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The Conservation and Utilisation Potential of Australian Dryland Acacias

Symposium held at Dalwallinu, Western Australia 13-14 July 2001

Edited by B.R.Maslin and A.S.George

FOREWORD

Comments by session convenors:
STEPHEN D. HOPPER
REX EDMONDSON
STEPHEN MIDGLEY

SESSION 1: SYSTEMATICS AND CONSERVATION

PAGES 1–9
The role and relevance of taxonomy in the conservation and utilisation of Australian Acacias
BRUCE R. MASLIN

PAGES 10–18
Phylogenetics and the conservation and utilisation of *Acacia* in Western Australia
MARGARET BYRNE

PAGES 19–35
Towards an understanding of variation in the Mulga complex (*Acacia aneura* and relatives)
JOSEPH T. MILLER, ROSE A. ANDREW AND BRUCE R. MASLIN

continued over...

PAGES 36–53
Rarity and threat in relation to the conservation of *Acacia* in Western Australia
MARCELLE L. BUIST, DAVID J. COATES AND COLIN J. YATES

PAGES 54–61
The translocation of two critically endangered *Acacia* species
LEONIE MONKS AND DAVID COATES

PAGES 62–71
Wattle I plant for wildlife?
B.M.J. HUSSEY

PAGES 72–93
Flora and vegetation of Burnerbinmah Station: a study of the plant communities in the Mulga shrublands of the Murchison Region, Western Australia
SUSAN PATRICK

PAGES 94–95
Australian Plant Name Index
LINDY CAYZER, LAURIE ADAMS, KIRSTEN COWLEY, BRENDAN LEPSCHI AND GREG WHITBREAD

SESSION 2: COMMERCIAL AND OTHER APPLICATIONS

PAGES 96–108
Acacia species as large-scale crops in the Western Australian wheatbelt
JOHN BARTLE, GRAEME OLSEN, JEROME CARSLAKE AND DON COOPER

PAGES 109–116
Economic potential of Western Australian *Acacia* species: secondary plant products
DAVID S. SEIGLER

PAGES 117–124
Livestock potential of Australian species of *Acacia*
ROBYN A.DYNES AND ANTHONY C.SCHLINK

PAGES 125–129
Review of the influence of *Acacia* species on establishment of Sandalwood (*Santalum spicatum*) in Western Australia
JON E.BRAND

PAGES 130–134
Direct seeding acacias of different form and function as hosts for Sandalwood (*Santalum spicatum*)
GEOFF S. WOODALL AND CHRIS J. ROBINSON

PAGES 135–138
The value of *Acacia saligna* as a source of feed for sheep
DELWYN HOWARD, GAYE KREBS AND MAARTEN VAN HOUTERT

PAGES 139–144
A search for novel biologically active compounds in the phyllodes of *Acacia* species
KRISTEN WICKENS AND MARCELLO PENNACCHIO

PAGES 145–146
Horticultural potential of *Acacia*
GRADY BRAND AND LUKE SWEEDMAN

PAGES 147–157
Reproductive potential of *Acacia* species in the central wheatbelt: variation between years
MANGADAS LUMBAN GAOL AND JOHN E.D. FOX

PAGES 158–160
Tourism potential of *Acacia*, with particular reference to Dalwallinu
CHRIS TATE

SESSION 3: SEED FOR HUMAN FOOD

PAGES 161–169
Potential of Australian acacias in combating hunger in semi-arid lands
ANTHONY RINAUDO, PRAKASH PATEL AND LEX A.J.THOMSON

PAGES 170–180
Domestication of wattles with edible seeds for the wheatbelt of Western Australia
MAURICE MCDONALD, BRUCE R.MASLIN AND LEX A.J.THOMSON

PAGES 181–184
Issues in the commercialisation of wattle seed for food
ANTHONY HELE

PAGES 185–191
Broadscale production of wattle seed to address salinity: potential and constraints
GRAEME OLSEN

INSIDE BACK COVER
This Issue (continued)

Foreword

The papers published here were presented at a Symposium, *The Conservation and Utilisation Potential of Australian Dryland Acacias*, held on 13-14 July 2001 in the Western Australian wheatbelt town of Dalwallinu. The Symposium aimed to explore the potential of Australian dryland acacias and in particular their role in helping solve some of the serious environmental and landscape problems currently confronting many rural communities and ecosystems, both within Australia and abroad. In southern Australia the most significant of these relate to land degradation and increasing salinity, caused primarily by clearing native vegetation for agriculture. Acacias have great potential to play in reversing this cycle of land deterioration.

The Symposium brought together scientists, land managers, other professionals, farmers and members of the community to explore a wide range of issues and possibilities involving acacias. This is the first time that such a broad-based evaluation has been made of this large group of plants. The Symposium covered a wide range of subjects including:

- role of genetics and systematics in understanding and using *Acacia* species effectively;
- evolution and conservation biology of *acacias;*
- use of *Acacia* species in salinity control, landscape amelioration and nature conservation;
- potential of *Acacia* species as a human food, as hosts for cultivating Sandalwood and as a source of gums and tannins;
- potential of *Acacia* species in tourism and horticulture;
- traditional use of *Acacia* species by indigenous Australians; and
- electronic dissemination of information.

Acacia (Wattle) is an important genus within Australia. Not only is it our largest group of vascular plants (around 1000 species currently recognised), but it is also the national floral emblem and was among the first plants collected from the continent (from the west coast of Western Australia in the late 17th century). Acacias dominate 60 to 70 per cent of the country and are particularly common in arid and semi-arid areas. The largest concentration of species occurs in the wheatbelt region of Western Australia, with Dalwallinu located near the centre of this great diversity.

Acacias are highly diverse in their form, biology and ecology, they occur over a wide range of soil types and climates. They are fast growing, are able to enrich soil by fixing atmospheric nitrogen and are easy establish and manage in cultivation. Australian acacias have been used abroad in many commercial, social and environmental programs, yet within Australia their enormous potential has not been realised. It is issue was an important focus of the Symposium.

It was very appropriate that the Symposium was held in Dalwallinu, not only because the genus *Acacia* is so diverse in the region but also because this community is currently attempting to develop tourism opportunities based on *Acacia* species. As a direct consequence of the Symposium, the Dalwallinu Shire is leading an initiative to establish an Environmental Interpretive Centre in the town.

The *Dalwallinu Acacia Symposium* was organised jointly by the Shire of Dalwallinu, Dalwallinu District Tourism (Inc.), Heartlands Tourism (Inc.) and the Department of Conservation and Land Management. In addition to the above agencies, financial support was provided by BankWest, the Wheatbelt Development Commission, Boekeman Toyota, the Office of the Minister for Agriculture, Forestry and Fisheries, and Advanced Visual Design. The businesses and people of the Shire of Dalwallinu are gratefully acknowledged and thanked for their support of the Symposium.

Keiran McNamara
ACTING EXECUTIVE DIRECTOR
Department of Conservation and Land Management
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Comments by session convenors

Session 1: Systematics and Conservation

STEPHEN D. HOPPER

Chief Executive Officer, Botanic Gardens and Parks Authority

Systematic research in *Acacia* is critical for sound utilisation and conservation. The job is far from complete. There are important practical and economic reasons for supporting the proposed submission to retain the name *Acacia* for the largest group in the genus as it currently stands–the 900 or so named Australian species.

Molecular systematics has revealed unexpected levels of genetic variation in both rare and common wattles. This finding has an important practical implication: the principle of using local seed wherever possible to maximise genetic and biodiversity conservation.

There are many rare and endangered species of *Acacia* whose biology and ecology have scarcely been investigated. Some are old, relictual species with no close relatives; others are recently evolved and have close sister species. Much more research on their biology is required to ensure their conservation. Also, one must not lose sight of the need to conserve genetic variation in common species. In the meantime, the most important conservation action is to care for and value every remnant of native vegetation. These are biological jewels–literally, the source of seeds for the future.

Praise for the prickly

Choosing the right local wattles when revegetating an area can help to create habitat for wildlife and control pest insects. Real biodiversity benefits can be generated with a little extra effort and sound local knowledge.

Session 2: Commercial and other applications

REX EDMONDSON

Convenor and Chair, Soil and Land Conservation Council of Western Australia

There has been encouraging progress in research as applied to the screening of *Acacia* and its role in the fight against land degradation, in particular dryland salinity. It is clear that acacias have an important role in the development of sustainable farming systems. Gains can be made both in agricultural systems and as a source of food for humans.

It is time to place this evidence before primary producers, in particular, and the wider community in general. Neither group relates readily to scientific papers, but there is now sufficient evidence to warrant setting up demonstrations at strategic sites in the agricultural regions promoting the advantages of acacias.

What better site than the Dalwallinu Shire, with its large number of native wattles? It is important to let farmers see the potential and methods of establishment, as they respond to this kind of presentation.

The *Dalwallinu Environmental Interpretative Centre* proposed for establishment in Dalwallinu would complement the Shire's strong focus on tourism. It could focus on scientific information and how it interfaces with the community.

The issue of protecting road verge vegetation was raised with passion, and it is clear that the many attempts to educate authorities on this need have not been effective in all cases. Over many years there have been reports and recommendations on the value of road verge vegetation–in many cases the last remnants of some species are found in these sites. The Department of Conservation and Land Management supports a Road Verge Conservation group. I suggest that this Symposium does likewise.

Session 3: Seed for human food

STEPHEN MIDGLEY

CSIRO Forestry and Forest Products, Canberra

Strong links and strategic alliances must be maintained between growers, marketers and government to ensure that emerging business and management systems remain coherent. Successful marketing depends on quality, pricing and consistency of supply.

The Symposium has shown that there is a great wealth and diversity of information on *Acacia* conservation and utilisation both in Australia and overseas. Successful use of this information will benefit future use of *Acacias*. There is a pressing need to collect, collate and disseminate available information, associated with a need to conserve, assemble and acknowledge traditional, indigenous knowledge.

There is a need to develop appropriate agronomic techniques to underpin broadscale *Acacia* planting, particularly how it will relate to established agriculture. Harvesting technology (do we modify the plant or the machinery?), understanding root architecture, spacing and competition with other crops are some issues highlighted for further research.

Wider commercial development of acacia seed as human food will require further work on nutritional (and anti-nutritional) profiles, toxicology and food safety, use for starch, gums, resin etc.

Those using and promoting acacias will have to be mindful of the potential of acacias to become weeds. Some characteristics that contribute to the success of acacias present a potential for weediness.

The role and relevance of taxonomy in the conservation and utilisation of Australian *Acacias*

BRUCE R. MASLIN[1]

[1]Department of Conservation and Land Management, Locked Bag 104,
Bentley Delivery Centre, Western Australia 6983 Email: brucem@calm.wa.gov.au

SUMMARY

In biology, taxonomy is defined as the science of delimiting organisms, naming them and determining their relationships. It is the foundation upon which all biological sciences rely. ***Acacia*** is the largest genus of flowering plants in Australia (comprising almost 1 000 species) and is an important component of many ecosystems, particularly in arid and semi-arid areas. The species exhibit considerable morphological, ecological and biological variation and as such offer considerable scope for economic, social and commercial utilisation. In order to undertake effective conservation, utilisation and management of this enormous resource it is essential to have meaningfully defined, and named, biological entities (e.g. species and infraspecific taxa)**.** The provision of names through taxonomic research is fundamentally important because names are the 'hooks' by which information about taxa is stored, retrieved and exchanged. Taxonomic keys are the tools that enable us to identify specimens. In a large genus like ***Acacia***, electronic multi-access keys have advantages over conventional paper-based keys. Voucher specimens, which enable names to be verified, provide an important mechanism for protecting the value of information assembled for taxa. The implications for Australia of the proposal to divide ***Acacia*** into five genera are discussed briefly.

INTRODUCTION

It is not coincidental that the first paper in these proceedings of the Dalwallinu ***Acacia*** Symposium deals with taxonomy. As discussed below, taxonomy is the foundation upon which all biological sciences rely because, in the absence of classifying organisms and naming them, biology has nothing to work with. Indeed, none of the papers presented in this volume would have been possible unless ***Acacia*** species had been discriminated and named.

There are almost 1 000 described species of ***Acacia*** in Australia (Maslin 2001b and 2001c) and an estimated 100 or so remain undescribed. This is an enormous resource which offers considerable potential for economic, social and environmental utilisation, but it is important that the species are conserved effectively and managed sustainably. It is the aim of this paper to examine the role of taxonomy in achieving these goals.

Acacia is ubiquitous in Australia. Species of this genus are represented in almost all major terrestrial habitats and they form a conspicuous, dominant element of many ecosystems, particularly in arid and semi-arid areas. The greatest species-richness occurs in the flat, edaphically complex, semi-arid wheatbelt region of south-west Western Australia (Hnatiuk & Maslin 1988). This area is located within the Transitional Rainfall Zone (Hopper 1979), so named because it lies between the arid interior of the continent and the temperate forest region near the south-western coast. The richness here may be illustrated by the fact that within a 100-kilometre radius of Dalwallinu there are about 185 species of ***Acacia***, this being the same number that occurs in North and South America combined, and more than occurs on the entire continent of Africa where 144 species are recorded (Maslin ***et al***. in press). The other principal area of species richness lies south of the Tropic of Capricorn in eastern Australia and is associated with the rocky tablelands of the Great Dividing Range. Although species numbers decline in the Arid Zone, acacias are often a more conspicuous and dominant element of the landscape there than elsewhere. Here for example we find the Mulga lands dominated by species of the ***A. aneura*** complex (Miller ***et al.*** this proceedings).

Besides the high number of species, acacias show great morphological, ecological and biological variation and so offer considerable scope for economic, social and environmental utilisation. Understanding these species, and in particular knowing how they might assist in providing solutions to the very serious problem of land degradation that has occurred in many agricultural regions, was a major theme of the Dalwallinu Symposium. Biological attributes of ***Acacia*** such as their diversity in growth form, longevity, coppicing or suckering ability, and their adaptation to a wide range of soil types and habitats, render them well-suited to a wide range of uses. Furthermore, they have the ability to fix atmospheric nitrogen, are usually easy to germinate and grow, and generally show good survival and rapid growth rates under cultivation.

Australian acacias are widely utilised, especially abroad (for reviews see Midgley and Turnbull in prep.; McDonald ***et al.*** 2001; Turnbull ***et al.*** 1998; Searle 1995, 1996; Thomson ***et al***. 1994). They are used for a range of purposes but in particular as a source of wood products (e.g. construction and high-value timber, pulp and

fuelwood), tannin, edible seeds, fodder and for land amelioration. Today, Australian ***Acacia*** species are grown in about 70 countries where they cover about 2 million hectares. As summarised by Midgley and Turnbull (in prep.) the most widely cultivated species are ***A. mearnsii*** for tannin, fuelwood and charcoal (c. 300 000 ha. in South Africa, Brazil, China and Vietnam), ***A. saligna*** for fuelwood, fodder and land amelioration (over 500 000 ha. in North Africa, the Middle East, western Asia and Chile), ***A. mangium*** for paper pulp and timber (over 800 000 ha. in Indonesia and Malaysia), ***A. crassicarpa*** for paper pulp and timber (about 50 000 ha. in Indonesia and Vietnam) and ***A. colei*** as a human food in India and sub-saharan Africa. In developing countries the demand for fuelwood is increasing as populations grow, and ***Acacia*** species are generally considered to be good fuel sources with high calorific values and biomass production (Thomson ***et al.*** 1994). In Australia, ***Acacia*** is largely an under-exploited resource. Although some commercial timber is gained from species such as ***A. melanoxylon*** (Blackwood; see Searle 1996) and ***A. celsa*** (Brown Salwood; see McDonald and Maslin 2000), most species grown in this country are used in amenity and land amelioration programs (McDonald ***et al.*** 2001). There is, however, a growing interest in exploring the potential for a more comprehensive use of ***Acacia*** in Australia, especially as widescale commercial crops in southern agricultural regions for salinity control (Bartle ***et al***. this proceedings).

WHAT IS TAXONOMY?

In biology, taxonomy is essentially the science of delimiting organisms, naming them, and determining their relationships. Taxonomy is the foundation upon which all biological sciences rely, but very few people understand what taxonomists actually do. As noted by Vane-Wright (1996), there is a need to both demystify taxonomy and make taxonomic products more readily accessible, not only to the scientific community but also to non-specialist users. In so doing this science may become better understood and appreciated, which in turn may lead to better resourcing of this crucial discipline.

Taxonomists assemble information about organisms from many sources and employ various methods to analyse and synthesise these data to arrive at a definition and classification of taxa, to apply names to them, and to develop generalised insights into their phylogeny and evolution. In other words, taxonomists:

- analyse natural variation to delimit and name taxa;
- provide a means for identifying taxa; and
- arrange taxa into predictive classification systems.

These points form a convenient framework for discussing the significance of taxonomy in the context of the conservation and utilisation of ***Acacia***. It should be remembered, however, that taxonomists also establish systems for assembling and disseminating knowledge about taxa and, as discussed below, provide scientific verification for their work through a system of vouchering.

Delimitation and naming*: *the determination of boundaries between taxa and the application of names to the biological entities that are recognised

The circumscription and naming of meaningful biological entities is at the core of the scientific discipline of taxonomy. Providing names (whether formal or informal) is of fundamental importance for biology because names enable us to communicate and exchange information about taxa. In fact, in the absence of names, biology has nothing to work with, the taxa for this purpose do not exist. Names are not merely tags or labels, however, rather they are the principal 'hooks' by which information about an organism is stored and retrieved. If taxa are poorly defined, or if the names applied to them are incorrect, then the information that is assembled and disseminated is likely to be wrong, or at least its value will be diminished. While it is most desirable that the taxa be formally named in accordance with the ***International Code of Botanical Nomenclature*** (Greuter ***et al***. 2000), there are circumstances where time and / or resources are limiting, and then an interim arrangement of informal 'phrase names' is acceptable. Therefore, the first imperative for effective conservation, utilisation and management of any biological organism is the provision of meaningfully circumscribed and accurately named taxa.

These points are well illustrated by the following examples drawn from recent studies in ***Acacia***.

