites, pulp.	EC	Wide spread regeneration after fire. In Australia trunks crooked and many cone holes, but there is wide tree to tree variation.	Y		1, 5, 7, 8, 14, 24, 34, 35, 36, 37	Rout & Doran (1974), Booth & Saunders (1984), CABI (2003)

Ranking: 1 = appearing very suitable 2 = less suitable 3 = unsuitable 4 = reported to have slow growth rates 5 = no information available on growth rates

Origin: Intro = introduced to
Tolerates: Dr = drought Fi = fire Fr = frost Sh = shade Ter = termites We = weeds Wi = wind WL = water logging
Site type – soil: texture: l = light m = medium h = heavy drainage: f = free imp = impeded sw = seasonally waterlogged reaction: ac = acid (pH < 7) n = neutral (pH = 7) alk = alkaline (pH > 7) tolerates: inf = infertile sal = salinity sh = shallow
Wood: MC = moisture content SG = specific gravity
Crop type: LR = long rotation SRC= short rotation coppice SRP = short rotation phase

General uses: A = agroforestry EC = erosion control LR = land reclamation SC = soil conservation SI = soil improvement R = revegetation

Standards Australia: listed as a commercially important tree to Australia or New Zealand (Australian Standards 2001).
FAO Listed: listed as high priority forest tree species by FAO Panel of Experts.
Seed suppliers: numeric values to be cross-referenced with section 3.10 Appendix 2 – Seed Suppliers.

Table 10. Potentially suitable species from summer rainfall zones.

Ranking	Botanical Family	Taxon Name	Habit	Origin	Rainfall Range	Tolerates	Site Type - Soils
1	*Anacardiaceae*	*Sclerocarya birrea*	Large tree 20m, DBH 70cm.	Europe, Africa. UK, Ethiopia.	200-1600	Dr	*Texture:* l, m; *Drainage:* f; *Reaction:* ac;Tolerates: sal, inf.
1	*Apocynaceae*	*Aspidosperma quebracho-blanco*	Medium tree 7-20m, DBH 30-85cm, generally straight stem.	South America. Argentina.	300-1200	Dr, Fi, WL, Wi	*Texture:* m, *h; Drainage:* f, *imp, sw; Reaction:* n, alk; Tolerates: sodic.
1	*Cornaceae*	*Cornus sanguinea*	Large shrub 2-4m (or small tree with short stem).	Europe, Asia. Belgium, France, Greece, Italy, Portugal, Spain, Iran, Iraq, Syria.	400-1400	Sh, Dr	*Texture:* m, h; *Drainage:* imp; *Reaction:* n, alk; *Soils:* frequently on calcium containing soils.
1	*Fabaceae*	*Pterocarpus angolensis*	Deciduous medium tree 10-12(-25)m, DBH 20-60 (-120)cm.	Africa. South Africa.	500-1500	Dr, Fi, Fr	*Texture:* l; *Drainage:* f; *Reaction:* ac, n, alk; *Tolerates:* inf; *Soils:* deep sandy soils. .
1	*Ginkgoaceae*	*Ginkgo biloba*	Tall, deciduous tree 30(-50)m, DBH 400 (-1000)cm. Stem straight and sparinly branched.	Asia. China, Turkey. Intro: Belgium, France, Italy, Spain, UK, Egypt, California, Chile, Australia - NSW, Vic.	330-2000	Dr, Fi, smoke, dust.	*Texture:* l, m, h; *Drainage:* f; *Reaction:* ac, n, alk;Tolerates: inf; *Soils:* alluvial, cambisols, clay, limestone, red, sandy. Grows best on deep, moist, fertile sandy loams with good drainage. Grows poorly on infertile soils in rocky, mountainous areas. D
2	*Betulaceae*	*Alnus nepalensis*	Tree 28-35m. Straight, clean stem.	Asia. Bhutan, China, India, Nepal.	500-2500	Fi (when matrure), We, Dr	*Texture:* l, m, h; *Drainage:* f, imp, sw; *Reaction:* ac, n; *Tolerates:* inf; *Soils:* acid, mountain, red, sandy, subtropical.
2	*Fabaceae*	*Styphnolobium japonicum*	Deciduous tree 25m, DBH 70cm.	Asia. China. Intro: Italy, Spain, UK.	600-1600	Sh, Dr, Fr	*Texture:* l, m; *Drainage:* f; *Reaction:* n, alk;Tolerates: sodic, sal; *Soils:* prefers deep moist, fertile, well drained sandy soils, and preforms well on limestone and saline (<0.15%).
2	*Rosaceae*	*Prunus dulcis*	Small tree 4-6m.	Europe, Asia. Afghanistan, Iran, Syria. Intro: NT, Qld, WA.	40-450	Dr	*Texture:* l, m; *Drainage:* f; *Reaction:* n, alk;Tolerates: sh, sal.
3	*Juglandaceae*	*Juglans nigra*	Tall tree 50m, DBH 150cm. Long clear stem, in open branches low down	North America. Canada, USA. Intro: Belgium, France, Italy, Spain, UK, Morocco, California, Australia - Tas, Vic, WA.	600-1800		*Texture:* l, m; *Drainage:* f; *Reaction:* ac, n, alk; *Soils:* good water holding capacity, good aeration, heavy and very light soils not suitable, grows well on deep fertile soils with low clay content, pH 6.5-7.5.
3	*Tamaricaceae*	*Tamarix chinensis*	Shrub or small tree 8m, DBH 30cm, deciduous.	Europe, Asia. Iran, Iraq.	50-1500	Dr, WL, Wi, Fr	*Texture:* l, m, h; *Drainage:* f, imp, sw; *Reaction:* ac, n, alk;Tolerates: sh, sodic, sal, inf.