In recent years certain tropical Australian acacias have assumed considerable commercial importance as sources of pulp and high-value timber, principally in south-east Asia. The main species being grown are ***A. mangium***, ***A. auriculiformis***, ***A. crassicarpa*** and the hybrid ***A. auriculiformis*** × ***mangium*** (Turnbull ***et al***. 1998; McDonald ***et al.*** 2001; Midgley and Turnbull in prep.). However, a less well-known tropical species, ***A. aulacocarpa***, which was also commonly grown in forestry field trials in south-east Asia, showed very variable performance, suggesting that more than one taxon was included under the name. A subsequent revision of the ***A. aulacocarpa*** group by McDonald and Maslin (2000) revealed that there are, in fact, six species included within what was formerly called ***A. aulacocarpa***. Of the four new species described in that paper, three–***A. celsa***, ***A. midgleyi*** and ***A. peregrina***–grow to large trees 30(-40) m tall and have potential as forestry plantation species. ***Acacia aulacocarpa*** itself was shown to be a variable taxon, ranging from a spindly small shrub to a small tree 8(-15) m tall, that appears quite unsuitable for major forestry use. Thus, the name ***A. aulacocarpa*** had no reliable biological meaning before the taxonomic work was undertaken because encompassed by this one name were six separate species. It was not until the taxonomists had gathered, recorded and analysed data, then drawn boundaries around and named the natural biological units that a meaningful framework was provided for furthering knowledge of the taxa involved. New data, together with at least some of the previously acquired data (see

Vouchering, below), could now be referred to the appropriate species instead of being 'pooled' under the one name, ***A. aulacocarpa***. Indeed, had the taxonomy of this group not been resolved there is a likelihood that the value of these data would have been greatly diminished, rendered essentially useless or even lost. It is worth noting that, just because a taxon has a name, it does not necessarily mean that the entity has precise biological meaning. The only way to ensure that taxa represent meaningful biological entities is to subject them to careful taxonomic scrutiny.

Similar examples of taxonomic resolution facilitating research and management of ***Acacia*** utilisation include:

- ***Acacia colei***, ***A. cowleana*** and related species as a source of seed for human food (Maslin and Thomson 1992; McDonald and Maslin 1997: see McDonald ***et al***. 1996 for discussion);
- ***Acacia acuminata*** as a host for Sandalwood (***Santalum spicatum***) (Maslin ***et al***. 1999; Brand 2002)
- ***Acacia tumida*** for use as fuelwood and in land rehabilitation (McDonald in prep.).

Effective conservation research and wildlife management also depend on well-defined, named taxa. This point is well illustrated by Burgman ***et al.*** (2000) in their study of almost 200 Western Australian species of ***Acacia*** that were listed on the Priority and Declared Rare Flora lists. They found that nearly a quarter of these species were neither formally described nor even informally recognised prior to 1970. This meant that neither science nor the relevant management agencies were aware of their existence until after this date. The study concluded that conservation research and setting conservation priorities depend on a sound taxonomy for, without it, conservation has nothing to work with; indeed, the first priority for conservation should be straight-forward species circumscription and description.

This point can be illustrated by reference to ***A. bifaria***, a species which in 1995 was given a formal name and which was segregated from its very similar-looking close relative, ***A. glaucoptera*** (Maslin 1995). ***Acacia bifaria*** was shown to be reasonably uncommon and was therefore included on the Priority Flora List. It had a fairly restricted distribution and was known from populations confined largely to degraded road verges around Ravensthorpe. ***Acacia glaucoptera***, on the other hand, was shown to be a common species with a wide geographical distribution. It therefore did not warrant particular conservation attention. Thus, before 1995 when the two taxa were not distinguished, ***A. bifaria*** was not afforded any protection because it was included within a broadly circumscribed species, ***A. glaucoptera***. According to Burgman ***et al.*** (2000), very few of the ***Acacia*** species then included on the Declared Rare Flora list or the Priority Flora list would have been guaranteed protection in Western Australia if the taxonomy of the ***Acacias*** had not progressed beyond that known in 1970. In other words, inadequate (or inaccurate) classifications may lead to the loss of diversity through inadequate protection.

Of course it is incumbent upon the taxonomist to do an effective job when they analyse variation and discriminate and name taxa. Unfortunately it takes time, and therefore resources, to produce good taxonomic work and the amount of resource needed depends on the size and / or complexity of the group being studied. However, it can be very costly if the taxonomy is inadequate or incorrect. In the above example of ***A. aulacocarpa***, imagine the problems that would have occurred in future plantings had the tall tree ***A. celsa*** not been properly distinguished from the spindly ***A. aulacocarpa***. The same applies in conservation work. Consider the potential waste of time, money and effort, and even possible legal ramifications, if species that are referred to the Declared Rare and Priority Flora lists are not 'good' biological entities. More often than not the amount of money spent on taxonomy is trivial compared with the benefits that are derived from the result of this work.

Identification: referring an individual specimen to a previously recognised group

Taxonomic keys are the principal means of identifying organisms. There are two basic types of key–the conventional dichotomous key that is normally produced as printed copy, and the interactive multi-access key that is produced via an electronic medium.

Conventional dichotomous keys comprise a sequence of questions that eventually lead to a name. Because of their linear structure, conventional keys suffer from a serious problem, the 'unanswerable couplet problem'; that is, if any question in the sequence cannot be answered then further progress is blocked (Maslin and Thiele 1998). For example, consider trying to identify a plant for which you have no flowers, in a key where most of the questions relate to flower characters. Despite this problem there is certainly a place for conventional keys but they can be hard to use, especially when the number of species included is large. In these cases the key maker often has to resort to 'cryptic' characters that are difficult to interpret, or to combinations of characters, in order to try and guide the user to the correct answer.

There are a number of contemporary conventional keys for identifying Australian Acacias but, except the one provided in the recently published ***Flora of Australia*** (Maslin 2001), these are regional in scope, or deal with specific species complexes. Regional keys to ***Acacia*** include:

- Western Australia: south-western W.A., Lewington (1998); Hamersley Range, Pilbara region, Maslin (1982); Kimberley region, Wheeler (1992).
- Victoria: Entwistle ***et al***. (1996).
- Queensland: Pedley (1978, 1979).
- New South Wales: Kodela and Harden (2002).
- South Australia: Whibley and Symon (1992).
- Northern Territory: Darwin region, Dunlop ***et al.*** (1995).
- Central Australia: Maslin (1981).

- South-eastern Australia: Costermans (1981); Tame (1992).

A key to some Australian ***Acacia*** species that are commonly utilised abroad is given in Maslin and McDonald (1996).

As discussed by Maslin and Thiele (1998), computer-based, interactive multi-access keys provide a solution to, or at least ameliorate, the problem of unanswerable couplets. Although multi-access keys also require users to answer questions in order to name taxa, the user chooses which questions to answer, and in what order–in other words, the user controls the identification process, rather than the key builder. Taking the example above, the multi-access key questions relating to flowers can be simply ignored and alternative ones used. Furthermore, with an interactive multi-access key the user can choose to use 'easy' characters early in the identification process. Most multi-access keys also allow users to select more than one answer to multiple-choice questions. This is important, because one is not forced to make a decision between qualitative character-states which, by their nature, may differ only by degrees. There are many other attractive features of interactive multi-access keys. For example:

- the computer programs can scrutinise character lists dynamically to find the best ones to use in order to identify a specimen most quickly (this is particularly useful if the user is not familiar with the group of organisms being keyed);
- suspect or wrong answers can be quickly deleted without having to backtrack laboriously through the key;
- context-sensitive help, perhaps in the form of annotated images or notes, can be provided to help with technical jargon or difficult characters;
- once an organism has been named it is simple to deliver a cluster of information about it, such as drawings, photographs, videos, sounds, distribution maps and notes.

Interactive multi-access keys are especially useful when dealing with large groups of organisms. Therefore, in a genus of the enormous size and variability of ***Acacia***, electronic keying is the only way to name specimens reliably and efficiently. The recently-published electronic key ***WATTLE: Acacias of Australia*** (Maslin 2001c) provides interactive identification for the entire Australian ***Acacia*** flora. This key greatly empowers the user and makes the identification process reasonably simple.

Interactive multi-access keys need not be restricted to providing names for taxa. They can also be very effective in selecting taxa that conform with non-morphological criteria such as environmental, biological or utilisation attributes. In this way one can, for example, list all species occurring in a particular geographical region, or those suited to commercial wood production, effective as wind breaks, helpful in salinity control, and so forth. The electronic key to ***Acacia*** species of the Kalannie region (Maslin 1998) was constructed with environmental utilisation in mind.

Classification and phylogeny: ***the placement of organisms within a hierarchical system and the determination of the historical relationships between them***

Modern biological classifications are hypotheses of evolutionary relationships that aim to bring related taxa together into groups that are commonly named and that are arranged in a hierarchical fashion. An effective classification will serve as a major summary of knowledge and is also likely to embody at least some predictive power. Predictive in this context means that if a species has some quality or characteristic then other species that have the same attributes are likely to appear close to it in the classification. This has practical (and potentially very significant) implications for conservation and resource management. For example, the grouping of genetically related taxa may facilitate the search for desirable chemical or biological attributes. Or, by providing a framework that reflects the genetic diversity within a taxon (e.g. a genus), a classification can be a useful tool for assessing biodiversity and for setting conservation priorities. Raven (1995) put the crucial role of classification in the following way: ' . . . it is ultimately the scientific process of classification–the grouping of organisms into meaningful units–that makes possible everything else in systematic, evolutionary and environmental biology, and which ultimately gives meaning to all of biology.' In Raven's sense the term classification applies to all levels of the taxonomic hierarchy, i.e. species, genera, families etc.; in the discussions below, I restrict my use of the term to the genus and infrageneric levels (e.g. subgenus, series, section) in ***Acacia***.

At the infrageneric level it is most regrettable that there is no meaningful classification for the 'Australian group' of ***Acacia***, namely, subgenus ***Phyllodineae*** which includes some 960 species. To some extent this shortcoming has constrained effective utilisation and conservation work, because people requiring knowledge of species relationships must either search literature for the relevant information or rely on the few taxonomic specialists to nominate presumed close relatives. In both these cases the information obtained can be somewhat limiting. The most generally used classification for subg. ***Phyllodineae*** is that of Pedley (1978) in which seven sections are recognised. This classification represents a good, pragmatic attempt at rationalising earlier schemes by Bentham (1842, 1864, 1875) and Vassal (1972)–the relationship between these various schemes is discussed and illustrated in a number of publications, e.g. Pedley (1987a), Maslin (1989), Chappill and Maslin (1995) and Maslin (2001a). While Pedley's scheme has certainly been a useful framework it is largely artificial, scarcely any of the sections being monophyletic (see Maslin ***et al.*** in press). A consequence of this is that the predictive power of the classification is diminished. Furthermore, 855 species (more than 80% of total within the subgenus) are contained in just three large sections, namely, ***Phyllodineae***, ***Plurinerves*** and ***Juliflorae***. Apart from being non-monophyletic each of these sections is simply too large to

show meaningful relationships between species. What is needed is a classification that aggregates related species into smaller groups that are formally named and arranged in a hierarchical framework that reflects their evolutionary relationships.

Undoubtedly, molecular information will prove pivotal to understanding evolutionary relationships between species of subgenus ***Phyllodineae*** and, consequently, to the establishment of a meaningful classification for the group. Recent DNA sequence data from Miller ***et al***. (in press) and Murphy ***et al.*** (2000 and in prep.) are generating new insights into species relationships, but to date these studies have involved only about 15% of the species comprising the subgenus. The challenge for the future is for these (very expensive) studies to be expanded to include more of the taxonomically 'critical' species (Maslin and Stirton 1998), then for taxonomists to correlate the molecular findings with morphological characteristics to produce a functional classification.

Despite the above-mentioned constraints there does exist for ***Acacia*** a body of knowledge of species relationships and this has facilitated a number of recent utilisation and conservation projects. For example, such knowledge was crucial in the assessment and ranking of about 350 ***Acacia*** species from the temperate dry zone of Australia for their potential as a source of seed for human consumption (Maslin ***et al***. 1998). Similarly, an assessment of the 500-odd taxa of ***Acacia*** from the South-West Botanical Province of W.A. was undertaken by the author recently to identify deep-rooted native species that might be suitable for widescale planting in the region for salinity control (Bartle ***et al***. this proceedings). This task was greatly facilitated by having a knowledge of species relationships because, when a species was located that possessed potentially desirable characteristics (e.g. pale heartwood), it immediately focused the search on its close relatives to see if they, too, shared these attributes.

Other examples of knowledge of species relationships aiding work on utilisation of ***Acacia*** is seen in Sandalwood (***Santalum spicatum***) host selection studies involving ***Acacia acuminata*** (Maslin ***et al.*** 1999; Broadhurst and Coates 2002; Byrne ***et al.*** 2002; Byrne this proceedings) and in the domestication research involving multipurpose utilisation of tropical dry-zone ***Acacia*** species (McDonald ***et al***. 1994).

In conservation research the study of Buist ***et al.*** (this proceedings) is a good example of how critical phylogenetic knowledge can be. This study aims to determine how ecological and genetic characters contribute to an understanding of rarity by comparing rare, geographically restricted species with their common, widespread closest relatives. The work is dependent upon taxonomic relationships having been determined for the species-pairs under study, namely ***A. lobulata*** and ***A. verricula*** (Cowan and Maslin 1990), ***A. anfractuosa*** (Maslin 1976) and ***A. sciophanes*** (Maslin 1977).

At the generic level it is now evident that, in the light of recent molecular and morphological evidence, ***Acacia*** is polyphyletic and cannot be maintained as a single genus. This means that the genus, as currently conceived, will be divided into a number of genera, and this will have significant and practical implications worldwide. Although splitting ***Acacia*** will improve the taxonomy of the group there will be unavoidable and unfortunate nomenclatural consequences. As currently defined, ***Acacia*** is a cosmopolitan genus of more than 1350 species placed in three large subgenera, namely, subgenus ***Acacia*** (c. 160 species, pantropical), subgenus ***Aculeiferum*** (203 species, pantropical) and subgenus ***Phyllodineae*** (960 species, largely confined to Australia). Pedley (1986) proposed that these three subgenera should be treated as distinct genera, namely, ***Acacia***, ***Senegalia*** and ***Racosperma*** respectively. Although Pedley's proposal was not taken up (see Maslin 1987, 1989, also see Pedley 1987a & 1989 for defence of his scheme), there has been significant morphological and molecular research over the past 15 years and it is now apparent that the genus will have to be divided into at least five genera (for discussion see Maslin ***et al.*** in press). These genera correspond to Pedley's groups except that the New World component of ***Senegalia*** will be divided into three genera. This new taxonomy is an improvement over the existing classification because it is saying that most of the 'Acacias' that occur, for example, in Australia are significantly different from those in Africa, Asia and the Americas.

This change will improve our ability to communicate meaningful information when we talk about '***Acacia'***. However, because there are internationally accepted rules that govern what names must be applied to each of the five genera, there is a possibility that the generic name of most 'Australian acacias' may be changed, perhaps to ***Racosperma***. The group comprising the 'Australian acacias' is not only by far the largest within the genus (almost 1 000 species), it is also the one that is utilised most extensively for commercial, social and environmental purposes. Therefore, there will be widespread global impact affecting many people if species of the 'Australian group' are given a new generic name. Within Australia such a change would cause many organisations and individuals to incur significant costs by having to modify information storage and retrieval systems. It is for this kind of reason, and in the interest of nomenclatural clarity and stability, that Maslin ***et al.*** (in prep.) are preparing a proposal to have the name ***Acacia*** retained for the 'Australian group'. This proposal will be considered by an international committee which governs botanical nomenclature and, given the urgency of this matter, it is hoped that it will not take long for a decision to be made one way or the other. It is clear from the above discussion that taxonomic classifications may have significant impact, both socially and economically, and taxonomists need to be very mindful of these sorts of issues.

Vouchering: collection and preservation of specimens representing an organism or taxon under study, therefore enabling verification of its identity

Hedberg (1979) noted that a basic requirement of scientific investigation is that the results should be verifiable. It must be possible for other researchers to check

the validity of the work by repeating experiments or observations. This implies that any biological material used for whatever purpose must be named reliably. The way to verify that names so used are correct is to examine the (voucher) specimen on which that name is based. If voucher specimens are not cited in research it can seriously diminish the value of information, because there may be no way to relate the data to a particular taxon. Given the obvious benefits of vouchering it is surprising that it is so often not done (see Hopper and Brown 2001 for examples).

Vouchering is especially relevant when a polymorphic species is divided, because verification of names through the examination of voucher specimens usually enables information to be correctly related to the appropriate segregated taxon. An excellent example of this is the study of ***A. aulacocarpa*** discussed above. For many years the Australian Tree Seed Centre (CSIRO Forestry and Forest Products) collected seed of '***A. aulacocarpa***' from Queensland and Papua New Guinea and distributed it, as numbered seedlots, for use in forestry plantation research both within Australia and abroad (principally south-east Asia). Seedlot numbers were linked to herbarium voucher specimens which were collected from the same plants as the seed and subsequently deposited in herbaria for safe keeping and future reference. As discussed above, McDonald and Maslin (2000) showed that the name ***A. aulacocarpa*** had been widely misapplied, and what was thought to be a single species in fact comprised seven distinct taxa. Because of the good vouchering practice by ATSC it was possible to publish a list of seedlot numbers showing the new names that applied to them, thus enabling users worldwide to align their operations with the new nomenclature (McDonald and Maslin 1998). Over the years a substantial body of research on '***A. aulacocarpa***' accumulated, and Thomson (1994) produced a comprehensive annotated bibliography of these publications. Unfortunately, voucher specimens were not cited all in these works. Therefore, while it is possible in some cases to relate the previously published information to one or other of the seven taxa recognised by McDonald and Maslin, there are many cases where it is not possible. In these latter cases the value of the previously published data is greatly reduced, or in some cases even rendered useless, because it is not known to what segregate of ***A. aulacocarpa*** they refer. This situation, which could have been avoided by citation of voucher specimens, is most unfortunate, not only because of the loss of information but also because it is wasteful of resources, given the expense of conducting the research in the first place.

Mulga is likely to be another case where a substantial amount of expensively-acquired data may be lost because of a lack of vouchering. Until relatively recently, typical Mulga was thought to comprise just two species, ***A. aneura*** and ***A. ayersiana***. Randell (1992) segregated the species ***A. paraneura*** and ***A. minyura*** and described two new varieties under ***A. aneura***, and Pedley (2001) increased the number of varieties of ***A. aneura*** to ten. It is possible that still more taxa will be recognised in this group (Miller et al. this proceedings). There is an extensive body of literature on Mulga (much relating to ecology and utilisation, e.g. Turnbull 1986) and it will be a challenge to see how much of this information can be related to the various taxa comprising this large, important arid zone species-complex.

Notwithstanding the importance of vouchers, it must be remembered that it is very expensive to collect and preserve voucher specimens: $41.89 per specimen was cited by Armstrong (1992) as the cost from collection to final placement in a herbarium but the standard measure now used by herbaria has now increased to around $52. Therefore, in some cases at least alternative strategies to retaining a voucher specimen may have to be considered to off-set at least the costs associated with specimen preservation. This applies particularly to studies that involve multiple sampling of the same taxon within a single population. For example, population genetic studies may require 10 or more individuals from numerous populations in order to generate a meaningful set of information. In such cases it may be prohibitively costly and physically impractical to retain all voucher specimens that are collected: photographing or scanning the specimens may be appropriate alternatives in these circumstances (even though there are costs associated with establishing and maintaining photographic and electronic records). There may also be situations where it is not necessary to keep voucher specimens indefinitely. These are important issues that confront and challenge herbarium managers.