Table 10. Potentially suitable species from summer rainfall zones continued…

Site Type - Habitat	Wood	Crop Type	Primary End Use(s)	General Uses	Comments	Source
	Light 560kg m^{-3} air dried, considerable distortion, tending to collapse and split, not durable. Colour: pinkish white.	SRC, LR	Sawn timber, food, fodder.	A		CABI (2003)
Dry forests.	Hard, heavy, flexible. Colour: Yellow to rose.	SRC, SRP	Sawn timber, woodware, tannins.	SI, LR, SC	Suseptable to defoliation by lepidopteran larvae.	CABI (2003)
Banks of rivers.	Heavy, hard, strong. Not much economic importance.	SRC	Pulp, fuel.	A, EC		CABI (2003)
	Resistent to termites.	SRC, SRP, (LR?)	Sawn timber, veneer, tannin.	A, SI	Annual temp, abs. min - no data.	CABI (2003)
Grows well with warm and dry spring and winters and moist and warm summers.	Fine texture, soft grain, resistent to decay, light density 450kg m^{-3}, high quality. Colour: sapwood light yellow, heartwood light yellowish brown.	SRC	Food, medicinal.	A	Light demanding. Will not be suitable for wood production in study area, but may have potential if grown for medicinal purposes.	CABI (2003)
Moist, cool, subtropical, best growth with >500mm rainfall and relative humidity >70%. Can't tolerate continued water logging.	Soft but tough, even grain. SG 0.32-0.37 g cm^{-3}, density 320-370 to 480-590 kg m^{-3}.	SRC	Sawn timber, pulp, fuel, fodder.	SI, EC, R, A	Light demanding.	CABI (2003)
Will not grow on waterlogged sites. Can't produce quality timber in excessively dry, exposed, or infertile soils.	Hard, elastic, straight grain. Colour: sapwood thin white, heartwood yellowish brown.	SRC, LR	Sawn timber, fodder.	A	Roots: deep, well formed.	CABI (2003)
		(LR?)	Sawn timber, food, fodder.	A		CABI (2003)
Aviod areas with out of season frosts, unsuitable where >4 days standing water at a time.	Heavy, hard, strong, heartwood durable.	LR	Sawn timber, veneer, fuel, food.	A, R, LR, SC	Dry season - no data. Roots: deep taproot, several lateral roots.	CABI (2003)
Muddy seashores.		SRC	Wood composites, pulp, fuel, fodder.	A, SI, R, LR, SC, EC	Salinity causing - leaves exude salt. Grows in extreme salt (1% or 15,000 ppm) and can effectively reduce the salt content, but brings salt to surface of non-saline areas. Invasive in USA, looking for biological control agents. Roots: deep taproot and fin	CABI (2003)

Tolerates: Dr = drought, Fi = fire, Fr = frost, Sh = shade, Ter = termites, We = weeds, Wi = wind, WL = water logging.
Site Type - Soils: texture: l = light, m = medium, h = heavy; drainage: f = free, imp = impeded, sw = seasonally waterlogged; reaction: ac = acid, alk = alkaline, n = neutral; tolerates: inf = infertile, sal = salinity, sh = shallow.
Wood: SG = specific gravity, MC = moisture content.
Crop Type: LR = long rotation, SRC = short rotation coppice, SRP = short rotation phase.
Uses: A = agroforestry, EC = erosion control, LR = land reclaimation, R = revegetation, SC = soil conservation, SI = soil improvement.

Table 11. Less suitable species.

Ranking	Botanical Family	Taxon Name	Habit	Origin	Rainfall Range	Tolerates	Site Type - Soils
4	*Betulaceae*	*Betula utilis*	Shrub to medium size tree 20m, irregular stem.	Asia. Afghanistan	200-600	Dr	*Texture:* l, m; *Drainage:* f; *Reaction:* n.
4	*Cupressaceae*	*Calocedrus decurrens*	Large tree 20-50 (-70)m, shrub on high altitude dry sites. DBH 100-250cm. Straight stem, buttress on large trees.	North America. Mexico, California, Nevada.	500-2000	Dr(seedlings sensitive in first year), Fi, Sh, Fr	*Texture:* l, *m, h; Drainage:* f; Reaction: very ac, *n; Tolerates:* inf, sh; Soils: alfisols, granite, mountain, serpentine, volcanic. Grows best on deep, moderately acid granitic and sandstone soils, as well as deep dry loam soils from basalt and andesite.
4	*Cupressaceae*	*Cupressus duclouxiana*	Tree.	Asia. China.	600-2500	Dr, Fr	*Texture:* l, m; *Drainage:* f; *Reaction:* ac, n ; Tolerates: inf; *Soils:* wide range.
4	*Cupressaceae*	*Juniperus virginiana*	Large shrub to small tree to tree 10-30 (-37)m, DBH 100(-160)cm.	North America. Canada, USA. Intro: Belgium, UK.	380-1520	Dr, Wi, Fr	*Texture:* l, m; *Drainage:* f, imp, sw; *Reaction:* ac, n ; *Tolerates:* sh; *Soils:* ultisols, grows best on deep, moist, well drained alluvial, soil depth >30cm, pH 4.7-7.8.
4	*Fabaceae*	*Albizia amara*	Small to moderate deciduous tree 6-9m. Clear stem 2.5-3.0m, crooked stem.	Asia. India, Sri Lanka. Intro: Ethiopia, Kenya, South Africa.	500-1000	Dr, Fr (when mature)	*Texture:* l; *Drainage:* f; *Tolerates: sh,* inf.
4	*Fagaceae*	*Quercus frainetto*	Deciduous tree 30-40m, DBH 350cm, straight stem.	Europe, Asia. Greece, Italy	400-1200	Sh, Fr	*Texture:* l,m; *Drainage:* f; *Reaction:* ac, n, alk.
4	*Fagaceae*	*Quercus macrocarpa*	Tree.	North America. Canada, USA. Intro: France.	380-1280	Dr	*Texture:* l, m, h; *Drainage:* f; *Soils:* fertile limestone soils.
4	*Hamamelidaceae*	*Liquidambar formosana*	Tree.	Asia.	600-2500	Fr	*Texture:* l, m; *Drainage:* f; *Reaction:* ac, n; *Tolerates:* inf.