CONCLUSION

It is clear that effective conservation and utilisation of ***Acacia*** depend upon having a sound taxonomy. In the first instance it is absolutely essential that meaningful biological entities be delineated and described accurately. These entities, whatever their rank (genus, species, variety etc.), are the basic building blocks upon which both conservation and utilisation rest. Secondly, it is essential that the biological entities be named because there is no other way of communicating about them. In fact, in the absence of a name the entities for this purpose do not exist and are therefore not available for consideration in either conservation or utilisation. While it is most desirable that taxa be formally named in accordance with the ***International Code of Botanical Nomenclature***, in circumstances where time and / or resources are limiting then an acceptable interim arrangement is to use informal 'phrase names'. Thirdly, it is essential that taxonomists provide effective means for identifying taxa, and this usually means constructing workable keys for identification. Once taxa are accurately identified then users can assemble, access and disseminate information about them. Fourthly, it is essential that organisms be classified into meaningful units (e.g. species, genus, family) because this provides the framework that makes investigation of organisms possible. It is therefore clear that neither conservation nor utilisation of ***Acacia*** (or any other biological organism) can proceed in the absence of sound taxonomic practices.

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Phylogenetics and the conservation and utilisation of *Acacia* in Western Australia

MARGARET BYRNE

Science Division, Department of Conservation and Land Management, Locked Bag 104, Bentley Delivery Centre, Western Australia 6883 Email: margaretb@calm.wa.gov.au

SUMMARY

The genus *Acacia* is a dominant component of the Australian flora and many species have been identified as requiring conservation management, and as having potential for utilisation for a wide range of purposes. Phylogenetics is particularly valuable in the south-west of Western Australia where the complex evolutionary history has resulted in a diverse flora with both relictual and recently evolved components. Phylogenetic analysis contributes to conservation of plants through identification of unique evolutionary lineages, determination of phylogenetic value for conservation priority setting, and identifying phylogenetically independent comparisons between rare and widespread species. Phylogenetic analysis also contributes to utilisation of plants through the identification of genetic and taxonomic units, particularly for species complexes where variation is unresolved. The contribution of phylogenetic analysis to these aspects of effective conservation management and efficient utilisation strategies are discussed with examples from various *Acacia* species in Western Australia.

INTRODUCTION

The genus *Acacia* is a dominant component of the Australian flora and hence *Acacia* species predominate in conservation of the diverse Australian flora, particularly in south-west western Australia which is a centre of diversity for *Acacia* (Hopper and Maslin 1978). Acacias also have a dominant role in utilisation as they are adapted to a wide range of environments, and as such they have been extensively planted overseas (McDonald *et al.* 2001; Midgley and Turnbull 2002). Some species have also been utilised in Australia (McDonald *et al.* 2001) and several are important for commercial revegetation purposes in Western Australia (Byrne and Broadhurst 2002). Whilst genetic analysis in general makes an important contribution to conservation and management strategies, phylogenetic analysis in particular is valuable in south-west Western Australia in the conservation and management of a diverse flora that has been subject to evolutionary forces over long time frames resulting in both relictual and recently derived species (Hopper and Maslin 1978).

Phylogeny is the relationship between groups of organisms as reflected by their evolutionary history, and phylogenetics uses genetic data to determine evolutionary relationships at lower taxonomic levels such as between species and between populations within species. Phylogenetic analysis can contribute to the conservation and utilisation of flora in several ways. Below species level it can identify different genetic lineages with unique evolutionary histories as conservation management units or evolutionary significant units (ESU's) (Coates 2000; Ryder 1986). A knowledge of phylogenetic relationships between species allows determination of the phylogenetic value (the degree of genetic distinctiveness) of species to assess priority for conservation activity (Byrne *et al.* 2001), and also enables appropriate comparisons to be made between rare and widespread taxa in assessment of their genetic diversity (Gitzendanner and Soltis 2000). A knowledge of phylogeny and the differentiation of genetic and/or taxonomic units is critical in the domestication of all species, but in particular for species complexes where genetic and morphological variation have not been resolved. Genetic studies of species for domestication have frequently found genetic differentiation within the species, which can be significant enough to identify separate entities requiring taxonomic revision, e.g. the tropical *A. aulacocarpa* (McGranahan *et al.* 1997; McDonald and Maslin 2000).

This review examines aspects of phylogenetics relevant to the conservation and utilisation of flora in Western Australia, especially in the south-west, with particular reference to understanding the evolutionary biology of *Acacia*.

PHYLOGENETICS AND EVOLUTIONARY HISTORY IN WESTERN AUSTRALIA

Unlike many areas of the world, the south-west of Western Australia has had a stable geological history with no major glaciation events (Hopper *et al.* 1996). The subdued landscape has no significant mountains and is dominated by a semi-arid zone between the high rainfall mesic region in the extreme south-west corner and the desert to the north and east (Hopper 2000). However, the area has

experienced climatic instability during the Pleistocene due to cyclic contraction and expansion of the arid and mesic zones, leading to a mosaic of habitats and edaphic complexity, particularly in the transitional semi-arid zone (Hopper *et al.* 1996). The area has a large, highly diverse flora characterised by both relictual taxa that have persisted through landscape stability and lack of glaciation, and more recently evolved components resulting from speciation in association with climatic oscillations (Hopper 1979, 2000). The complex mosaic of soil types and habitats has led to a high degree of natural isolation and fragmentation within the flora, causing significant local endemism and a high turnover of taxa across the landscape, affecting both relictual and recently evolved components.

The evolutionary history of the region would be expected to have had significant effects on the structuring of genetic diversity within the flora. In a naturally fragmented landscape many species persist in geographically restricted and disjunct distributions. Genetic studies using nuclear isozyme markers on Western Australian species that are rare and restricted, particularly those with disjunct distributions, have commonly revealed different genetic lineages (Coates 2000). Phylogenetic studies using chloroplast DNA (cpDNA) have confirmed the evolutionary distinctiveness of these lineages (Byrne *et al.* 1999, 2001), and indicate that genetic processes associated with historical eco-geographic barriers to gene flow may have led to the formation of distinct evolutionary lineages in many species. These evolutionary lineages often warrant separate conservation management (Soltis and Gitzendanner 1999) and should be treated as conservation management units or ESU's (Coates 2000). Identification of these lineages enables conservation action to be focused at this level where necessary, thus ensuring that the protection of distinct lineages is addressed. Evolutionary lineages may be present even in the absence of morphological differentiation (Byrne *et al.* 1999, Coates 2000). For example, populations of *Acacia anomala* that occur in two areas 30 km apart are genetically divergent and represent separate evolutionary lineages (Coates 1988). These populations also show differences in reproductive strategy, the northern populations reproducing sexually and the southern ones clonally.

In contrast, extensive gene flow between populations of species that are widely distributed would generally be expected to limit the geographic structuring in such species. Given the evolutionary history of south-west Western Australia, however, widespread species in the region may be expected to show some structuring in genetic diversity. Most studies of the nuclear genome of such species have revealed little genetic differentiation between populations (e.g. Byrne 1999; Byrne *et al.* 2002b; Hines and Byrne 2001) but phylogenetic studies using cpDNA have shown substantial differentiation in the chloroplast genome in these species (Byrne *et al.* 2002a; Byrne *et al.* 2002c; Byrne and Hines unpublished data). This is because analysis of the chloroplast genome can provide insights into the historical processes influencing population structure (Avise 2000; Schaal *et al.* 1998) since maternally inherited organelle markers retain information about past population history in present day population structures (Ennos *et al.* 1999). The differentiation observed in the chloroplast genome in the widespread species in Western Australia indicates that they have also been affected by historical isolation and fragmentation as would be expected from the history of the region.

For example, *Acacia acuminata* is a widespread species complex that has three described taxa and several informal variants. Two of the described taxa have been treated as either separate species (*A. acuminata* and *A. burkittii*) or subspecies (Kodela and Tindale 1998; Maslin 2001). Here I follow the *Flora of Australia* treatment which ranks them as subspecies (Tindale and Kodela 2001). *Acacia acuminata* subsp. *acuminata* has broad phyllodes and compressed seeds and occurs in the south west of the distribution; subsp. *burkittii* has terete phyllodes and large globose seeds and occurs from the southern arid zone of Western Australia to western New South Wales (Maslin *et al.* 1999). The third taxon, *A. oldfieldii*, has striated pods and is restricted to the Moresby Range north of Geraldton. A variant with narrow phyllodes occurs between typical subsp. *acuminata* and subsp. *burkittii*, and a small-seeded variant occurs in the north of the species' distribution. A phylogenetic study of the *A. acuminata* complex revealed a very high level of diversity in the chloroplast genome and an unexpectedly high level of intra-population variation (Byrne *et al.* 2002c). The phylogeny of *A. acuminata* showed that the variation was not specific to taxa within the complex (Fig. 1), and the pattern of distribution of the variation suggests that the lack of congruence between taxa and cpDNA variation is caused by lineage sorting of ancestral polymorphisms rather than hybridisation, although ancient hybridisation may be a factor in the origin of a variant with narrow phyllodes. The phylogeny identified two separate lineages that were geographically based, the main lineage being distributed throughout the range of the species and the second restricted to the centre of the range. Nested clade analysis (Templeton *et al.* 1995) identified past fragmentation as the primary cause of the differentiation between the two lineages, which is consistent with climatic instability during the Pleistocene. Another species where significant differentiation in cpDNA has been observed is *A. verricula* (Byrne *et al.* 2001), the southern population at Ravensthorpe being genetically divergent from the other populations sampled. The Ravensthorpe population occurs in an upland region of exceptional species richness and high endemism (Hopkins *et al.* 1983; Hopper *et al.* 1996), and it has been suggested that the divergence of the flora in this region has been influenced by geographic isolation following landscape dissection, combined with climatic fluctuation (Hopkins *et al.* 1983). The genetic divergence of the Ravensthorpe population identified by cpDNA analysis is consistent with this hypothesis (Byrne *et al.* 2001).

The association of phylogenetic lineages with geographic distribution is the basis of phylogeography. Such studies have also identified distinct, geographically separated lineages in the widespread York Gum, *Eucalyptus loxophleba*, (Byrne and Hines unpublished data) and

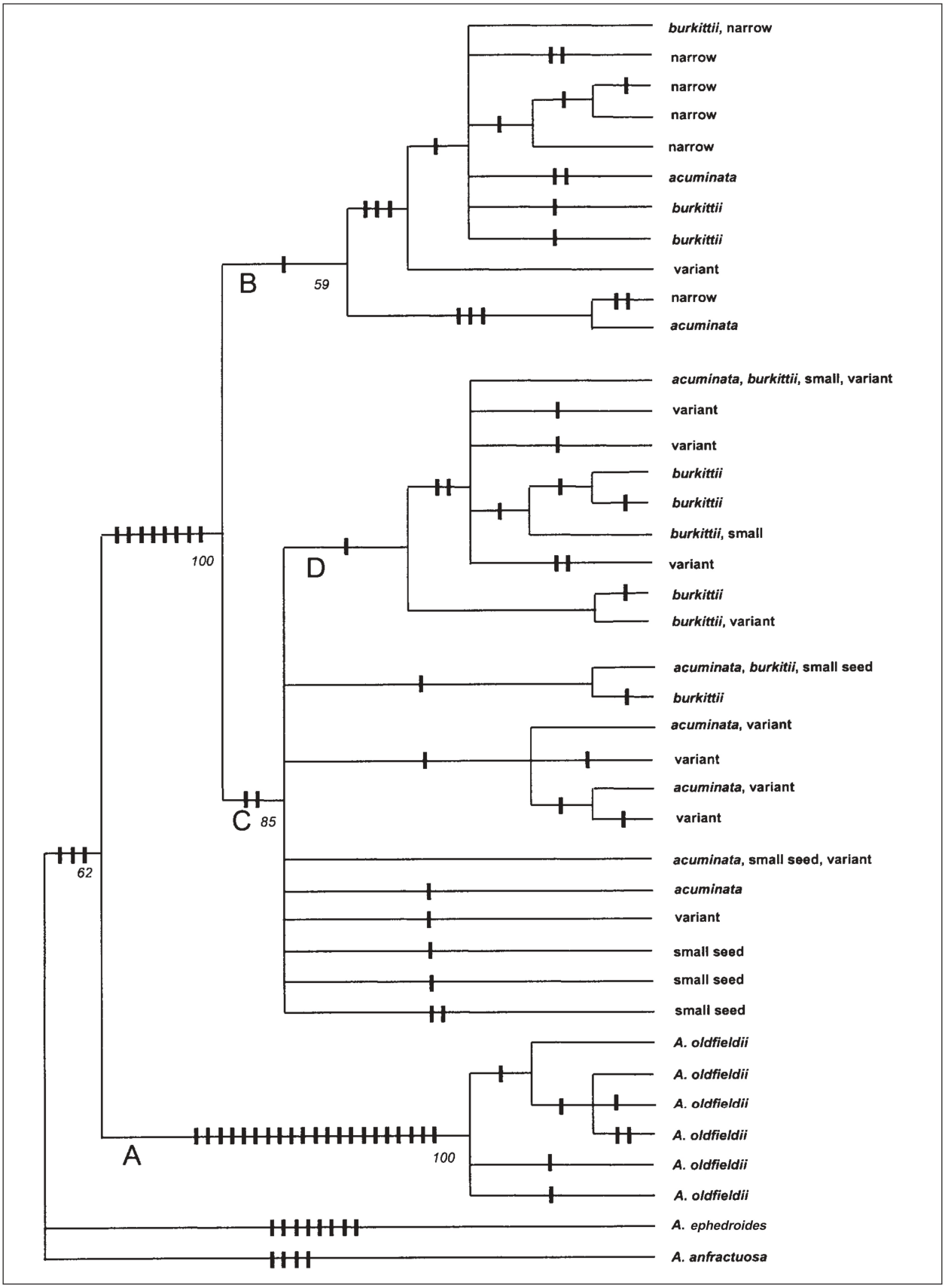


Figure 1. Phylogenetic parsimony tree of haplotype relationships in the Acacia acuminata *complex including* A. oldfieldii. *Bars on lines represent mutations. Numbers below lines represent bootstrap confidence values (%). Letters at nodes represent major clades. Taxa to right of branches contain the haplotype on that branch.* Acacia ephedroides *and* A. anfractuosa *were used as the outgroups.*

Sandalwood, *Santalum spicatum*, (Byrne *et al.* 2002a). Comparative phylogeographic studies such as these can identify major historical events that have had significant effects on the flora throughout the region. The identification of two lineages within all the widespread species so far studied suggests that there may have been contraction to broad refugial areas in the north and south of the south-west region. These refugial areas may not be as discretely defined as those resulting from periods of glaciation, as the climatic changes resulting from oscillations between the mesic and arid zones would not be expected to be as intense as during glaciation. However, the presence of distinct geographically located lineages suggests that the climatic changes have been significant enough to lead to isolation through range contraction in both the arid and mesic directions. The effects of historical isolation are still evident in the chloroplast genome, even though subsequent favorable climatic conditions have allowed range expansion of the lineages and established the widespread distributions present today.

PHYLOGENETIC RESOLUTION FOR CONSERVATION AND UTILISATION

Both efficient utilisation and effective conservation strategies rely on being able to identify, define and name specific units (Maslin this proceedings). A lack of understanding of taxonomic units and their genetic relationships hinders the utilisation and domestication of native species (Byrne and Broadhurst 2002), and conservation management activity is focused on taxonomic species since they are generally the primary units for conservation (Coates and Atkins 2001). The flora in south-west Western Australia contains many species complexes with a high degree of unresolved morphological variation. Resolution of taxonomic and genetic units within these complexes is important so that their commercial potential can be fully utilised and/or the conservation status of units appropriately recognised.

Currently three *Acacia* species complexes have commercial potential and are of interest for utilisation in agroforestry programs to address land degradation problems associated with salinity in Western Australia (Byrne and Broadhurst 2002). Resolution of the taxonomic and genetic units in these complexes is required for efficient domestication of the species so that selection for appropriate traits may be made from taxa displaying the desired characteristics (Byrne and Broadhurst 2002). One of these species complexes is *Acacia acuminata* which has three described taxa and several informal variants as described above. A combined genetic/taxonomic study was carried out to resolve the morphological variation present within the complex (Broadhurst and Coates 2001; Byrne *et al.* 2002c; Maslin *et al.* 1999). A study of the nuclear genome (Broadhurst and Coates 2001) showed that *A. oldfieldii* is highly significantly different from the *A. acuminata* complex. Within the rest of the complex the small-seeded form is also genetically distinct from the two subspecies, subsp. *acuminata* and subsp. *burkittii*, which form separate clusters, with the narrow phyllode variant intermediate between the two but closer to subsp. *acuminata*. Identification of the taxa within the complex enables appropriate assessment of desired traits and performance of taxa, and provides a basis for the selection and breeding for these characteristics.

Another species complex of interest for agroforestry is *A. microbotrya*. A preliminary study of genetic variation in the *A. microbotrya* complex showed some genetic differentiation between the recognised variants, var. *microbotrya* which occurs mainly in the south of the distribution and var. *borealis* which occurs to the north of var. *microbotrya* (Elliot *et al.* 2002). A full study encompassing the range of geographic distribution and morphological variation, and including other variants and taxa, is currently being undertaken.

Resolution of species complexes is also important to establish their conservation status. The rare *A.* sp. 'Dandaragan' is currently gazetted as a phrase name and listed as critically endangered, but there is some uncertainty about its taxonomic status in relation to the common *A. microbotrya*. *Acacia* sp. Dandaragan is restricted to a ridge outside Dandaragan on the western edge of the range of the widespread *A. microbotrya* complex, and may be a morphological variant of, or the end of a morphological cline from, *A. microbotrya*. Research showed *A.* sp. Dandaragan to be morphologically and genetically distinct from the *A. microbotyra* variants at a level expected of subspecies or species (Elliot *et al.* 2001) and confirmed the independant status of the taxon. The identity and conservation status of rare species may be masked by the unresolved morphological variation present in species complexes such as *A. microbotrya* and phylogenetic studies provide assistance in resolving these taxonomic ambiguities.

PHYLOGENETICS AND SETTING PRIORITIES IN CONSERVATION

Conservation management operates in a framework of setting priorities due to competition for land use and limited funding for conservation activities (Coates and Atkins 2001). Most often the driving force is the degree of threat to specific taxa (Hopper 2000) but many authors have suggested that all taxa are not equal and that some means of assessing their biodiversity value should be used (Crozier 1992; Faith 1992; Humphries *et al.* 1995; Vane-Wright *et al.* 1991). Phylogenetic diversity is one such means of assessing biodiversity value, whether priorities are placed on phylogenetic distinctiveness (Vane-Wright *et al.* 1991), character richness (Faith 1992) or taxa from rapidly evolving clades (Erwin 1991).

The phylogenetic value of relictual species and recently evolved species are quite different, even though both categories of species may be rare and restricted. Two rare species of *Acacia* (*A. sciophanes*, *A. lobulata*) occurring at the north-western edge of the range of their more common

widespread relatives were thought to represent recent speciation due to their morphological similarity, restricted distributions and occurrence in an area of high speciation. A study of the phylogenetic relationships using chloroplast DNA between the pairs of taxa showed that they had quite different evolutionary patterns (Byrne *et al.* 2001). *Acacia sciophanes* shares a common ancestor with its more common relative *A. anfractuosa* (Fig. 2) but the two species have diverged relatively recently (Byrne *et al.* 2001). The level of cp DNA diversity within the species was comparable even though *A. sciophanes* has a much more restricted distribution than *A. anfractuosa*. In contrast, phylogenetic relationships between the second pair of species with a similar distribution pattern in the same area showed that the rare *A. lobulata* was genetically very distinct from the more widespread *A. verricula*, and they have been separated from a common ancestor for a long period, in the order of 3 million years (Byrne *et al.* 2001). *Acacia lobulata* was also distinct from several other taxa from the *A. flavipila* alliance including an eastern Australian species, *A. ixiophylla*, which coalesced to a common ancestor with *A. verricula* and another species in the alliance (Fig. 3). *Acacia lobulata* does not have close affinities with any other species and may represent a relictual species with no extant close relatives. The study also showed that *A. lobulata* had some cpDNA variation despite being highly restricted, suggesting that it has been separated for long enough for mutations to arise in the slowly evolving chloroplast genome. *Acacia lobulata* and *A. verricula* were believed to be close relatives due to the presence of reticulate venation on the phyllodes, although *A. verricula* has flat and *A. lobulata* terete phyllodes. This is likely to be an example of morphological convergence masking the evolutionary relationships between these taxa.

Another rare species that occurs at the edge of the distribution of its widespread presumed relative is *A. oldfieldii* which is restricted to two populations in the Moresby Range north of Geraldton. It is morphologically similar to the widespread complex *A. acuminata* (discussed above), but a nuclear study showed it to be significantly divergent from taxa in that complex (Broadhurst and Coates 2001). A phylogenetic study using cpDNA confirmed the distinctiveness of *A. oldfieldii* (Byrne *et al.* 2002c) as there were a high number of mutations (26) differentiating it from the other taxa in the *A. acuminata* complex (Fig. 1). This degree of divergence was unexpected given the low level of morphological differences between them and is another example of a relictual species with a restricted distribution.

These studies show that similarities based on morphology and geographic distributions are not necessarily reliable in identifying relictual species or recent speciation, whereas phylogenetic analysis can readily do so by determining the degree of evolutionary divergence between species. Recently derived species will show little divergence from their close relatives, while relictual species will show greater levels of divergence The nucleotide divergence between species of Western Australian acacias that have been studied using cpDNA variation are given in Table 1, and demonstrate examples of both ancient relictual species, and those more closely related to other species through recent evolution from a common ancestor.

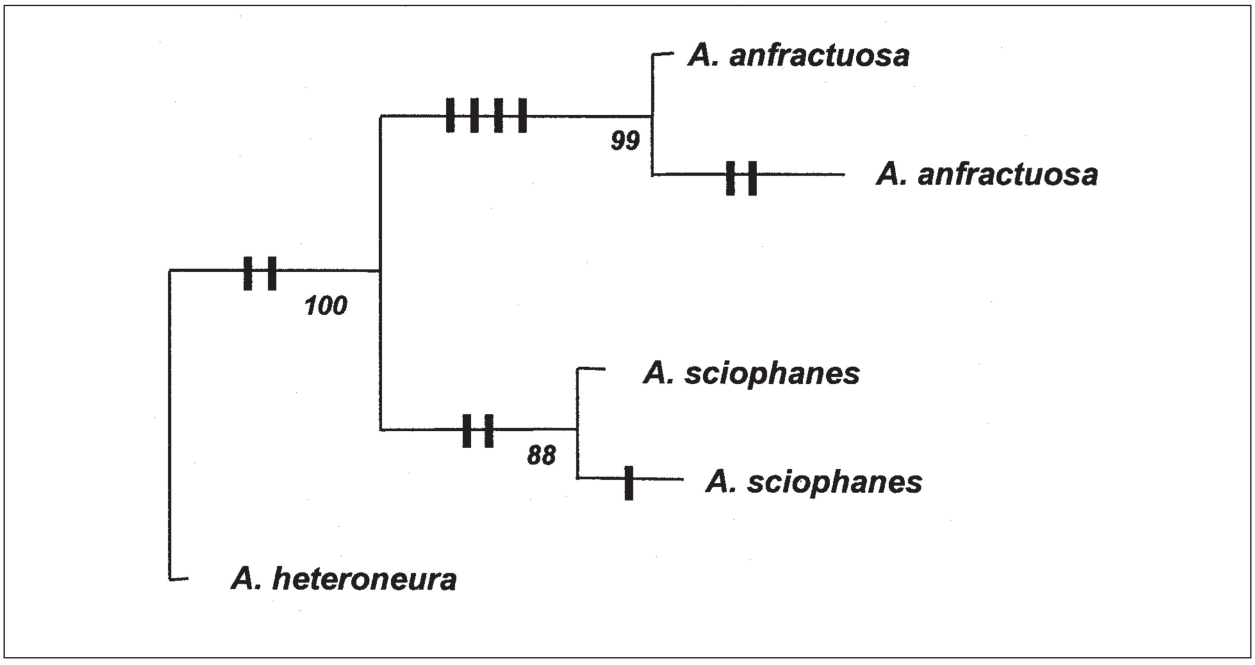


Figure 2. Phylogenetic parsimony tree of haplotype relationships in Acacia sciophanes *and* A. anfractuosa. *Bars on lines represent mutations. Numbers below lines represent bootstrap confidence values (%).* Acacia heteroneura *was used as the outgroup and is from the same alliance as* A. sciophanes *and* A. anfractuosa.

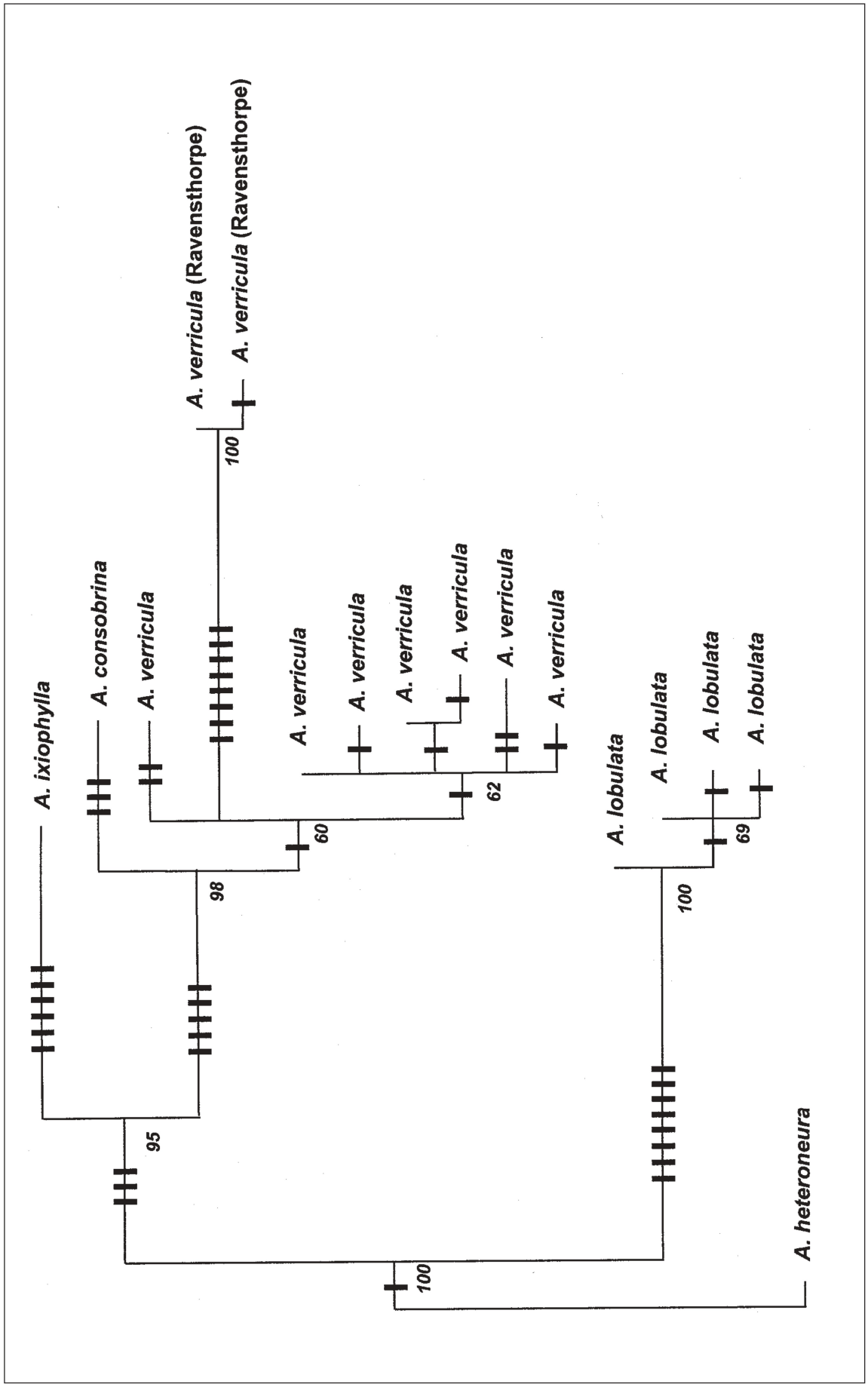


Figure 3. Phylogenetic parsimony tree of haplotype relationships in Acacia lobulata *and* A. verricula. *Bars on lines represent mutations. Numbers below lines represent bootstrap confidence values (%).* Acacia heteroneura *was used as the outgroup and is from a different alliance.* Acacia ixiophylla *is an eastern Australian species from the* A. flavipila *alliance.* Acacia consobrina *is another Western Australian species from the* A. flavipila *alliance.*

PHYLOGENETICS AND SPECIES COMPARISONS IN CONSERVATION

A goal of conservation programs is to conserve genetic diversity so that the evolutionary potential of the species is maintained (Hamrick *et al.* 1991). Hence a focus of genetic studies of rare species has been the level of genetic diversity within populations and species. Comparison of the levels of genetic diversity has often shown rare species to have lower levels of genetic diversity compared to widespread plants with similar life history traits (Hamrick and Godt 1989), but the range in levels of diversity varies greatly. Rather than comparisons to a mean for rare or widespread species, Karron (1987) pointed out that it was more logical to make comparisons between congeneric species. Comparison between rare species and a widespread common relative helps to elucidate the particular aspects that limit the success of rare species (Gitzendanner and Soltis 2000) and this applies to comparisons of ecological parameters as well as genetic diversity. Felsenstein (1985) has also suggested that comparisons of congeners should use fully resolved phylogenies to ensure that the studies utilise the full power of phylogenetically independent comparisons.

Genetic studies have shown that several rare acacias in Western Australia are not depauparate in terms of genetic diversity compared with the levels of diversity generally observed in *Acacia* species, including many from eastern Australia (Buist *et al.* this proceedings). The rare species do, however, show lower levels of diversity when compared to their widespread relatives in phylogenetically independent comparisons (see Buist *et al.* this proceedings). For example, *A. sciophanes* and *A. anfractuosa* have similar morphological characteristics with the same sparce wispy, ghost-like form. *Acacia anfractuosa* is distributed over a 300 km range in the semi-arid zone of south-west Western Australia, and *A. sciophanes* is restricted to two populations on the western edge of that range. A study of genetic diversity in the two species showed that *A. anfractuosa* maintained average genetic variation within and between populations, whereas *A. sciophanes* showed lower levels of variation within populations and greater level of variation between populations in relation to their geographic distance (Tischler 1998). The rare *A. oldfieldii* also showed lower levels of genetic diversity than any taxon of the *A. acuminata* complex presumed to be its closest widespread relative (Broadhurst and Coates 2001). Properly resolved phylogenies make it easier to identify species pairs between which appropriate phylogenetically independent comparisons can be made for both genetic and ecological data. Comparisons between rare species and their close common relatives indicate how they differ, and therefore contribute to determining those aspects of a species' biology that may be factors in its rarity.

TABLE 1
Nucleotide divergence between *Acacia* species, and between lineages in *A. acminuata*.

SPECIES/LINEAGE	NUCLEOTIDE DIVERGENCE (%)
A. sciophanes – *A. anfractuosa*	0.072
A. lobulata – *A. verricula*	0.334
A. lobulata – *A. ixiophylla*	0.382
A. verricula – *A. ixiophylla*	0.152
A. oldfieldii – *A. acuminata*	0.287
A. acuminata lineage B – *A. acuminata* lineage C	0.083

CONCLUSIONS

Phylogenetic analysis is particularly valuable in an ancient, stable landscape such as the south-west of Western Australia, both for conservation of the flora and for efficient utilisation of native species for commercial production and revegetation. Phylogenies provide appropriate comparisons of genetic and ecological data between rare species and their widespread congeners, identify the phylogenetic value of species for setting conservation priorities and differentiate between relictual and recently evolved species. Phylogeny is also valuable in identifying and clarifying taxonomic ambiguities within both rare and widespread species, and comparative phylogeography is beginning to identify significant patterns in the evolutionary history of the south-west region.

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Towards an understanding of variation in the Mulga complex (*Acacia aneura* and relatives)

J.T.MILLER[1,2], R.A.ANDREW[1] AND B.R.MASLIN[3]

[1]Centre for Plant Biodiversity Research, CSIRO Plant Industry, GPO Box 1600, Canberra, Australian Capital Territory 2601

[2]Current address: Department of Biological Sciences, The University of Iowa, Iowa City, Iowa 52242, USA; email: jt-miller@uiowa.edu

[3]Department of Conservation and Land Management, Locked Bag 104, Bentley Delivery Centre, Western Australia 6983; email: brucem@calm.wa.gov.au

SUMMARY

Acacia aneura and its close relatives form a highly variable species complex commonly known as Mulga. They are small trees that dominate the vegetation of arid regions, in all occupying around 20% of Australia. This paper discusses and illustrates some of the more important types of variation found in Mulga, especially growth form and phyllode and pod morphology. This variation occurs both between and within populations and often results in a very complex mosaic of mixed Mulga populations. The underlying genetic and biological factors responsible for this variation are explored. While hybridisation is probably one cause of the variation, our use of microsatellite markers has not been able to provide direct evidence of this; however, the sampling done to date has been very small. Genetic developmental mechanisms such as polyploidy, apomixis and neoteny are maintaining this diversity. The Mulga complex contains multiple ploidy levels, including triploids, tetraploids and pentaploids, and polyembryony is a common feature in all these polyploids. Microsatellite data have identified fixed heterozygozity in populations with some genetic differences among morphotypes. Progeny arrays of 24 morphotypes indicated that over 95% of the plants have the same genotype as the mother plant. This accumulating evidence indicates that the Mulga complex is reproducing through facultative apomixis. Additionally the retention of juvenile characteristics (neoteny) is seen in many populations and also increases the variability. Given the importance of Mulga to the ecology, management and sustainable utilisation of arid zone ecosystems, it is important that the classification of the group adequately reflect the biological reality that exists in nature, if indeed this is achievable. The work reported here, and in related molecular and population studies, provides a basis for testing new classifications of Mulga. It also provides new information that can contribute to an improved classification of the group.

INTRODUCTION

The name Mulga is most commonly applied to the large, woody, perennial, arid zone species *A. aneura* F.Muell. ex Benth. and its close relatives. The name also denotes the vegetation type that is dominated by these species and which covers about 20% of the land surface of Australia (Everist 1949). According to Maiden (1907) the name Mulga alludes to a long, narrow shield made by Aborigines from *Acacia* wood.

Mulga is a very common, significant component of Australian arid zone vegetation and as such is important to the ecology and environmental management of these ecosystems. Furthermore, Mulga is the most economically significant acacia of the arid zone, primarily because it is an important source of fodder, especially during times of drought.

Species of the Mulga group, especially *A. aneura* itself, are notoriously variable, and identification of these taxa, both in the field and from herbarium material, is often very difficult. Understanding this variation and its causal factors, and being able to identify the taxa reliably, are critically important to the effective management, conservation and utilisation of this valuable resource. Two recent revisions of Mulga (Randell 1992; Pedley 2001) have helped clarify some of the taxonomic complexity within the group and have provided aids to identification (for naming species see also Maslin 2001). Very little is known, however, about the genetic basis of this variation, the origin of the different forms of Mulga, or the ecological factors that allow them to coexist in often bewilderingly complex mixed populations. Previous studies have suggested that these patterns of variation are due to a complex mix of sympatry and putative hybridisation in the major species (Davies 1976), geographic variation within the species, and sympatric variation within *A. aneura* itself (Pedley 1973; Lamont and Fox 1981; Fox 1986; Cody 1989). In the light of our own field studies it appears likely that while hybridisation is a major factor in creating diversity, there are other mechanisms maintaining this diversity. These mechanisms could include polyploidy and apomixis such as are found in other legume taxa of the arid zone, e.g. the *Senna artemisioides* group (Randell 1970), as well as neoteny.

This overview paper introduces some of the more important patterns of variation in Mulga and some of the genetic and biological mechanisms responsible for the great diversity displayed by species of this group. In so doing this will lead to a better understanding of the evolutionary history of these plants and how they relate to their environment, and quite possibly provide the basis for an improved classification of Mulga. The fundamental genetic question is whether plants of the same morphotype[1] share immediate common ancestry, irrespective of whether they grow side-by-side or are widely distributed. Furthermore, it is important to understand the genetic relationships among morphotypes, in particular whether morphotypes arise independently within populations through *in situ* hybridisation events, or whether the morphotype has a more ancient origin from a single area and has spread independently through arid Australia.

The data presented here have been acquired from four field excursions we conducted over the last few years to Mulga-diverse areas in the Mt Magnet and Pilbara regions of W.A., southern N.T., S.A. and north-western N.S.W. Based on this field experience and subsequent glasshouse and preliminary laboratory studies, hypotheses have been developed concerning variation in Mulga and a preliminary account of these ideas is presented below.