Table 11. Less suitable species continued…

Site Type - Habitat	Wood	Primary End Use(s)	General Uses	Comments	Source
	Tough, even grained, seasons well, durable undercover. Colour pinkish white. Ave mass 694kg m^{-3}.	Veneer, fuel, fodder.	R, LR, SC, EC	Susceptible to heavy browsing, not commercially exploited. Annual temp, mmthm, mmtcm, abs min - no data. Light demanding.	CABI (2003)
Lower and drier portions of mixed conifer forests. Dry summers, cool moist winters, most abundant on hot and dry south facing slopes. Uncommon on limestone. For establishment - well drained soils in the open.	Durable, resistant to decay when exposed to moisture, straight grain, hard knots, pleasant fragrance.	Sawn timber, roundwood.	R, SC, EC	Roots: spreading and extensive, slow growth in first year but extend rapidly after this.	CABI (2003)
Montane regions of China	Good quality timber.	Sawn timber, veneer.	SC	Occurences in lower end of rainfall range would need supplementary water for good growth, therefore growth rates would be slow.	CABI (2003)
Dry rock outcrops to wet swampy land.	Resistant to insect and disease attack, durable, workable, low strength, high stock resistance, numerous knots, moderately heavy SG 0.44 g cm^{-3}, density 530kg m^{-3} at 12% MC. Colour: sapwood white, heartwood red to darkish brown.	Sawn timber, oils.	SI, EC, SC	Dry season, mmtcm, abs min - no data. High calcium content in foliage, seed dispersed by birds, host of cedar apple rust - problem for apple growers. Roots: fibrous. Light demanding.	CABI (2003)
	Hard, heavy.	Sawn timber, fodder.	SI, R, LR	Rainfall regime, dry season, annual temp, abs min - no data.	CABI (2003)
Sensitive to cold winds, requires good light and nutrients for good growth.	Fine grain.	Sawn timber, fuel, fodder.	R, SC, EC		CABI (2003)
Dry uplands, sandy plains, moist bottomlands.	Commercially valuable.	Sawn timber, roundwood.	R	Dry season, annual temp, mmthm - no data	CABI (2003)
		Sawn timber, resin, fodder.		Occurences in lower end of rainfall range would need supplementary water for good growth, therefore growth rates would be slow.	CABI (2003), Ciesla (2002)

Table 11. Less suitable species continued…

Ranking	Botanical Family	Taxon Name	Habit	Origin	Rainfall Range	Tolerates	Site Type - Soils
4	*Juglandaceae*	*Carya ovata*	Large tree 39m, deciduous.	North America. Canada, Mexico, USA	600-2100	Wi, Sh	*Texture:* l, m, *h; Drainage:* f; *Reaction:* ac, n; *Soils:* ultisols, alfisols, mollisols, alluvial. Moist soils of alluvial origin.
4	*Juglandaceae*	*Juglans regia*	Deciduous tree 25-30m, DBH 150cm, straight stem.	Europe, Asia. Greece, Afghanistan, Iran, Iraq, Syria. Intro: WA.	600-2000		*Texture:* l, *m; Drainage:* f; Reaction: n, *alk; Soils:* arid, chemozems, chestnut, loess, sandy. Grows on fertile, deep, well drained, non-stratified loamy soil, anything else will effect root health therefore tree size and vigour.
4	*Oleaceae*	*Fraxinus angustifolia*	Medium tree 25m.	Europe, Asia, Africa. France, Greece, Italy, Portugal, Spain, Afghanistan, Iran , Iraq, Syria, Morocco, Tunisia.	500-2000	WL, Wi	*Texture:* l, m, h; *Drainage:* imp, sw; *Reaction:* ac, n, alk ;Tolerates: sal; *Soils:* wide range, although prefers deep soil with abundant soil water and light texture .
4	*Pinaceae*	*Picea orientalis*	Tree 40(-69) m, DBH (-225)cm.	Europe, Asia. Turkey. Intro: France, Australia - ACT.	600-1400	Sh	*Texture:* m; *Drainage:* f; *Reaction:* ac, n; *Soils:* deep brown, dark brown, sandy clay or silty clay forest soils.
4	*Pinaceae*	*Pinus canariensis*	Tree 30-40m, DBH 100-120cm.	Europe. Spain. Intro: SA, NSW	250-600	Dr, Fi	*Texture:* l, m; *Drainage:* f, imp; *Reaction:* ac, n, alk; *Tolerates:* sh, inf.
4	*Pinaceae*	*Pinus gerardiana*	Moderate tree 15-18m, DBH 50-80 (-120)cm.	Asia. Afghanistan	375-750	Dr, Wi, Fr	*Texture:* l, m; *Drainage:* f; *Reaction:* n; *Tolerates:* sh, inf.
4	*Ulmaceae*	*Ulmus americana*	Large tree 30-38m, DBH 150cm, stem straight and clean for 15-18m.	North America. Intro: Australia	350-1500	WL, Sh, Fr	*Texture:* l, m, h; *Drainage:* f, imp, sw; *Reaction:* ac, n, alk; *Soils:* alfisols, inceptisols, mollisols, ultisols, alluvial, pH 5.5-8.0. Best growth on rich well drained loams.

Table 11. Less suitable species continued…

Site Type - Habitat	Wood	Primary End Use(s)	General Uses	Comments	Source
Sloping upland sites, north and east facing slopes, steep rocky slopes.	Hardwood, high toughness, bending, stiffness, crushing strengths, shock resistance, dense, SG 0.72 g $cm^{-3.}$ Colour: sapwood white, heartwood pink or red to brown.	Sawn timber, veneer, fuel.	A		CABI (2003)
Dry hot climate to continental climate of Russia. Trees damaged by early and late frosts >-3°C.	Strong, heavy 670kg m^{-3} at 15% MC. Colour: dark.	Sawn timber, veneer, tannin, food.	A, R	Occurences in lower end of rainfall range would need supplementary water for good growth, therefore growth rates would be slow. Light demanding. Mmthm, mmtcm, mean annual temp, dry season duration - no data. Roots: taproot, lateral branches 3-4 times crow	Streets (1962), Booth & Saunders (1984), Ciesla (2002), CABI (2003)
	Resistant and elastic.	Sawn timber, fuel, fodder.	EC		CABI (2003)
Mountain species.		Pulp, woodware.		Vulnerable to pests especially bark beetles. In the lower rainfall areas of this species' range, growth is slow.	Booth & Saunders (1984), CABI (2003)
Dry exposed mountain slopes, sub-tropical dry climates.	Strong, excellent durability. Density 640-720 kg m^3. Colour: sapwood yellow, heartwood reddish-brown.	Sawn timber, roundwood, wood composites.	A, EC, SC, SI	Maintains good form on poor soils and in rainfall to 500mm. Roots: strong taproot.	Cremer (1990), CABI (2003)
Dry temperate forest, grows on very dry, barren hillsides with bear rocks.	Straight grained, non durable, density 580kg m^{-3}. Colour: sapwood white to yellowish, heartwood reddish brown to dark brown.	Sawn timber, food.		Light demanding.	CABI (2003)
High humidity, riparian. Poor growth on dry sites.	Coarse grained, heavy, strong, lacks durability, warps, and splits badly. Colour: sapwood white, heartwood light brown to brown with reddish tinge.	Sawn timber, pulp.		Roots: widespread, but quite shallow. Dutch Elm Disease (DED) has killed many trees. Regenerates profusely but seldom grows beyond sapling or pole size before DED takes hold. Not used anymore due to DED, but can inject with systemic fungicides.	CABI (2003)

Table 11. Less suitable species continued…

Ranking	Botanical Family	Taxon Name	Habit	Origin	Rainfall Range	Tolerates	Site Type - Soils
5	*Burseraceae*	*Boswellia papyrifera*	Deciduous tree.	Africa. Ethiopia	500-800	Dr	*Texture:* l; *Tolerates:* sh.
5	*Burseraceae*	*Boswellia sacra*	Shrub or small tree -7.5m. Single or multi-stemmed.	Asia, Africa. Ethiopia, Somalia	100-500	Dr	*Texture:* l; Reaction: alk; Tolerates: sh, *inf; Soils:* only limestone and dolomite.
5	*Cupressaceae*	*Juniperus foetidissima*	Medium tree 10-15(-22)m, DBH 50-60 (-200)cm.	Europe, Asia. Greece, Iran, Syria.	500-1200	Dr, Fr, Wi	*Texture:* l,m; *Drainage:* f; *Reaction:* n, alk; *Tolerates:* inf.
5	*Hippocastanaceae*	*Aesculus hippocastanum*	Medium tree 20-30m.	Europe. Greece	500-1100	Fi, Sh	*Texture:* m,h; *Reaction:* n, alk; *Soils:* fertile .
5	*Pinaceae*	*Cedrus atlantica*	Tree.	Africa. Algeria, Morocco	500-1800	Dr, Fi, We, Sh, Fr	*Texture:* m; *Drainage:* f; *Reaction:* ac, n; Tolerates: inf, sh; *Soils:* alfisols, cambisols, luvisols, podzoluvisols, rendzinas. Succeeds on basic soils.
5	*Pinaceae*	*Pinus edulis*	Small tree 5-15(-21)m, DBH 15-75cm, irregular growth form, stem often branching low.	North America. Mexico, California	250-560	Dr, Fr, Wi, Fi	*Texture:* l, m; *Drainage:* f; *Reaction:* n, alk; *Tolerates:* sh, inf ; *Soils:* alfisols, arid, inceptisols, entisols. Sandstone, shales, limestones, granites, metamorphic rocks, volcanic. Grows in rocky gravels to fine clays. pH 6.5-8.4.

Table 11. Less suitable species continued…

Site Type - Habitat	Wood	Primary End Use(s)	General Uses	Comments	Source
		Veneer, wood composites, frankincense.		Rainfall regime, dry season, all temps, abs min - no data.	CABI (2003)
Arid zone beyond monsoon areas. Favour hot humid climate, but require access to water to grow well, but will survive under dry conditions.		Tannins, fodder, frankincense.		Rainfall regime, dry season, all temps, abs min - no data.	CABI (2003)
Mountains of eastern Mediterranean.	Durable to insects and fungi, light, density 490kg m^{-3} at 0% MC, 517kg m^{-3} air dry. Colour: sapwood yellowish, heartwood reddish brown.	Sawn timber, veneers, tannins, fodder.	R, EC	Hasn't been planted for timber production.	CABI (2003)
Humid, semi-humid, but also semi-dry .	Soft, low density and strength.	Sawn timber, fuel, fodder.		Dry season >0 months.	CABI (2003)
	Good quality timber.	Round wood, fuel, oils.	R, SC	Mean ann temp, mmtcm - no data. Light demanding.	CABI (2003)
Semi-arid mountain areas, parent material - sedimentary.		Sawn timber, food.	EC, R, SC	Roots: taproots (6.4m) and lateral roots (x2 radii of canopy).	CABI (2003)

Table 12. Excluded species.