Distribution and ecology

Communities with Mulga species as the dominant or co-dominant occupy 15 million square kilometres or about 20% of the Australian continent (Everist 1971, cited in Johnson and Burrows 1981). They occur in a discontinuous belt between c. 20° and 35°S latitude and 113° and150°E longitude in the central and southern parts of the arid zone from near the west coast of W.A. eastwards through N.T. and S.A. to central Qld and N.S.W., and far north-western Vic. The distribution of the 'core group' of Mulga, namely, *A. aneura* (10 varieties), *A. ayersiana*, *A. minyura* and *A. paraneura*, is shown in Figure 1. Mulga is adapted to environments where the soil water regime is almost always limiting for growth, but where there is a possibility of recharge at all seasons (Johnson and Burrows 1981). As discussed by Midgley and Gunn (1985), Mulga communities predominate where the mean maximum temperature of the hottest month is 36-40°C and the mean annual rainfall is mainly 200-250 mm (although in the easternmost areas it rises to 500 mm); they are conspicuously absent from the semi-arid regions with a regular summer or winter drought (Nix and Austin 1973). In the driest areas direct precipitation figures may give a misleading impression of the amount of water the trees get as Mulga often receives 'run off' water from surrounding areas (it is in these areas that the densest stands occur). Mulga communities grow on a range of soil types but the densest stands are usually on red earth and sand or red clayey sand; rarely on alkaline soil and almost never on black cracking clay.

As discussed by Johnson and Burrows (1981), *A. aneura* is very well adapted for survival in harsh, arid conditions. Its phyllodes are held vertically rather than horizontally, thereby aiding water redistribution and minimising heat absorption. The sclerophyllous phyllodes are hairy, have a resinous covering and are drought resistant by means of dormancy. The plants 'aestivate' when drought occurs and resume growth within four days after water again becomes available (Slatyer 1965). They also have the capacity to channel water down their phyllodes and stems so that rainfall is concentrated at the base of the trunk (Slatyer 1965; Pressland 1973). This stem flow increases significantly the amount of water available to the roots, for example, 25 mm of rainfall can be concentrated into 140 mm within the root zone of the tree, making small showers more effective (Kerle 1995).

Utilisation

Mulga is not only a very important component of arid zone natural ecosystems but also provides many commodities for man. In traditional Aboriginal cultures *A. aneura* is an important source of food; not only are its seeds consumed (first being roasted and ground into a paste) but Mulga plants provide habitats for honey ants, lerps (which produce 'honey dew') and wasps (which produce 'mulga apples'). Mulga is also a source of wood for weapons, digging sticks and sacred objects; *A. minyura* provides copious resin, called 'kiti', which was traditionally used by men in the production of tools and spear throwers. For further information on Aboriginal usage of Mulga see Aboriginal Communities of the Northern Territory (1993), Kerle (1995), Latz (1999) and Cowley (2001).

As summarised by Doran and Turnbull (1997), Mulga forms a significant part of the dry-range diet of sheep in Australia, but without supplementary high quality feed it is barely sufficient for subsistence. Further information on the fodder value of Mulga is given in Everist (1949, 1969), Chippendale and Jephcott (1963), Askew and Mitchell (1978), Cunningham *et al.* (1981), Goodchild and McMeniman (1987) and Mitchell and Wilcox (1994).

TAXONOMY

The taxonomic imperative

It is somewhat surprising that a species-group like Mulga that is so widespread, common and important to the structure of arid zone ecosystems, and which is so important to the pastoral industry, has received so little taxonomic attention. In terms of species numbers the Mulga group is not especially large, but in terms of variation and taxonomic complexity few Australian plant groups would rival Mulga. Over the past 100 years or so

[1] We use the term morphotype to define a group of plants that share similar-looking morphological features, e.g. growth form, phyllode shape, size and/or colour, pod form, etc.

an extensive body of literature has been published on Mulga, dealing primarily with its ecology, biology, Aboriginal utilisation and relevance to the pastoral industry (for reviews see Everist 1969, Johnson and Burrows 1981 and Doran and Turnbull 1997). Although some authors did recognise that different 'forms' of Mulga exist and discussed them as separate entities (e.g. Everist 1969; Beard 1976: 43; Pedley 1973), many treated Mulga simply as a single species, namely, *A. aneura*. As discussed below, the current classification of Mulga recognises four distinct species (comprising 13 separate taxonomic entities) as the 'core' of the group, and future studies may well show that more taxa should be recognised. Therefore, caution should be exercised when interpreting previous studies because it may not always be clear which of the taxa as defined in Pedley's classification (2001) is meant. Furthermore, as noted by Randell (1992), as the taxonomic concepts of Mulga become increasingly refined there may well be a need to re-evaluate earlier concepts. Extending this notion to the future it is imperative that the classification of Mulga reflect the biological reality that exists in nature, if indeed this is achievable. The importance of defining and naming meaningful biological entities is discussed by Maslin (this proceedings) and what is said there applies particularly to Mulga.

In 1971 Preece considered that, because of the amount of variation in *A. aneura*, it was dangerous for ecologists to apply their results too far beyond the population being studied. While this was sound advice at the time the situation today has improved through the taxonomic work of Randell (1992) and Pedley (2001). There now exists a taxonomic framework that helps users to generalise the results of their studies beyond the population level. As discussed below, however, it is quite possible that future studies will further refine the classification of Mulga and produce a scheme that accommodates even better the complex patterns of variation in many populations.

Definition of Mulga

As used here the term 'Mulga group' refers to 10 species (Table 1), comprising a core group of four species, *A. aneura* F.Muell. ex Benth. (Common Mulga, containing 10 varieties), *A. ayersiana* Maconochie (Uluru Mulga), *A. minyura* Randell (Shrubby Desert Mulga) and *A. paraneura* Randell (Weeping Mulga), together with six close relatives, namely, *A. atopa* Pedley, *A. brachystachya* Benth. (Turpentine Mulga or Umbrella Mulga), *A. clelandii* Pedley (Cleland's Mulga), *A. craspedocarpa* F.Muell. (Hop Mulga), *A. ramulosa* W.Fitzg. (Bowgada or Horse Mulga, containing two varieties) and *A. subtessaragona* Tindale and Maslin. Other species not far removed from the Mulga group include *A. coolgardiensis* Maiden (Sugar Brother) and perhaps *A. catenulata* C.T.White (Bendee).

Although field workers can often recognise plants as belonging to the Mulga group through characters such as growth form, foliage colour and their place in the landscape, such identifications are not necessarily reliable. To identify Mulga accurately one must resort to cryptic characters (i.e. attributes that are often visible only with the aid of magnification). However, there is no single character that uniquely defines the entire Mulga group and, indeed, the group is so variable that even a combination of characters produces a definition that is almost meaningless, at least in terms of gross morphological features. The four species of the core group of Mulga, however, can be uniquely defined by a reasonably small suite of characters. This combination of attributes (listed below) is found in *A. aneura*, *A. ayersiana*, *A. minyura* and *A. paraneura* but not in any other species.

- Trees or (usually tall) shrubs with hard, grey or blackish bark.
- Branchlets (at least when young) invested with short, straight, silvery white, appressed hairs.
- Phyllodes not spiny tipped, flat or terete (never angular in cross-section), striate by numerous, fine, closely-spaced, longitudinal nerves, the nerves commonly resinous (at least on young phyllodes) and with short, straight, silvery white, appressed hairs between them (hairs sometimes cover the entire surface of the phyllode).
- Inflorescences simple (i.e. not racemose or paniculate) with the flowers arranged in cylindrical spikes or sometimes in obloid (never globular) heads.
- Sepals free or very shortly united at their base.
- Pods flat, thin-textured (often papery, never woody), commonly reticulately veined and with or without a narrow marginal 'wing' (see Randell 1992: 108 for discussion of the 'wing').
- Seeds transversely or obliquely aligned in the pod, the aril rather small and white or very pale yellow.
- Distribution largely confined to the arid zone (Figure 1).

The six close relatives of the core group possess many but not all of the above attributes; each relative has one or more characters that are at variance. For example, *A. craspedocarpa* has reticulately veined phyllodes, *A. ramulosa* and *A. brachystachya* have non-resinous phyllodes and usually terete pods, *A. atopa* and *A. subtessaragona* have quadrangular pods and *A. clelandii* has ± longitudinal seeds. Some of these taxa, especially *A. craspedocarpa*, hybridise with various members of the core group of Mulga.

VARIATION IN MULGA

Mulga species show a great deal of variation in morphological features, especially growth form, phyllode shape, size and colour, and pod morphology. This variation is evident both between different populations of the one taxon and between different taxa within the one population. People with field experience of Mulga commonly encounter mixed-populations containing few

TABLE 1
The Mulga core group and related taxa.

Mulga core group	*A. aneura* F.Muell. ex Benth. (Common Mulga) var. *aneura* var. *argentea* Pedley var. *conifera* Randell var. *fuliginea* Pedley var. *intermedia* Pedley var. *macrocarpa* Randell var. *major* Pedley var. *microcarpa* Pedley var. *pilbarana* Pedley var. *tenuis* Pedley *A. ayersiana* Maconochie (Uluru Mulga) *A. minyura* Randell (Shrubby Desert Mulga) *A. paraneura* Randell (Weeping Mulga)
Closely related to Mulga core group	*A. atopa* Pedley *A. brachystachya* Benth. (Umbrella Mulga,Turpentine Mulga) *A. clelandii* Pedley (Cleland's Mulga) *A. craspedocarpa* F.Muell. (Hop Mulga) *A. ramulosa* W.Fitzg. (Bowgada, Horse Mulga) var. *ramulosa* var. *linophylla* (W.Fitzg.) Pedley *A. subtessaragona* Tindale & Maslin
More distantly related to Mulga core group	*A. coolgardiensis* Maiden (Sugar Brother) ?*A. catenulata* C.T.White (Bendee)



Figure 1. Distribution of the 'core group' of Mulga: A. aneura *(10 varieties)*, A. ayersiana, A. minyura *and* A. paraneura. *Data derived from a compilation of the maps presented in Pedley (2001). Cartography by John Maslin.*

to many different morphotypes[2]. Applying names to the morphotypes has in the past been extremely difficult, not only because very few formal names were available, but also because it is difficult to know with certainty which morphotypes represent the same taxonomic entity. The studies of Randell (1992) and Pedley (2001) have helped clarify some of this taxonomic complexity within the group and have provided aids to identifying the taxa, but the genetic basis of the variation is little understood.

Our preliminary field studies have provided us with an excellent, albeit somewhat limited, opportunity to examine variation in a number of Mulga populations. This work has led to a better understanding of population variation and the distribution of morphotypes, which in turn has allowed the definition of hypotheses that can be tested by molecular methods (see below).

The difficulty in understanding Mulga and applying names to the myriad of forms, lies in the extreme variability in plant habit, foliage and pods. The distribution of morphotypes within a population can provide an indication of the underlying genetic mechanisms responsible for this variation. The following discussion attempts to describe the morphological variation in the core group of Mulga. In a later section we discuss the possible genetic determiners of this variation.

Habit variation

Mulga plants often have distinctive field facies and the main growth attributes that produce these are the following:

- height (shrubs or trees about 3-15 m high);
- number of main stems arising from ground level (one to many);
- angle of divergence of lateral branches from the main stems (horizontal to erect);
- posture of the main branches and branchlets (erect to pendulous);
- overall shape of the plants (rounded, obconic, diffuse, etc.);
- colour and density of the crown foliage.

Figures 2–4 illustrate some of the morphotypes found in members of the 'core group' Mulga. These images show that not only is Mulga very variable in growth form, there is no such thing as a 'typical' Mulga habit. Nevertheless, many taxa have characteristic features and these aid their identification in the field, provided that one knows what characters to look for and that hybridisation has not obscured them. Although many Mulga plants are obconic trees (Figure 2A, 2B, *A. aneura* var. *aneura*) some are shrubs, for example, *A. minyura* (Figure 3A) which is characteristically multi-stemmed with a dense, rounded crown, and *A. aneura* var. *macrocarpa* (Figure 3B) which has a more open, spreading crown. The number of stems arising from ground level can vary, not only between taxa but also within the one taxon; for example, *A. ayersiana* may be either single-stemmed (Figure 4B) or multi-stemmed (Figure 4C). The angle of divergence of the lateral branches from the main stems commonly imparts a distinctive aspect to the plants. For example, *A. aneura* var. *tenuis* (Figure 3E) typically has a distinctly erect branching pattern, whereas in *A. aneura* var. *conifera* (Figures 2E-G) the lateral branches diverge more or less at right angles from the main stem. A very distinctive growth form is that of *A. paraneura* (Figure 4A) which has a whispy open crown with pendulous branchlets. Crown colour in Mulga is most often a greyish green (e.g. *A. aneura* var. *aneura*), but it is silvery grey or blue-grey in taxa such as *A. ayersiana* and *A. minyura* and typically pale green in others such as *A. aneura* var. *tenuis*. Crown colour may be dominated by the colour of the new shoots and can therefore vary seasonally; in taxa such as *A. aneura* var. *fuliginea* the plants assume an overall brownish hue when making new growth.

Field observations suggest that, while some morphotypes maintain a single habit throughout their life, others change as they mature. In the latter case the adolescent plants are often more bushy and rounded than the adults (Figures 4B-D, *A. ayersiana*; Figures 3C-D, *A. aneura* var. *pilbarana*). Juvenile plants also appear to have distinctive facies and there would be a practical advantage (to ecologists for example) in being able to ascribe names to these confidently; further study of juveniles is needed.

It seems likely that in some taxa, at least, growth can be arrested at particular stages of development (e.g. the adolescent phase), and therefore some of the variation observed in Mulga populations may be due to this phenomenon. In other words, plants may look superficially very different (in both growth habit and phyllode morphology) but may in fact represent the same genetic entity. The very distinctive 'pine tree' habit of *A. aneura* var. *conifera* may possibly be an example of arrested development, although this is yet to be confirmed through detailed field study and genetic investigation. Typical var. *conifera* plants grow to tall trees (reaching c. 10 m high) with one (or sometimes two) straight, erect trunks and numerous, short lateral branches which diverge almost at right angles from the main trunk (Figures 2E-G). These plants have a scattered distribution (Pedley 2001: 476) and appear not to be especially common. An intriguing question is whether the so-called 'Christmas tree' form of Mulga that is encountered in some populations of at least *A. aneura* var. *aneura*, var. *pilbarana* and var. *tenuis* is the same entity as *A. aneura* var. *conifera*. Pedley (2001) thinks not, and he may well be correct. However, our field observations at a few sites have provided insights into the origins of 'Christmas tree' Mulga and, even if these morphotypes are taxonomically different from var. *conifera*, they may provide clues as to the origin of this variety. Figure 2D shows a typical 'Christmas tree' morphotype that occurred (at a very low frequency) within a mixed Mulga population; this population, about 30 km north of Meekatharra, W.A., contained plants of *A. aneura*

[2] The term morphotype is used here to denote a group of plants that share similar-looking morphological features, e.g. growth form, phyllode shape, size and/or colour, pod form, etc.



Figure 2. Habit variation in Λ. aneura. ***A*** – Λ. aneura var. aneura *(single-stemmed);* ***B*** – Λ. aneura var. aneura *(multi-stemmed);* ***C*** – Λ. aneura var. aneura *(note wide-spreading branches below fork and ascending branches above fork);* ***D*** – Λ. aneura var. aneura *('Christmas tree' morphotype);* ***E-G*** – Λ. aneura var. conifera.
All photographs by B.R.Maslin except 2F by H.Hewitson.

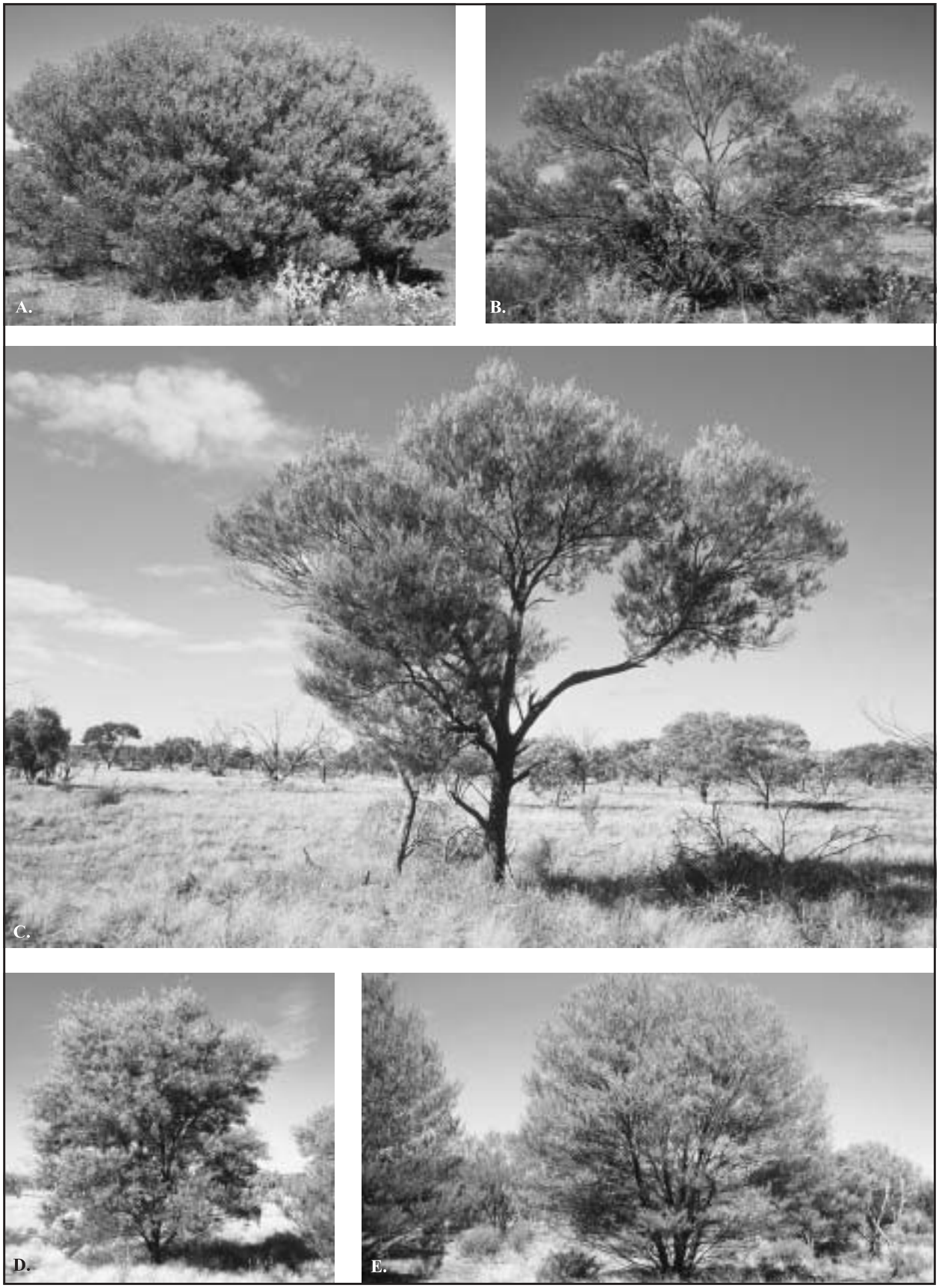


Figure 3. Habit variation in A. aneura *and* A. minyura. ***A*** – A. minyura*;* ***B*** – A. aneura var. macrocarpa*;* ***C*** – A. aneura var. pilbarana *(mature plant);* ***D*** – A. aneura var. pilbarana *(juvenile plant);* ***E*** – A. aneura var. tenuis.
All photographs by B.R.Maslin.