Taxon Name	Source	Reason Excluded
Acacia albida	CABI (2003)	Absolute minimum 0°C, thorns.
Acacia caven	CABI (2003)	Bears rigid spines, strong weediness, highly invasive.
Acacia karroo	CABI (2003)	Thorns, aggressive colonizer, easily takes over grasslands.
Alnus acuminata	CABI (2003)	Suffers from heat, drought, out of season frost >-5°C.
Alnus glutinosa	CABI (2003)	Requires moist and wet conditions, doesn't grow well in dry conditions.
Arbutus unedo	CABI (2003)	Sheltered position, not exposed to dry winds.
Carya illinoinensis	CABI (2003)	Grows on floodplains, requires too much water for good growth.
Gleditsia triacanthos	Streets (1962), Booth & Saunders (1984), Marco & Paez (2000), Lefroy (2002), CABI (2003), ICRAF (2003)	Thorns, forms thickets, high potential invasiveness. Thornless cultivars are available.
Metasequoia glyptostroboides	CABI (2003)	Will only do well on moist sites, it is much more sensitive to drought than *Pinus radiata*.
Paulownia tomentosa	CABI (2003)	Young trees susceptible to frost, prefers >1000 mm rainfall
Pinus ponderosa	Simpfendorfer (1981), Cremer (1990)	Foliage disease which is in Australia, suited to high cool areas of Vic and Tas.
Pinus radiata	CABI (2003)	Growth rates in this rainfall zone inadequate.
Pinus sabiniana	Hall *et al.* (1972)	Should not be grown as timber tree, moderate growth but poor form.
Populus nigra	CABI (2003)	Requires too much water, intensive management, soil needs lots of aeration before planting.
Prosopis alba	CABI (2003)	Thorny tree, entry to Australia prohibited by legislation.
Prosopis chilensis	Streets (1962), Cony & Trione (1996), Ciesla (2002), CABI (2003), ICRAF (2003)	Spiny, root system shallow, entry to Australia prohibited by legislation.
Prosopis glandulosa	CABI (2003)	Thorny, invasive, weed, entry to Australia prohibited by legislation.
Quercus pubescens	CABI (2003)	Requires >800 mm rainfall for good growth.
Quercus robur	CABI (2003)	Young tree susceptible to frost, requires ground water 80-100 cm below the surface.

Table 12. Excluded species continued…

Taxon Name	Source	Reason Excluded
Quercus suber	CABI (2003)	Saplings need shelter for 4-5yrs on sunny sites, requires irrigation for good growth during first summers. Survives in low rainfall but produces little cork, needs 700-800 mm rainfall.
Robinia pseudoacacia	Hall *et al.* (1972), Cremer (1990), CABI (2003).	Young foliage killed by frost, has strong spines and vicious suckering habit. Not a timber species.
Salix alba	Cremer (1990), CABI (2003).	Not competitive outside natural habitat, needs access to water table, weed.
Salix fragilis	Simpfendorfer (1981), Cremer (1990)	Grows well on stream banks, weed.
Salix purpurea	CABI (2003)	Grows on sandy and silty soils close to flowing water, weed.
Salix triandra	CABI (2003)	Found in riparian habitats and will colonise wet areas of cultivated areas, weed.
Salix viminalis	CABI (2003)	Found along riverbanks, where it forms dense thickets, weed
Salix vitellina	Simpfendorfer (1981), Cremer (1990)	Liable to serious damage by possums and stock due to high palatability, weed.
Sesbania cannabina	CABI (2003)	Prickly leaves, grows in seasonally wet sites.
Sorbus aucuparia	CABI (2003)	Thrives near bogs, streams and swamps, too small to warrant growth for timber, summer drought and heat cause problems.
Tilia tomentosa	CABI (2003)	Moist sheltered sites.

3.5 Potential Limitations

The potential limitations of this type of analysis need to be acknowledged. Some important considerations are discussed below.

3.5.1 Climate

3.5.1.1 Moisture

Where other factors are not limiting, growth rates in low-medium rainfall zones are often directly associated with the amount of moisture available to the plant (Cremer 1990). If moisture is limited then growth rates will be slow and if the soil is waterlogged, then growth will also be slow. Depending upon the species requirements, growth rates are greatest somewhere between these to extremes.

Two sites that receive the same rainfall may not have the same amount of moisture available to the plant. Moisture availability is determined by temperature, sunlight, wind, soil type and depth, local topography, groundwater accessibility, salinity and rainfall (Harwood & Bush 2002). This is an important consideration when one of the main climatic indicators is rainfall range that does not take into consideration other factors. Therefore the effective moisture availability to the species may be more or less than the rainfall ranges suggest.

When a plantation is established in areas with a long dry season or during a drought period, it maybe necessary to water or irrigate the trees/shrubs in the first year to ensure their survival while they establish themselves. Long-term averaged data does not reflect year to year variations so there may be problems if trees are planted during a drought period (Jovanovic & Booth 2002). Trees are more likely to survive drought if their roots have effective access to at least two metres of soil (Harwood & Bush 2002).

3.5.1.2 Temperature

The minimum winter temperature is probably the most limiting factor in the exchange of species between sites (Wright 1963). Out of season frosts for species that exhibit dormancy during the winter months are a potential problem. Some deciduous species and conifers that are dormant during the very cold winter months are not tolerant to out of season frosts. In the spring when they sprout the tender growth can be damaged by frost, even though the species can withstand over minus 20°C temperatures during dormancy.

3.5.1.3 Soil

Soil type can determine the success or failure of a species on a particular site. Therefore this information was presented (where known), in terms of texture (light, medium, heavy), tolerances (sodic, saline, infertile), reaction (acid, neutral, alkaline), drainage (free, impeded, seasonally waterlogged) and the soil preferences. Given the variability of the soil throughout the study area, this will assist in matching species to a particular site type. It should be noted that just because a species can grow in particular soil conditions, does not mean that it will thrive in these conditions.

3.5.2 Growth rates

Selection of moderate to fast growing species was considered one of the most important factors in the selection process. Growth rates are influenced by many biological, ecological and management factors, and how a species performs on a particular site type will not be known with certainty until tested (Maslin & McDonald *in press*). Growth will be slower for species on low-rainfall sites compared with its preferred site (Spencer 2001).

3.5.3 Site description

A site description usually involves determining the climate, topography (slope, aspect, local relief), soil (parent material, soil texture, depth, colour, stoniness, pH, water relations) and management regime (site preparation, weed control, fertilising, protection, spacing, thinning) (adapted from Eldridge *et al.* 1994). In this case the species have been pre-selected to fit the climate of the area. Over such a large area of land there are large variations in environmental factors. As a result more than one species may need to be planted as site conditions vary (Eldridge *et al.* 1994). It should be noted that forestry is like growing any other crop: the better the quality of the site, the better the return (Dunchue 1999).

It is recommended to carry out an economic evaluation before planting large-scale plantations. In some cases markets for the end product can not be found or distances to processing plants are too far, thus being of little economic value (Eldridge *et al.* 1994).

3.5.4 Species trials

The list of species presented in this report is largely based on qualitative rather than quantitative information. Booth and Saunders (1984) reviewed tree species trials in Australia and provided an index to over 600 native and exotic tree species from 16 reports, some of which are presented here. More recently Lott (2001) compiled a report of plantation hardwood and farm forestry trials in Australia. Besides *Pinus* species, only a few of the trees and shrubs presented in this report have been included in species trials.

The information tabulated in *"Section 4"* indicates what a species can withstand or tolerate, but does not ensure that the species can grow on a particular site, as other unreported factors may make a site unsuitable. This report provides suggestions from which species can be selected for trials within the study area. These trials will provide information not only on survival, but also on the relative performance of the species on different sites.

The study area shown in Figure 2 is vast and includes many different land units. It will probably be impractical to evaluate all land units, but species trials should be set up on a wide range of different land units. Some species may grow well on one land unit, whereas others may perform well over numerous land units. It is better to trial many different species rather than just a few. The unsuitable species will soon become apparent when they have unacceptable growth rates or die for some reason.

If a species performs well in the species trial on a particular land unit then it is reasonable to assume that it will perform the same way on the same land unit within the entire study area (Eldridge *et al.* 1994). It is always recommended to evaluate species in small scale trials before large scale commercial plantations are established. It can cost as much to plant a species which may grow poorly or even die as a species which will flourish (Jovanovic & Booth 2002).

It is advisable to wait the full rotation of a species to determine its health, value and desirability on the land unit (Heybroek 1982). It is easy to see a particular species perform well in the early stages of a species trial and assume that it will be acceptable over the whole rotation. Doing this is a gamble. In the long term, the success of introduced species will depend on tree survival and adequate growth (Ryan *et al.* 2002).

3.5.5 Crop type

Three crop types have been proposed, following Maslin & McDonald's (*in press*) approach: short rotation coppice, short rotation phase and long rotation. Coppice and phase crops are most likely to offer commercial returns that are competitive with other farming enterprises (Maslin & McDonald *in press*). Whereas, long rotation crops within the dry zone, are not an attractive proposition to the land manager due to an expected 10-100 years before a financial return is achieved. Blakemore *et al.* (2003) recently conducted research on sawn timber from the low rainfall (400-600 mm yr^{-1}) areas of southern Australia.

They surveyed eight sites throughout New South Wales and Victoria that contained farm forestry examples of *Eucalyptus, Callitris* and *Pinus* species. They concluded that trees suitable for sawlogs were extremely poor, which highlights the difficulties of growing sawlogs in low rainfall areas.

For short rotation crops, hardwood species are generally far superior to softwoods. Many have the ability to sprout from the stump allowing coppice and pollarding crops, an attribute which is rare in softwoods (Heybroek 1982). It is possible to grow a short rotation hardwood crop on sites that are prone to erosion as they can be harvested without the need for replanting (Heybroek 1982).

3.5.6 Weed potential

Weeds are a serious threat to Australia's primary production and biodiversity conservation (Paynter *et al.* 2003). Some typical characteristics of weeds are fast growth rates, clonal and sexual reproduction, ability to sucker, ability to survive in harsh conditions, lack of predators and invasive tendencies (aggressive colonisers).

Co-incidentally, it is these type of characteristics being sought in species for FloraSearch. Paynter *et al.* (2003) argue that no more species should be introduced to Australia before better predictive techniques of weed potential have been developed, as the risks far out weight any perceivable advantage.

The Australian Quarantine and Inspection Service determine the weed potential of species according to a Weed Risk Assessment system (Paynter et al. 2003). It is a question based scoring method that involves answering up to 49 questions on the species to be imported. The questions include information on climatic preferences, biological attributes, and reproductive and dispersal methods. The survey can be obtained from: http://www.affa.gov.au/content/output.cfm?ObjectID=D2C48F86-BA1A-11A1-A2200060B0A04014

Where known, the weediness of a species is presented in the relevant table. Some high risk species were excluded as they are Weeds of National Significance, or bear thorns. Other species are still included due to closely correlating with the characteristics deemed desirable by FloraSearch.

3.5.7 Seed source

The study area does not have to exactly fit all the climatic conditions from the natural range of a species to be successfully relocated (Wright 1963). Although, the performance and characteristics of a species in it's native habitat provides the best indication of successful introduction to another location (Wright 1963).

Most tree species are genetically highly variable. Genetic homogeneity is the rare exception as shown in *Pinus resinosa* (Heybroek 1982). Given this, the source of germplasm is an important consideration. Most of the species presented occur naturally over large geographic areas, with part of their distribution within the climatic indicators of the study area. These are the areas from which the germplasm should be sourced, as it will be more suited to the climate of the study area. Genetic material from outside this climate should not be totally ignored as its performance may prove to be acceptable. This will remain unknown until tested.

3.5.8 Diseases and pests

There are three risks from diseases affecting the viability of large scale plantations introduced into a new environment (adapted from Boyce 1954):

- A minor disease from the natural range of the species may be introduced and thrive in its new environment devastating the species;
- The species will encounter a native disease in its new environment to which it has no resistance; and
- A disease is introduced that is destructive to native trees or populations.