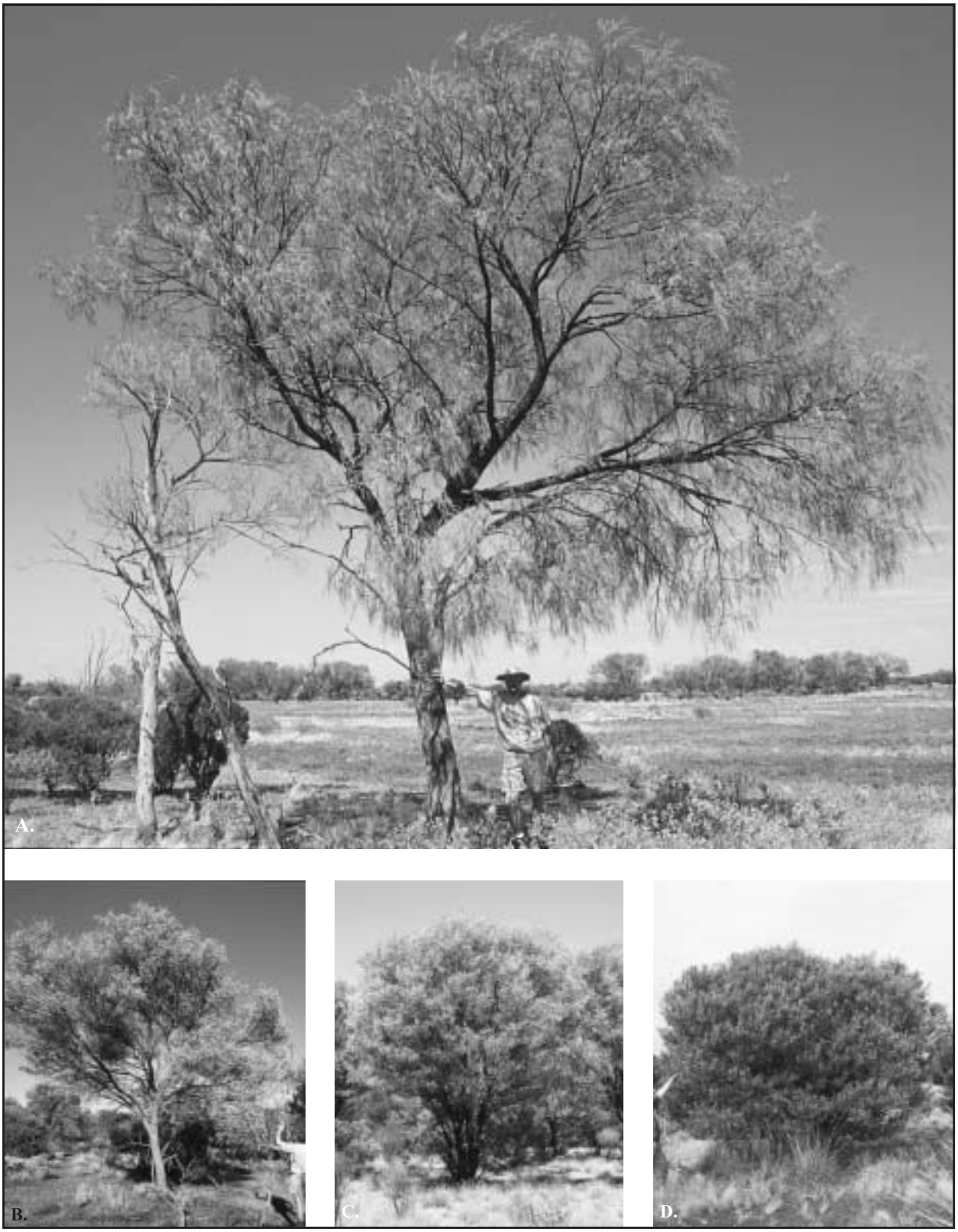


Figure 4. Habit variation in Λ. paraneura *and* Λ. ayersiana. ***A*** *–* Λ. paraneura *(note pendulous branchlets);* ***B-D*** *–* Λ. ayersiana *(**B** – mature, single-stemmed plant; **C** – mature, multi-stemmed plant; **D** – juvenile plant).*
All photographs by B.R. Maslin.

var. *aneura* and other Mulga taxa. Here, the 'Christmas tree' morphotype possessed a single, straight, erect main trunk and widely spreading lateral branches, as in var. *conifer*. Adjacent to this plant, and occurring at a higher frequency within the population, were morphotypes that can best be described as having a 'pseudo-conifer' growth habit (Figure 2C). These plants had a single trunk for about 1-2 m above ground level, at which point it divided into two main stems. The lateral branches below the divide were quite short and diverged almost at right angles, whereas above the divide the lateral branches were longer and had an ascending to erect aspect. It is not hard to imagine that once the lower branches were lost and the plant continued to grow, it would attain a mature growth form similar (or identical) to that which is commonly seen in var. *aneura* (Figure 2A). Similarly, it is easy to imagine a 'Christmas tree' morphotype resulting, had the trunk of the 'pseudo-conifer' plant not divided and had all the lateral branches retained their horizontal aspect. Whether or not these 'Christmas tree' morphotypes would ultimately mature into 'typical' var. *conifera* is not known.

In several isolated populations *A. aneura* var. *conifera* maintains its characteristic growth habit but the phyllodes vary significantly (terete and green vs. flat and greyish) which suggests that plants attributed to this variety may not all share a common ancestry. More field studies are needed to understand these developmental phenomena better, but this is type of problem can also be addressed by DNA methods.

Phyllode variation

Perhaps the most striking variation among Mulga plants is in phyllode shape and size, although colour also varies and can be a significant factor contributing to the overall 'look' of the plants (see above under *Habit variation*). Phyllode variation can be expressed between individuals of the one taxon over its geographic range, between individuals of different taxa within the one population, or at different stages of growth within an individual plant. It is intra-population variation that is normally the most striking (and the most confusing for field workers), and this is often compounded by genetic factors (discussed below) such as hybridity between morphotypes. Figure 5 shows a range of phyllodes from one mixed Mulga population encountered during the course of our study. This demonstrates the great complexity that can exist within populations.

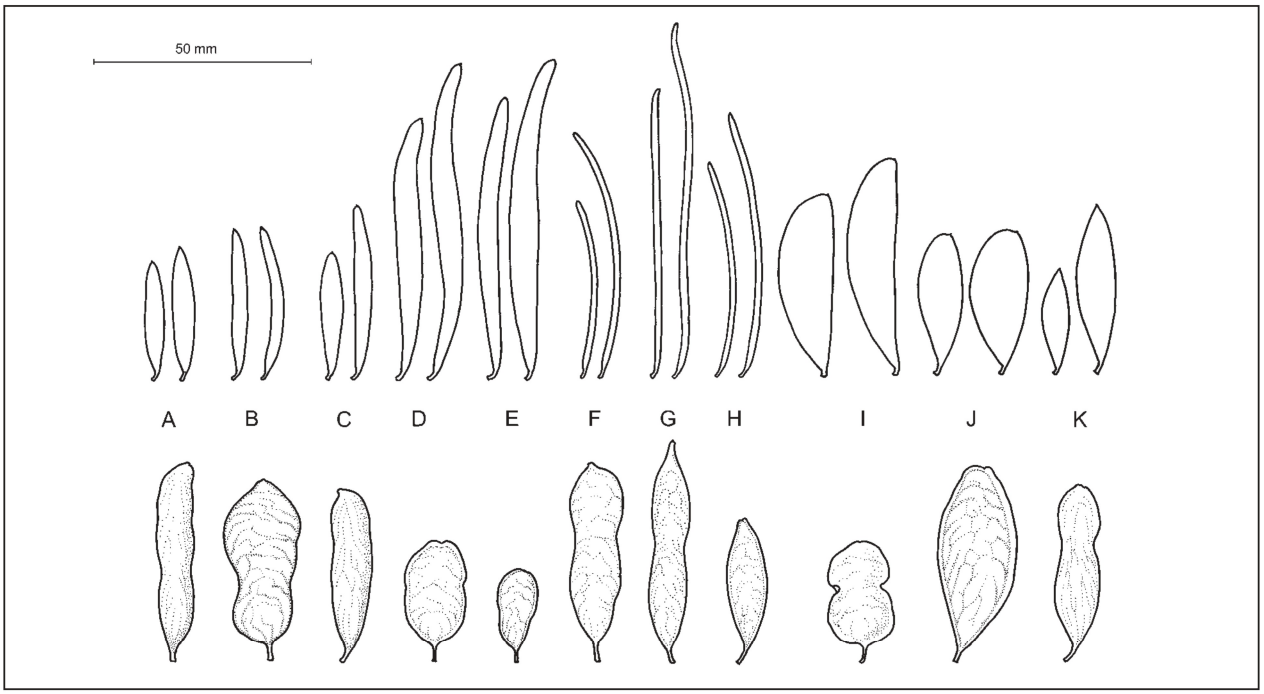


Figure 5. Phyllode and pod variation sampled randomly (and not thoroughly) from a mixed Mulga population near Mt Magnet, W.A. ***A*** *and* ***C*** – A. minyura x A. ramulosa var. ramulosa *(B.R.Maslin & J.T.Miller 7924C & G respectively);* ***B*** – A. aneura var. macrocarpa x A. minyura *(B.R.Maslin & J.T.Miller 7924B);* ***D*** *and* ***E*** – A. aneura var. major *(B.R.Maslin & J.T.Miller 7924F & H respectively);* ***F*** – A. aneura var. aneura *(B.R.Maslin & J.T.Miller 7924J);* ***G*** – A. aneura var. microcarpa x A. ramulosa var. ramulosa *(B.R.Maslin & J.T.Miller 7924);* ***H*** – A. aneura *var.* microcarpa *(B.R.Maslin & J.T.Miller 7924A);* ***I*** – A. aneura var. argentea *(B.R.Maslin & J.T.Miller 7924I);* ***J*** – A. craspedocarpa *(B.R. Maslin & J.T.Miller 7924D);* ***K*** – A. craspedocarpa x A. minyura *(B.R.Maslin & J.T.Miller 7924E)*
Determinations by L.Pedley (BRI) from herbarium material, except 7924F & H which were determined by B.R.Maslin. Voucher specimens lodged at the W.A. Herbarium (PERTH).

Within the 'core group' of Mulga the phyllodes vary from terete to flat, straight to variously curved, short to long and linear to narrowly elliptic. The smallest phyllodes occur on *A. minyura* (0.5-2.5 cm long and 2-4 mm wide), the widest on *A. ayersiana* and *A. aneura* var. *major* (reaching 10 mm and 8(-13) mm wide respectively) and the longest on *A. paraneura* (7-20 cm). Although phyllode size is an easy character to observe and measure, it is variable and therefore is, in itself, generally not a reliable means of identifying taxa.

A striking example of phyllode variation on a single plant was observed in two populations of a probable new taxon (referred to herein as Holey Mulga) that we inspected near Alice Springs, Northern Territory. Plants of this species show three distinct phyllodes forms (Figure 6):

- juvenile phyllodes are oblong, elliptic or oblanceolate and are short and broad (about 15-25 x 5-10 mm);
- adult phyllodes are narrowly linear and 40-70 x 1.5-2 mm;
- adolescent phyllodes are intermediate in both shape and size, i.e. narrowly oblong-elliptic and about 25-40 x 3-5 mm.

Some plants contain all three phyllodes types, juveniles on the lower branches, adults on the upper branches and the adolescents in between. However, plants bearing only juvenile, adolescent or adult phyllodes also occur. From observations to date it is probable that in this taxon both the juvenile and adolescent foliage may persist on fully grown plants, but it is not known if these plants ever become biologically mature, i.e. capable of producing flowers and fruits (to date only fully grown plants bearing adult foliage have been collected in fruit). Thus, in Holey Mulga one may encounter plants bearing any one of three very different phyllode types and this can cause problems with identification, particularly when using herbarium material. In the field, however, plants of this taxon can usually be reliably identified by their fluted trunks (similar to those found in *A. coolgardiensis* from W.A. and *A. catenulata* from Qld and north-eastern N.T.) and by the fact that they always grow on rocky ridges. Also, when the plants die from old age, drought or fire they show very distinctive holes in their trunks where lateral branches once emerged, thus the common name Holey Mulga.

It is likely that at least some of the variation observed in Mulga populations can be accounted for by neoteny and heteroblasty, as just described for Holey Mulga. To what extent this occurs will be determined only by further field study.

Pod variation

The most important variable in the fruit of the core group of Mulga is the position of the vein that lies at or near the margin of the pod. As discussed by Randell (1992), this vein supplies the placenta of the developing seed via the funicle. In the past the area between the vein and the margin of the pod has been incorrectly termed a 'wing', and the width of this wing can be useful in distinguishing certain taxa. In *A. aneura* var. *aneura*, var. *macrocarpa* and var. *pilbarana*, for example, the wing is absent or extremely narrow, whereas in taxa such as *A. ayersiana*, *A. minyura* and *A. aneura* var. *intermedia* and var. *major* it is 1-2 mm wide (Pedley 2001). Sometimes the wing is not easy to discern because the submarginal vein may not be overly prominent when viewed on the outer surface of the pod. In these cases it is best to split the pod open and inspect the vein on the inner surface of an individual pod valve. Other carpological features useful in identifying taxa include pod (and seed) size, pod colour and to a less extent the prominence of surface reticulations and density of the indumentum. Acacia *aneura* var. *tenuis*, for example, has distinctively shiny, pale brown pods, while *A. aneura* var. *macrocarpa* and var. *microcarpa* have large and small pods respectively (Pedley 2000).

There is some evidence that pod and phyllode size and shape covary. Both Cody (1989) and Andrew *et al.* (in review) found that phyllode and pod variation are congruent. This suggests that, at least in the plants studied by these authors, pod and phyllode traits are either linked or the same genes may affect the traits.

Variation within populations

Perhaps the most perplexing aspect of the Mulga complex is that the above-mentioned variation in plant habit, phyllodes and pods often occurs in a single population. Such populations usually contain from a few to more than a dozen morphotypes. It is not uncommon for some of these morphotypes to re-occur in adjacent or more distant populations, often in association with different morphotypes. This results in a very complex mosaic of morphotypes in mixed populations across arid landscapes. Single morphotype populations are apparently rare but have been seen, for example, in *A. aneura* var. *pilbarana*.

An important approach to understanding what controls variation in Mulga is to know the way that characters vary within populations. If the variation for a particular attribute (e.g. phyllode size) patterns into discrete classes then this indicates that there may be a barrier to gene flow between the morphotypes. However, if the variation is continuous it may indicate that hybridisation occurs among the morphotypes. A few studies have examined phyllode length variation within Mulga populations and the results of these indicate, not unexpectedly, that different patterns exist. Cody (1989), for example, found a continuous distribution of phyllode dimensions at Yelma in Western Australia. On the other hand, Andrew *et al.* (in review) found a disjunct distribution of phyllodes characters in a population near Mt Connor in the Northern Territory. As discussed below, developmental, genetic or environmental factors (or a combination of these) may be responsible for the observed patterns of character variation within populations.

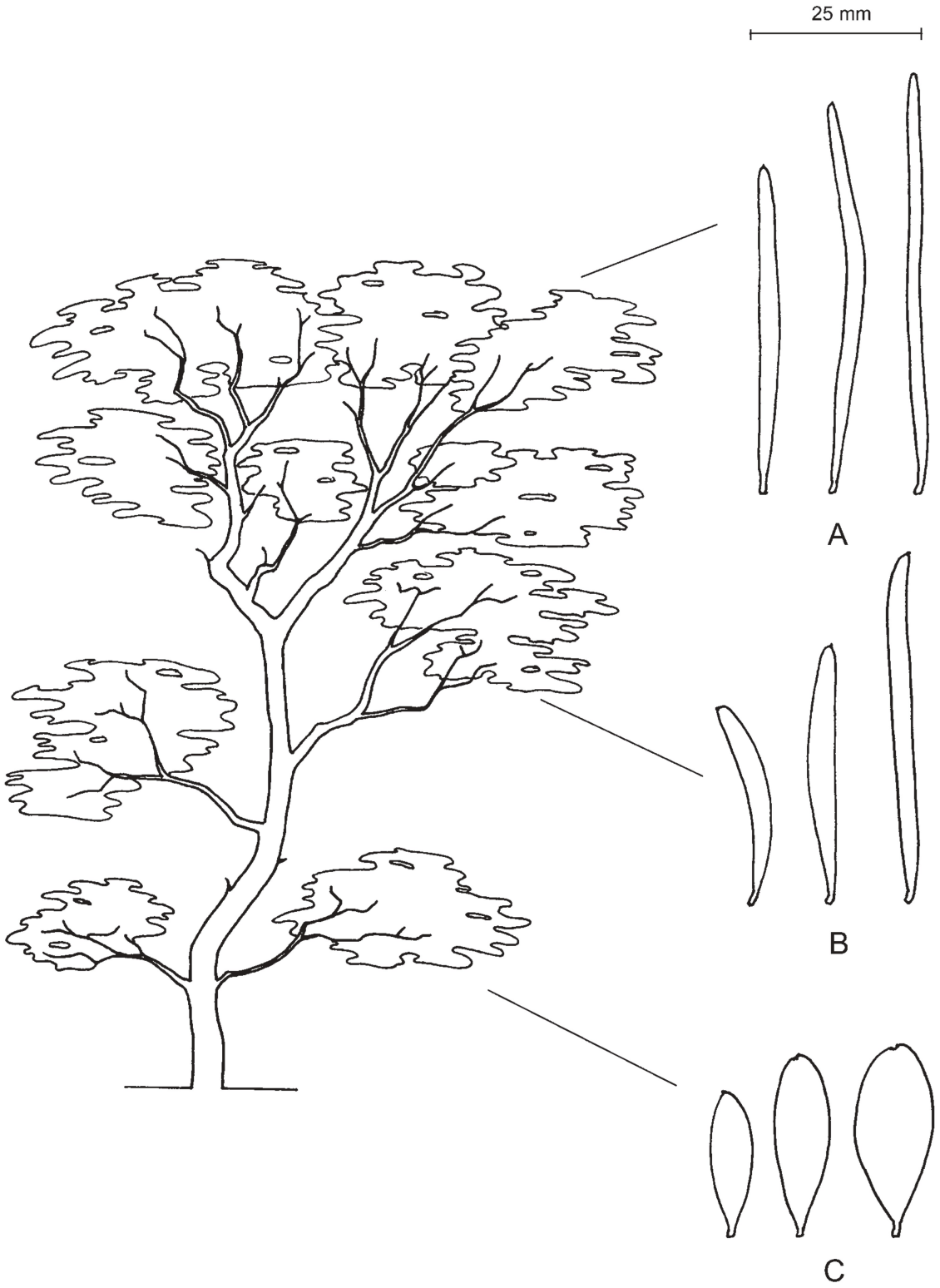


Figure 6. Acacia *sp. nov. (Holey Mulga) showing heteroblastic foliage on a single plant. A – mature phyllodes found on upper branches; B – intermediate phyllodes; C – juvenile phyllodes found on lower branches.*
A from B.R.Maslin 8149(iii); B from B.R.Maslin 8149(ii); C from B.R.Maslin 8149(i). Voucher specimens lodged at the W.A. Herbarium (PERTH). Collection from near Alice Springs, N.T.