To minimise these risks, germplasm should be obtained from healthy sources already in Australia. If this is not possible then seed should be sourced from disease free areas in other countries. Material entering Australia should be free of soil, have no contamination from other seeds, have no live insects, and no plant material mixed in with the seed.

Due to the risk of disease, some species are unable to be brought into Australia, although they may already have been introduced. For example, *Pinus* species are prohibited from specified countries, due to the risk of introducing Pitch Canker, and *Ulmus* species due to the threat of Dutch Elm Disease. There is no alternative but to identify, if possible, healthy populations of these species already in Australia from which to source seed for further trials.

Insect pests also pose a threat to the successful introduction of exotic species. There is the possibility of insects already in Australia having a negative impact on any introduced species. In addition there is the potential of insects being introduced once a plantation is established. An example of this is *Pinus radiata* which was affected from the accidental introduction of the Sirex Wasp during the 1970s. This wasp drills a hole into the tree and deposits its eggs, along with a toxic mucus and a symbiotic fungus. Once the larvae hatch they bore along the grain of the tree making the tree of little value for sawlog production. A combination of the fungi and boring weakens the host tree, leading to its death.

3.6 Conclusion

The species identified in this report have been reported to fit the climatic indictors provided. It is not advised to immediately take this information and start planting large scale areas. The limitations noted in Section 3.5 need to be acknowledged and taken into consideration before any action takes place.

Once again, it is very difficult to grow commercial timber species in an area with a mean annual rainfall of less than 500 mm yr^{-1}, without irrigation. Success is only likely on deep soils, or where the trees have access to another source of water.

Weediness potential is a major consideration for the introduction of any species. It should be reinforced, that species were not eliminated from this study purely on weediness potential as these characteristics closely correlate with the criteria deemed desirable by FloraSearch.

3.7 Acknowledgements

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3.9 Appendix 1 – Text of Letter Sent to International Networks

Australia is facing some major challenges in combating dryland salinity. One of these challenges is the need for landscape scale change in landuse to reduce ground water recharge. An area of particular interest is the 250 and 600 mm rainfall zone lying in the southern states of SA, NSW and Victoria and extending to the northern extent of an area dominated by winter rainfall systems. Figure 1 highlights the areas of eastern Australia (green areas) of interest.

CSIRO is a partner in the FloraSearch Project – a long-term initiative which hopes to lead to the development of new woody perennial crops that will replace or be integrated into more traditional annual based farming systems in the wheat/sheep zone of southern Australia. The guiding principals of the project are that:

- New crops need to be commercially viable
- Species be woody perennials
- Can provide feedstock to large scale industrial product production
- Cultivation will be dryland not irrigated, and focus on recharge areas not discharge sites.

The product areas of highest priority identified so far include wood products (e.g. sawn timber, roundwood, composites, pulp and paper etc), gums, essential oils, tannins and fodder. Although the focus so far has been on native species, we feel it is important to review the potential of exotic species in the development of new crops.

We are aiming to identify a number of exotic species worthy of further consideration in species trials and ultimately for crop development research and would be grateful for your help in this task. Figure 2 identifies those areas of the world that have close similarities with the rainfall of our target areas and Table 1 gives a summary of key climatic indicators. It is expected that potentially attractive species will occur naturally in areas of the world with equivalent climatic conditions to southern Australia or have been demonstrated to grow successfully under cultivation in such climate zones. For example, we have already had success with *Pinus brutia*, *P. halepensis* and *P pinaster* and this is why we are seeking your advice to extend the range of exotic species under trial.

Specifically, can you suggest woody perennial species from your country or region with potential to be developed as economic crops. There is no clear definition of this scale but provision of feedstock for industrial scale products is envisaged rather than small niche crop areas. Can you assist through identifying institutions and researchers working on such species or holding knowledge of these species.

In the longer term we hope to develop monographs of species of interest but in the meantime would be grateful if you could provide basic information on the species including botanical family, life form, country of origin and product potential. Please also identify for each species their weed potential &/or presence of thorns as these plants are likely to be deemed unsuitable for introduction.

Many thanks for your help. If you are not the most suitable person to handle this request could you please pass onto a more appropriate colleague. I look forward to hearing from you.

With best wishes

Stephen Midgley
International Business Director
24 February 2003

3.10 Appendix 2 – Seed Suppliers

This table is to be cross referenced with Table 9.

1 **Australian Tree Seed Centre**
PO Box E4008
Kingston, ACT 2604
Australia

Telephone: (61-2) 6281 8211
Fax: (61-2) 6281 8266
Email: ffp-atsc@csiro.au
Internet: http://www.ffp.csiro.au/tigr/atscmain/

2 **Ellison Horticultural Pty. Ltd.**
PO Box 365
Nowra, NSW 2541
Australia

Telephone: (61-44) 214255
Fax: (61-44) 230859
Telex: AA 71849 (ELISON)

3 **Harvest Seeds**
325 Mc Carrs Creek Road
NSW 2084
Australia

Telephone: (61-2) 94502699
Fax: (61-2) 94502750
Email: harvest@ozemail.com.au

4 **M.L. Farrar Pty. Limited**
PO Box 1046
Bomaderry, NSW 2541
Australia

Telephone: (61-44) 217966
Fax: (61-44) 210051
Telex: AA171133 FLAMY

5 **Department of Conservation and Land Management, Seed Centre**
Manjimup
WA 6258
Australia

Telephone: (61-8) 97721288
Fax: (61-8) 97721305
Email: markd@calm.wa.gov.au

6 **Goozeff Seeds Pty Ltd.**
PO Box 3022
North Nowra, NSW 2541
Australia

Telephone: (61-44) 210731
Fax: (61-44) 210731

7 **Forestry Canada, National Tree Seed Centre, Petawawa National Forestry Institute**
PO Box 2000, Chalk River
Ontario K0J 1J0
Canada