Variation between populations

As mentioned above, both discrete classes and continuous variation in phyllode size have been found in Mulga populations. Figure 7 presents data from 18 populations in the Mt Magnet area of W.A. where plants were collected to represent the range of variation. The figure depicts the length versus width of phyllodes and shows the variation in phyllode size from obviously small in *A. minyura* to large in *A. ayersiana*. Other than the extremes of the size range it is not possible to detect distinct size classes in this particular study. These results confirm field observations that populations consist of morphotypes varying in phyllode size and that a single morphotype can have a wide distribution. This sort of quantitative approach should be applied also to other structures such as pods and seeds, and extended to populations across the entire geographic range of Mulga.

Another important key to understanding the complexity in Mulga is to determine whether the similar-looking morphotypes in different populations actually represent the same genetic entity. For example, a plant from Central Australia may have the same habit and phyllode morphology as one from W.A. The critical question is whether these two plants have a common ancestor (and occur in their respective geographic areas by natural distribution processes) or whether they have arisen independently in each area by local processes (such as hybridisation), resulting in similar-looking forms. If these plants are shown to be of the same genetic type it would indicate a common origin of the morphotype. This would suggest that the morphotype is maintaining its genetic integrity and could be considered worthy of formal taxonomic recognition. If, however, the two morphotypes had different genetic signatures it would indicate that they may be of local origin, and that the similar morphology may be due to parallel evolution or separate hybridisation events. It is this type of question that may be addressed with molecular marker techniques.

FACTORS CONTRIBUTING TO VARIATION

Genetic techniques used to study variation

The past decade has seen an explosion in tools available to study plant genetics and, in particular, the relatively new DNA technique Simple Sequence Repeats (SSRs or microsatellites). These methods allow the study of genetic relationships among plants both within and between populations. In particular, these markers can identify the parents and offspring of hybridisation events. Other important genetic techniques, and ones that we have employed in our study of Mulga, are cytology and embryology. Data derived from observations of chromosomes can identify barriers to reproduction, since plants with different numbers of chromosomes are generally incompatible.

While field study of Mulga has contributed significantly to our understanding of variation, the use of glasshouse grown plants has been critical to developing an understanding of the underlying genetics. Growing plants to study development, cytogenetics and molecular genetics is helping to unveil some of the mysteries surrounding the morphological variability in Mulga.

Hybridisation

Hybridisation among Mulga morphotypes, leading to the creation of new morphotypes, has been considered a major factor in Mulga diversification (Davies 1976; Randell 1992; Pedley 2001). Our own field observations and morphometric studies (Figures 7 and 8) show that, in many Mulga populations, morphotypes occur that seem intermediate in form (e.g. in shape and size of phyllodes) between two or more other morphotypes. This suggests that the intermediate form may be a hybrid derived from the local parental plants. However, hybrids do not always express the intermediate character states of the parents, as some contain novel or transgressive morphological characters (McDade 1990; Riesberg and Ellstrand 1993).

Additionally, two morphotypes may hybridise to create unique progeny but these may be infertile. In these cases the hybrids may increase the amount of variation observed within a population but, being infertile, do not contribute to future gene pools.

Locally derived hybrids appear to dominate some populations. For example, in the Mt Magnet area of W.A. many populations contain *A. aneura*, *A. craspedocarpa* and putative hybrids between the two. *Acacia craspedocarpa* has relatively short, broad phyllodes with a distinctive reticulate nervature (due to anastomosing minor nerves) and large pods (Figure 8D); *A. aneura*, on the other hand, has long, narrow phyllodes with parallel (not reticulate) nerves, and smaller pods (Figure 8A). The putative hybrids can be readily recognised by the phyllodes which are intermediate between the putative parents not only in size but also in their nervature (i.e. they have relatively few anastomoses, therefore the reticulum is not pronounced) (Figures 8B, 8C). Populations can be dominated by the hybrids (often also including F2 back crosses to one or other of the putative parents) with various *A. aneura* and *A. craspedocarpa* morphotypes interspersed, creating a complex mixture of plants. It is not known whether these hybrids persist and are reproductively successful although mature seeds have been collected from many of them. If this same type of complex hybridisation occurs between similar-looking morphotypes then it is more difficult than in the *A. aneura/craspedocarpa* example to distinguish between the parents and hybrids. If these hybrids are interfertile then the complex genetic mixture gets even more complicated, and the differences between the morphotypes may become even less evident.

Molecular markers have been employed to investigate the role of hybridisation in one population of *A. craspedocarpa* containing one morphotype of *A. aneura* and several putative hybrids. This population was located

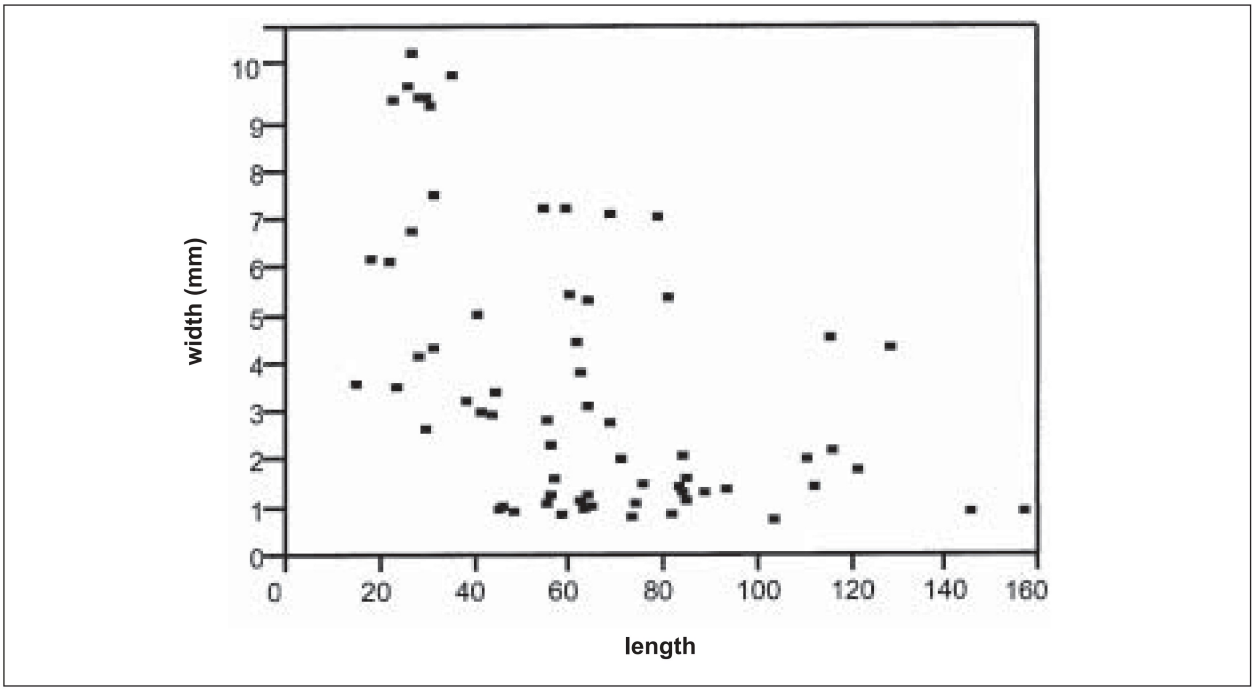


Figure 7. Plot of the length (x-axis) and width (y axis) of various mulga phyllodes collected in the general Mt. Magnet/Meekatherra area of Western Australia (B.R.Maslin, J.Miller, L.Sweedman & B.Cole BRM 7892-7924). Each point is the average from the measurement of three phyllodes from a single tree.

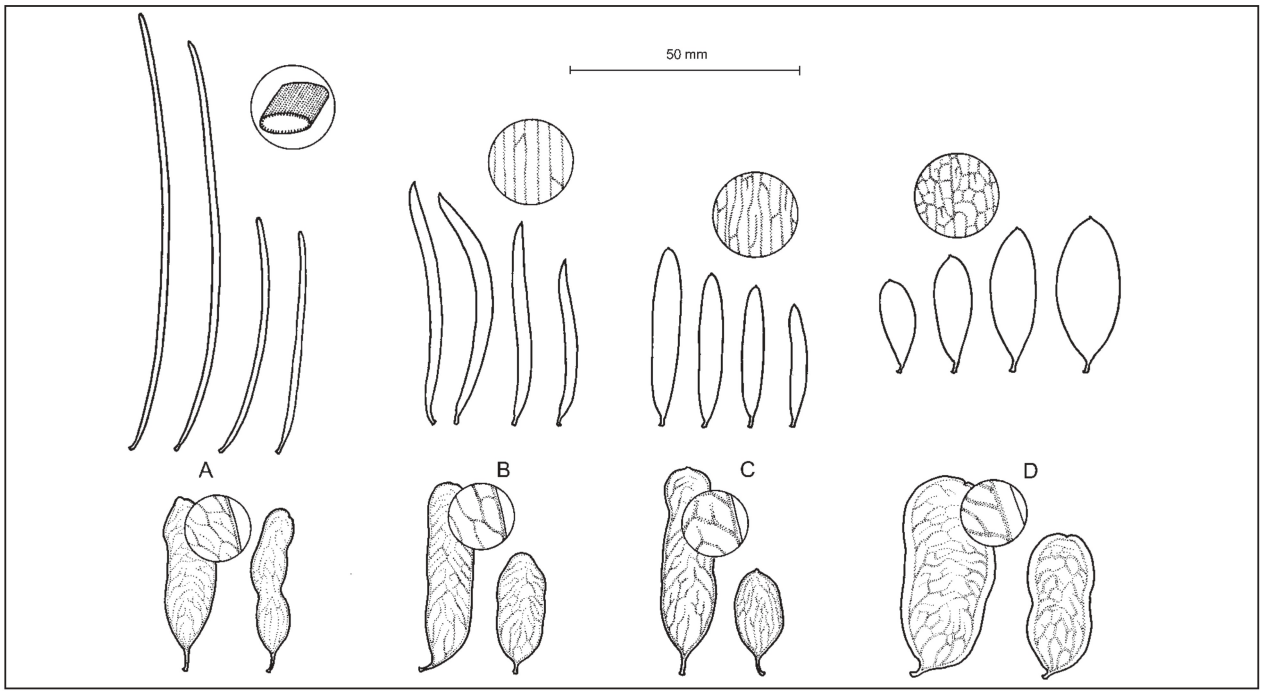


Figure 8. Acacia aneura var. aneura x A. craspedocarpa *hybrid complex near Mt Magnet, W.A.* ***A*** – A. aneura var. aneura *(pods not winged; phyllodes linear with insert showing finely striate, parallel nervation);* ***B*** *and* ***C*** – A. aneura var. aneura x A. craspedocarpa *hybrids showing intermediate pods and phyllodes (note inserts showing few anastomosing minor nerves, i.e. phyllodes not conspicuously reticulate);* ***D*** – A. craspedocarpa *(pods winged; phyllodes short and broad, with insert showing distinctive reticulate nervature).*
A from B.R.Maslin, J.Miller, L.Sweedman & B.Cole (BRM 7892); B from B.R.Maslin, J. Miller, L.Sweedman & B.Cole (BRM 7892E); C from B.R. Maslin, J.Miller, L.Sweedman & B. Cole (BRM 7892D); D from B.R.Maslin, J.Miller, L.Sweedman & B.Cole (BRM 7892C). Voucher specimens lodged at the W.A. Herbarium (PERTH).

23.5 km west of Mt Magnet and the plants referred to below were vouchered under *B.R. Maslin et al.* 7892A-E. Hybrid plants will receive half of their alleles from one parent and the other half from the second parent. If each parent has specific alleles not found in other plants these alleles will be added together in the hybrid progeny. However, microsatellites in the Mt Magnet population did not show this additive profile of alleles of the putative parents in the putative *A. aneura/craspedocarpa* hybrids (Miller *et al.* in prep). The sample size in this particular study, however, was small and not all possible parental plants were sampled. This population appeared to have only one *A. aneura* morphotype which suggests that there may be less genetic variation within this morphotype. Chloroplast DNA from the *psb*A-*trn*H intergenic spacer was also sequenced for these plants. *Acacia craspedocarpa* differed from *A. aneura* by two deletions and the putative hybrid also had these two deletions. Since chloroplast DNA in *Acacia* is maternally inherited this suggests that *A. craspedocarpa* is the maternal parent of the putative hybrid. More detailed sampling of this population is necessary to test whether there is sufficient genetic variation within the *A. aneura* morphotype to suggest its parentage in the hybrid. Alternatively, the parent of this hybrid may have died out in the population. If not, the putative hybrid may fall within the natural range of genetic variation of *A. craspedocarpa*. If this is indeed the case, then it will require a major redefinition of *A. craspedocarpa* because phyllode nervature and shape in putative hybrid plants is very different from that found in typical *A. craspedocarpa* (compare Figures 8B and 8C with Figure 8D).

Microsatellite sampling was more detailed in a population near Mt Connor in the N.T., studied by Andrew *et al.* with the same molecular DNA markers. This population contained five non-overlapping morphotypes including a putative *A. aneura* x *A. minyura* hybrid. The microsatellite markers were consistent with the morphology in recognising the same genotypes and found little or no genetic variation within morphotypes. Analysis of the hybrid using SSR did not show alleles in common with the samples of the two parental species. A multivariate analysis did not place the putative hybrids as intermediate to the two parents. While the sampling in this study was more detailed than in the *A. craspedocarpa* example, the putative parents at Mt Connor may not have been sampled. One possible explanation for this might be that the hybridisation events occurred elsewhere and that the seed was transported to Mt Connor by water; it is common in these arid environments for large volumes of water to flood the landscape when heavy rains occur.

The lack of direct proof for hybridisation to date should not be regarded as evidence against hybridisation occurring in Mulga. Another possible explanation for the lack of additive alleles in the putative hybrid may be backcrossing of the hybrids to parental species and with other hybrids containing genetic variation, thus obscuring the ability to identify additivity of alleles. Also, if hybridisation events occurred sufficiently in the past, the hyper-variable microsatellite markers may have changed their alleles through mutation and the evidence for hybrid additivity lost. At present it is not clear which explanation is most likely to account for the data found to date.

Polyploidy

The Mulga complex has been considered to be polyploid at least in part. Tetraploids have been reported by Buhkari (1997) and Maslin (unpublished). The recent work by Andrew *et al.* at Mt Connor led to the discovery of triploids, tetraploids and pentaploids. During meiosis the number of copies of chromosomes is halved as the gametes form. Since the halving of triploids and pentaploids does not lead to complete sets of chromosomes in the gametes these plants usually are not fertile. Chromosomes were counted from seedling root tips from seeds collected off trees with heavy seed set. Some of these seedlings were triploids and others pentaploids, suggesting that the mother plant had the same ploidy level and had higher fertility than would be expected by sexual reproduction alone.

Diploid Mulga has been reported only from material cultivated outside Australia (Tixier 1965). A diploid plant of *A. ayersiana* var. *latifolia* (= *A. ayersiana*, *fide* Pedley 2001: 322) was found by flow cytometry but has not been confirmed by the more accurate method of chromosome counting (Miller unpublished). This specimen was a seedbank accession from the Charleville area of south-western Queensland. This area has not been extensively collected by us and may hold a key piece to the puzzle. Diploid members of the complex could point to an ancestral types that have given rise to new morphotypes via auto or allopolyploidisation events. The use of cytogenetics to study chromosome pairing during meiosis within a polyploid genome may give a better understanding of the origin of the polyploid event. A fruitful future study in Mulga would be to undertake a concerted search for naturally occurring diploid plants.

Polyembryony

During field trips seeds were collected whenever possible. When these seeds were germinated in glasshouses, many aberrant plants with more than two cotyledons or two multiple meristems were noted. Fox (1979) also noted twin meristems in *A. aneura* but found that these plants soon died, but this mortality was not seen in our glasshouse experiments. In our case further germinations were undertaken in petrie dishes to examine the aberrant seedlings more closely. Twenty or more seeds harvested from each of over 24 plants throughout the range of Mulga in Central and Western Australia were germinated. This survey represented all available morphotypes for which we have been able to collect in seed. A proportion of aberrant seedlings were identified in all populations, the most common having three cotyledons. Further dissection of these plants led to the discovery of two sets of true first leaves. Two complete plants, with two distinct pairs of

cotyledons, two hypocotyls and roots, were also commonly seen. The relative placement of these twin plants varied. At times the two plants could be easily separated and could be grown on individually in pots. After re-establishment in glasshouse pots the plants grew normally. Other twins were intertwined and could not be separated without damaging the plants. Between these extremes there was a range of twins including forms with two apical meristems and a single root. A cross-section of the hypocotyl indicated that the plants had two vascular systems. It appears that usually only the strongest of the two plants survives the germination process, with a low level of survival for multiple plants.

The presence of more than one embryo in a seed is called polyembryony. It can have multiple causes and has been found in sexual (Asker and Jerling 1992) and asexual species. Two or multiple embryos may be due to apomixis, the adventitious growth of an asexual embryo from maternal tissue. Cell division of the maternally derived nucellus tissue, which surrounds the embryo sac, gives rise to multiple asexual embryos in *Senna* series *Subverrucosae*. In this species the sexually derived embryo may or may not persist and develop, leading to multiple embryos of both sexual and asexual origin (Randell 1970).

Apomixis

The arrays of seedlings used in testing seedling development and polyembryony were surveyed with SSR markers for variation among the siblings and to the mother plant (Miller *et al.* in prep). Over 95% of the progeny were identical to the mother plant and the siblings, suggesting that they are of asexual origin (Miller *et al.* in prep). Most loci studied were heterozygous, such as a tetraploid plant with three alleles at a single locus. If the plant was self-pollinating (most *Acacia* are outcrossers) the expected segregation of alleles in the self-pollinated progeny did not occur. It is also unlikely that outcrossing would have produced the identical genotype of the maternal parent in the progeny.

The progeny data and the microsatellite data from Andrew *et al.* (in review) indicate that Mulga can produce a clonal population genetic structure via apomixis. Andrew *et al.* found more genetic differences among morphotypes than within morphotypes and some morphotypes, including triploids and pentaploids, displayed identical genotypes within the dozen plants sampled, providing evidence of fixed heterozygozity that can not be well-explained by sexual reproduction.