Telephone: (1-613) 5892880
Fax: (1-613) 5892275

8 **National Forest Genetics Resources Centre**
PO Box 4000, Fredericton
New Brunswick E3B 5P7
Canada

Telephone: (1-506) 4523289, 4523530
Fax: (1-506) 4523525
Email: bdaigle@femr.forestry.ca

9 **Nova Tree Seed Co. Inc.**
Box 102, Middle Musquodoboit
NS, BON IXO
Canada

Telephone: (1-902) 3842979
Fax: (1-902) 3842979

10 **Forestry Department**
Louki Akrita
1414 Nicosia
Cyprus

Telephone: (357-2) 304335/6
Fax: (357-2) 451419

11 **DANIDA Forest Seed Centre**
Krogerupvej 21
DK-3050 Humlebaek
Denmark

Telephone: (45-49) 190500
Fax: (45-49) 160258
Cable: FORESTSEED Humlebaek

Telex: 16600 dk att: FORESTSEED Humlebaek
Email: dfsc@sns.dk; dfscdk@post4.tele.dk
Website: http://home4.inet.tele.dk/dfscdk

12 **Office National des Forêts, Service Graines et Plants**
Supt. 39300 Champagnole
France
Telephone: (33-84) 514209
Fax: (33-84) 514663

13 **Martens GmbH + Co, Klengen & Baumschulen KG**
Postfach 1140
D-63924 Kleinheubach
Germany
Telephone: (49-9371) 6031
Fax: (49-9371) 80890

14 **Niedersächsische Forstliche Versuchsanstalt Abt. C - Forstpflanzenzüchtung**
Forstamtstr. 6
D-34355 Staufenberg OT Escherode
Germany
Telephone: (49-5543) 940822
Fax: (49-5543) 940861
Email: nfv-abtc@t-online.de

15 **Ministry of Agriculture, Directorate of Forest Resource Development**
3-5 Hippokratous Str. -GR-11064
Athens
Greece
Telephone: (30-1) 3601780
Fax: (30-1) 3601851

16 **Seed Export Company**
PO Box 543
Guatemala City
Guatemala
Telephone: (502) 2326125, 2515247
Fax: (502) 2536491
Cable: LEWALD-GUATEMALA
Telex: 6127 FPKCO GU

17 **Kumar International**
Ajitmal 206121
Etwah (UP)
India

18 **Tosha Trading Company**
161, Indira Nagar Colony,
PO - New Forest, Dehra Dun, U.P., 248006
India
Telephone: (91-135) 620984
Fax: (91-135) 620196

19 **Shivalik Seeds Corporation**
47 Panditwari, PO Premnagar
Dehra Dun 248007 (U.P.)
India
Telephone: (91-135) 683348
Fax: (91-135) 683-776

20 **Bisht Enterprises**
Baniyawala, Prem Nagar, Dehra Dun-248007 (U.P.)
India
Telephone: (91-135) 683191, 683014
Fax: (91-135) 683331

21 **Neelkantheshwar Agro-Seeds and Plantations**
B' Block Commercial Complex - B6/G4, Dilshad Garden
DELHI-110095
India
Telephone: (91-11) 2274277, 2298494, 2299449
Fax: (91-11) 2112974

22 **Forest & Range Organization (Afforestation & Parks Bureau)**
Chalus, PO Box 46615/185
Caspian Forest Seed Centre - Koloudeh - Mahmood Abad - P.Code 46311
Iran
Telephone: (98-191) 22661, 22825 (+122733 4366)
Fax: (98-191) 26526 (+122733 3357)

23 **Israflora, Forest Seeds of Arid Zones**
PO Box 502
Kiryat-Bialik 27000
Israel

Telephone: (972-4) 8737155
Fax: (972-4) 8700643
Cable: 972-4-737155
Telex: 46400 BXHA

24 **Setropa Ltd.**
PO Box 203
1400 AE Bussum
Netherlands

Telephone: (31-35) 5258754
Fax: (31-35) 5265424
Cable: SETROPA BUSSUM

25 **New Zealand Tree Seeds**
PO Box 435 Rangiora
North Canterbury 8254
New Zealand

Telephone: (64-3) 3124635
Fax: (64-3) 3124833
Email: nzseeds@voyager.co.nz
Website: http://www.voyager.co.nz/~nzseeds/index.html

26 **Direccao Geral Florestas - CENASEF**
Av. Joao Cristomo, 26
1050 Lisboa
Portugal

Telephone: (351-1) 3124915
Fax: (351-1) 3124989

27 **The Inland & Foreign Trading Co (Pte) Ltd.**
Block 79A Indus Road #04-418
Singapore 169589
Singapore

Telephone: (65) 2722711 (3 lines)
Fax: (65) 2716118
Email: iftco@pacific.net.sg

28 **Ministerio de Medio Ambiente - Direccion General de Conservacion de la Naturaleza – Servicio de Material Genetico**
Gran via de S.Francisco 4
28005 Madrid.
Spain

Telephone: (34-1) 3476037, 3476038, 3476039
Fax: (34-1) 3476268, 3476302

29 **National Tree Seed Programme**
PO Box 373
Morogoro
Tanzania

Telephone: (255-56) 3192, 3903
Fax: (255-56) 3275
Email: ntsp@twiga.com
Website: http://www.twiga.com/ntsp

30 **Ministry of Agriculture, General Direction of Forestry**
30, Rue Alain Savary
Tunis 1001
Tunisia

Telephone: (216-1) 891141
Fax: (216-1) 801922

31 **Forest Tree Seeds And Breeding Research Directorate**
PK 11
Gazi / Ankara
Turkey

Telephone: (90-312) 212 65 19
Fax: (90-312) 212 39 60

32 **The Henry Doubleday Research Association**
Ryton on Dunsmore
Coventry, CV8 3LG
United Kingdom

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