These multiple lines of evidence indicate that apomixis plays an important role in Mulga populations. The observations of polyploidy, microsatellite marker patterns and especially polyembryony suggest that these plants are apomictic. Apomixis is asexual reproduction through a seed. There are several forms of apomixis depending on the origination of the asexual embryo.

Based on data and observations outlined above the following is a working hypothesis explaining part of the Mulga variation. Ancestral morphotypes of diploid Mulga, either through hybridisation or autopolyploidy, gave rise to polyploid morphotypes. The polyploid morphotypes are facultative apomicts. Sporadic hybridisation occurs both within morphotypes and among plants differing in morphological characteristics. These plants are maintained in the populations due to apomictic reproduction. The polyploidy and apomixis act as barriers to gene flow and allow the maintenance of these hybrids. Recurring hybridisation among morphotypes and their subsequent maintenance by apomictic reproduction creates the highly variable populations.

Neotony

Neoteny, the retention of juvenile features in the adult growth phase, as described above for Holey Mulga (see *Phyllode variation*). Understanding ontogenetic developmental sequences in foliage, from the juvenile through adolescent to adult, is likely to be more important in understanding variation within Mulga than has hitherto been appreciated. As mentioned above in discussing phyllode and habit variation, a working field hypothesis to explain the variation in Mulga was neoteny. We consider this a retention of juvenile characters when the juvenile form is reproductively mature.

This was shown to be a major factor in Holey Mulga in which we observed three classes of phyllodes. Some trees bore one class, others all three. Holey Mulga grows only on rocky ridges in central Australia where other Mulga morphotypes tend not to grow, hence the three classes of phyllodes could be identified easily. This is important because some trees with juvenile and intermediate-sized phyllodes are as large as trees with mature phyllodes.

Other Mulga morphotypes may have a similar range of phyllode diversity relating to developmental stages. Putative developmental stages have been seen in other populations which, however, all consisted of multiple morphotypes, hence these predictions will need to be tested with molecular markers.

Neoteny also appears to be a possible causal factor in producing some growth forms in the Mulga group. As discussed above under *Habit variation*, there appears to be a relationship among the habits of *A. aneura* var. *conifera*, the 'Christmas tree' form as well as the pseudo-conifer habit. As mentioned above these same DNA markers can play an important role in identifying juvenile plants and associating these to morphotypes of the corresponding adults.

In this case the plants of varying maturity for phyllode and habit will be tested with DNA markers. These markers will identify closest relatives regardless of maturity. If *A. aneura* var. *conifera* originated multiple times from different Mulga morphotypes the markers will identify that each *A. aneura* var. *conifera* population is more closely related to a different local morphotype than it is to other plants of *A. aneura* var. *conifera*. This information will be invaluable in reassessing the classification of this taxon.

Additionally, patterns may be discernible among morphotypes in their maturation process from juvenile to adulthood, thereby giving us a better understanding of Mulga development as a whole.

FUTURE WORK

Field, glasshouse and laboratory work has begun to shed some light on the genetic reasons for the variation in Mulga. In order to form a useful nomenclatural system for Mulga more work must be done. Firstly, more collections should be made in areas so far not visited. These collections will amplify the knowledge of variation and may uncover diploid members of the complex that could be putative progenitors. DNA markers should be used at the population level to address the issues of hybridisation and neoteny. These markers also should be used to test the relationships of morphotypes both within and among populations. Even with this detailed knowledge the construction of a nomenclature for Mulga will most probably prove difficult due to the extreme genetic complications within this intriguing group of plants.

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Rarity and threat in relation to the conservation of *Acacia* in Western Australia

MARCELLE L. BUIST[1,2*], DAVID J. COATES[1] AND COLIN J. YATES[1]

[1] Science Division, Department of Conservation and Land Management, Locked Bag 104, Bentley Delivery Centre, Western Australia 6983; email marcelleb@calm.wa.gov.au

[2] Department of Soil Science and Plant Nutrition, School of Earth and Geographical Sciences, University of Western Australia, Nedlands, Western Australia 6907 (*corresponding author)

SUMMARY

The genus ***Acacia*** provides clear illustrations of both the floristic diversity of Western Australia (with nearly 800 of the 1200 known taxa found in the State) and the critical conservation status of a significant component of the flora. Twenty-six percent of acacias in W.A. are either listed as threatened (Declared Rare Flora) or rare and poorly known (Priority Flora). This paper explores rarity and threat in relation to the conservation of ***Acacia*** in W.A. Rarity is ascertained using the three components of geographical range, habitat specificity and abundance. The factors which then pose immediate threats to survival of the taxon are identified to determine the likelihood of population persistence and further priorities for conservation. The threats include invasive flora and fauna, inappropriate fire regimes, habitat destruction associated with clearing activities, alteration of hydroecology, and demographic and genetic effects associated with small declining populations. These threats are also identified to impact on the persistence of rare acacia taxa. Understanding the ecological and genetic consequences of rarity in terms of low numbers of small, often fragmented populations can provide vital clues to the development of management actions and conservation strategies for rare and threatened species. A particularly effective approach to understanding rarity and its implications for conservation is to carry out comparative reproductive, genetic and ecological studies on the rare species and closely related more common species. This approach and single species studies are included in this review to provide examples of how ecological and genetic research can lead to an understanding of the factors that may constrain population's persistence. Our conclusions are that, like the rest of the flora, most rare and threatened ***Acacia*** taxa occur in W.A.'s Wheatbelt where there has been extensive habitat alteration. In this region the presence of relictual taxa, complex patterns of genetic diversity, highly fragmented remaining native vegetation, small plant population sizes and introduction of invasive weeds and herbivores makes conservation management a complex task. We show that basic and applied research into rarity and threat in ***Acacia*** can provide valuable information for the conservation of this large, diverse genus.

INTRODUCTION

The South-West Botanical Province of Western Australia has an exceptionally rich flora with an estimated 8451 vascular species, 79% of which are endemic (Beard ***et al.*** 2000). The region has been recently recognised as a hotspot of plant diversity and endemism of global significance (Myers ***et al.*** 2000). The flora is characterised by relictual and more recently evolved species; extensive radiation within genera of woody perennials; high species turnover within habitats and across the landscape; and a large number of rare species with naturally small populations and highly localised, often disjunct distributions (Hopper 1992; Hopper ***et al.*** 1996). The reasons for south-western Australia's extraordinary plant diversity and endemism have been explored in a number of reviews (Hopper 1979; Hopper 1992; Hopper ***et al.*** 1996).

Whilst these patterns of plant diversity are characteristic of the entire south-west, they are best expressed in the woodlands, heath and scrubs, in particular mallee heath and scrubs that grow in that part of the south-west receiving between 300 and 800 mm rainfall (the Transitional Rainfall Zone ***sensu*** Hopper 1979). This area is now occupied largely by Western Australia's major agricultural zone, the Wheatbelt, where there has been extensive habitat alteration with approximately 75% of the native vegetation cleared (Beeston ***et al.*** 1996). The amount of native vegetation remaining varies across the Wheatbelt with as little as 2% in some shires and up to 59% in others (Weaving 1999). Throughout this region the remnant vegetation is disjunct and fragmented, with few remaining tracts of bushland greater than 100 ha (Wallace and Moore 1987). Consequently, a significant proportion of W.A.'s unique floral biodiversity exists in remnants of native vegetation of varying size, shape and connectivity in highly altered landscapes. Within these remnants, disturbance and hydrological regimes have changed and exotic weeds, grazing animals and diseases have been introduced. Perhaps, not surprisingly in such a

diverse flora, W.A. has a large number of rare and threatened plants including many taxa in ***Acacia*** (Table 1).

This paper explores rarity and threat in relation to the conservation of ***Acacia*** in Western Australia. Following a brief introduction to provide context, we examine concepts associated with biological rarity and threat, before a general discussion of threatening processes in the flora of south-west W.A. We subsequently explore rarity and threat in ***Acacia***. Finally we provide an overview of basic and applied research on the conservation biology of ***Acacia*** in the region.

BIOLOGICAL RARITY

A significant step in prioritising the conservation needs of natural ecosystems is to identify which components are rare. Biological rarity is usually defined by geographical range, habitat specificity and abundance (e.g. Rabinowitz 1981). Restricted distribution and low numbers typically define rare plant populations (such as ***Acacia cochlocarpa*** subsp. ***cochlocarpa***, Yates and Broadhurst 2002) but the term has also been extended to include taxa occurring in large numbers within a narrow geographical range (such as ***Acacia lobulata***, this paper, and ***Acacia*** sp. 'Dandaragan', Elliott ***et al***. 2002) and diffuse populations over a wide geographical range (the prairie grasses of Missouri, Rabinowitz ***et al.*** 1978).

Often rare plants are limited to a specific habitat. For example, in south-west W.A., granite outcrops and inselbergs are scattered throughout the landscape, providing specialised habitats for a large number of endemic plants, many of which are rare. ***Acacia aphylla*** and ***Acacia denticulosa*** are granite endemics (Hopper ***et al***. 1997; Brown ***et al***. 1998). The specialised habitat is determined by abiotic and biotic factors affecting the taxon's fundamental niche and therefore its distribution and abundance (Burgman and Lindenmayer 1998). Limited availability of habitat or narrow eco-tolerances may cause a taxon to be rare (Stebbins 1980; Harper 1981; Rabinowitz 1981; Drury 1980; Pate and Hopper 1993). Rarity is often a phenomenon in time as well as space (Stebbins 1980). The taxon may be historically rare or the result of a recent shift in plant or landscape dynamics. Main (1981) hypothesised that some rare species may be adapted to past conditions and unable to expand in the current environment; should conditions revert to a former state, they may be better equipped to function and increase in abundance. Fiedler and Ahouse (1992) recognised that the age of a taxon (temporal persistence) is important for defining rarity and assigning hierarchical causes. They hypothesised that the most probable factors causing rarity in species that are narrowly distributed but have persisted for a long time in the landscape are their evolutionary history, the history of the Earth processes during their long existence, and their population biology.

The three components of rarity – geographical range, habitat specificity and abundance – are the products of a myriad of abiotic and biotic interactions and, as a consequence, there may be many causes of a species' rarity (Fiedler and Ahouse 1992; Burgman and Lindenmayer 1998). A taxon may have a restricted distribution due to narrow environmental tolerances such as climate or long distance dispersal barriers. Habitat specificity may be the result of long, complex physiological adaptations to an uncommon habitat. Low abundance may result directly from scarce dispersal resources, chance environmental conditions or events, ecological interactions such as pollination and competition, and factors related to reproductive biology and the genetic system.

Distribution and abundance can be readily quantified and therefore, with stringent and extensive survey procedures, rarity can be defined (Burgman and Lindenmayer 1998). Identification of habitat specificity is not as easily overcome. An understanding of the environmental variables that constitute the habitat requires thorough description and experimentation. Complex interactions of both biotic and the abiotic factors hamper understanding the causes of rarity. For example, what are the impacts of predators and pathogens and how do climate and edaphic conditions affect population dynamics? The cost and duration of these investigations are further limitations.

THREAT AND EXTINCTION PROBABILITY

When the rare components of an ecosystem are identified, the factors that pose immediate threats to survival of the taxon will determine the likelihood of population persistence and priorities for conservation. A rare, highly threatened taxon has a high probability of becoming extinct. The greater the magnitude of the threat, the more appreciable the risk of decline or extinction (Burgman and Lindenmayer 1998). Therefore, while rarity describes a taxon's distribution, abundance, and habitat specificity, threat relates to the taxon's ability to persist over time

TABLE 1
Number of conservation taxa contained within each category for total flora in the Western Australia and for *Acacia* taxa (Government Gazette 2001).

	CRITICALLY ENDANGERED	ENDANGERED	VULNERABLE	PRIORITY (RARE AND POORLY KNOWN)	EXTINCT
Number of total flora	106	126	105	2059	17
Number of *Acacia* taxa	12	7	3	183	2

and its risk of extinction. Following the identification of rarity in a plant taxon, prioritising that taxon for conservation actions will be determined by the level of threat.

A number of approaches for assessing threat have been developed based on an assessment of risk of extinction (Given and Norton 1994; Chaslson and Keith 1995; Burgman and Lindemayer 1998). For example, the International Union for the Conservation of Nature and Natural Processes (IUCN) classifies rare and threatened species based on a series of terms and their associated qualitative descriptions (Mace and Lande 1991; IUCN 1994). The IUCN criteria utilise information relating to population size, distribution of individuals, fluctuations in abundance and risk of extinction. Another approach is the point scoring methodologies usually based on linear ranking (Molloy and Davis 1992). A more definitive ranking of individual taxa or grouping of taxa results from this method but it also has the limitation of applying the weighting of variables across all taxa (Given 1994; Burgman and Lindemayer 1998). The prioritisation of threatened flora in Western Australia was initially based on this approach but has since been modified and the IUCN approach of rule sets and qualitative systems is now applied.

Conservation priorities in the Western Australia flora are based largely on two broad categories, Threatened Flora and Priority Flora (rare and poorly known flora) (Brown ***et al***. 1998; Coates and Atkins 2001). Threatened Flora have the highest conservation status and are protected under the Western Australian Wildlife Conservation Act 1950. Based on the IUCN criteria, Threatened Flora in Western Australia are subdivided into three categories: Critically Endangered, Endangered and Vulnerable (IUCN 1994). Taxa already determined to be extinct in the wild are listed as Presumed Extinct. The second broad category, Priority Flora, represents two sub-groups of taxa: flora that are possibly rare or threatened but for which there are insufficient survey data to determine their conservation status accurately, and taxa regarded as rare but whose populations are not threatened.

THREATENING PROCESSES IN THE SOUTH-WESTERN FLORA

Although the interaction of habitat destruction and natural rarity may be the reason for many taxa becoming threatened initially, there are continuing threats associated with the contemporary landscape that may be contributing to the decline of remaining populations (Yates and Broadhurst 2002). These threatening processes detrimentally affect the survival, abundance, distribution or potential for evolutionary development which can lead to local extinction (Burgman and Lindenmayer 1998).

Current major threats to threatened flora populations in south-west W.A. have been described by Coates and Atkins (2001) and include continued habitat destruction; the potential effect that being a small isolated population might have on attracting pollinators, producing sufficient quantities of seed and maintaining genetic diversity; and declining rates of seedling establishment and increased rates of adult mortality through interactions with introduced exotic weeds, herbivores, rising saline water tables and introduced pathogens such as ***Phytophthora cinnamomi***. In addition to this, altered fire regimes can impact on threatened populations. Reduced frequency of fire can result in a decline in population sizes in taxa dependent on fire-related cues for germination. Alternatively, increased frequency of fire can result in a decline in population size in taxa that have long primary juvenile periods.

Continued destruction of habitat

A significant proportion of flora in south-west W.A. is also threatened by factors resulting from continued clearing, roadwork, recreation, mining activities, and agricultural processes. For example, Critically Endangered species such as ***Davesia euphorbioides***, have populations that are in severe decline, initially associated with land clearing for agriculture and subsequently due to road and rail works (Robyn Phillimore[1], personal communication).

Small population size

Small population size has been identified as a significant threatening process affecting plant populations (e.g. Menges and Dolan 1998; Morgan 1999; Groom 2001; Lamont ***et al***. 1993; Wolf 2001; Jennersten 1988; Menges 1991; Widen 1993). As the population size decreases, demographic and genetic effects are considered to become major limiting factors in population survival. Simply, smaller populations have a greater probability of extinction through stochastic processes alone. Factors affecting the demographics of rare plant populations include floral and pollen characteristics, seed production, predation and dispersal, and seedling establishment. Floral characteristics (Pantone ***et al.*** 1995; Ruiz de Clavijo 1997), a lack of compatible pollen (Wolf 2001) and a reduction in pollinators (Karron 1987, Campbell and Halama 1993; Jennersten 1998; Lamont ***et al***. 1993) were all found to be symptomatic of small population size. Studies on the impacts of population size on seed production have found that in some cases seed production declines with decreasing population size (Lamont ***et al***. 1993; Morgan 1999; Cunningham 2000; Hendrix and Kyhl 2000; Hackney and McGraw 2001; Wolf and Harrison 2001). Others have found that population size has no impact on reproductive success (Kennington and James 1997; Costin ***et al***. 2001; Mustajrvi ***et al***. 2001; Yates and Broadhurst 2002).

In cases where there is a reduction in seed output (Banks 1980; Menges 1991; Lamont ***et al***. 1993; Kearns and Inouye 1991; Morgan 1999; Hendrik and Kyhl 2000), then predation on this seed (Wolf ***et al.*** 1999), dispersal and seedling establishment (Rabinowitz 1978; Fiedler 1987; Baskin ***et al***. 1997; Baskin and Baskin 1988) are likely to be limiting factors and affect the regeneration potential of plants in small populations. These deficiencies

can lead to reduced reproductive fitness and affect population demographics. Genetic effects such as inbreeding have also been shown to be a consequence of small population size (Prober and Brown 1994; Buza ***et al***. 2000). This may lead to lower genetic variation over time and reduced potential to adapt to changing environmental conditions or resist disease (Babbel and Selander 1974; Banks 1980; Karron ***et al***. 1988; Pleasants and Wendels 1989).

Interactions with introduced weeds, herbivores and pathogens

Many threatened plant taxa in south-west W.A. are restricted to small, disturbed remnants and road verges that have large edge-to-area ratios and are surrounded by agricultural land. In many of these remnants, invasive weeds, particularly grasses, are abundant and can have a significant impact on seedling establishment and growth of native plants through competition for resources (D'Antonio ***et al***. 1998; Eliason and Allen 1997) and allelopathy (Hobbs and Atkins 1991). Competition with invasive weeds has been identified as a major threat to rare and threatened taxa in ***Acacia*** including ***A. aprica*** in south-west W.A. (Yates and Broadhurst 2002), ***A. whibleyiana*** in South Australia (Jusaitis and Sorenson 1998) and ***A. axillaris*** in Tasmania (Lynch ***et al***. 1999).

The introduced root pathogen (***Phytophthora cinnamomi***), which causes dieback, is a major threat to plant biodiversity in south-west W.A., particularly in areas receiving greater than 400 mm rainfall (Gioia ***et al***. 1997). Species such as ***Banksia brownii*** are highly threatened and in significant decline because of their extreme susceptibility to ***P. cinnamomi*** (Kelly and Coates 1995). Currently, the Threat Abatement Plan for Dieback Caused by the Root-Rot Fungus (***Phytophthora cinnamomi***), lists 70 Western Australian Declared Rare Flora as threatened or potentially threatened by ***P. cinnamomi*** (Gioia ***et al***. 1997). However, taxa in ***Acac***ia are not currently known to be susceptible to ***P. cinnamomi*** (Brian Shearer[2], personal communication**.**).

Altered landscape hydrology

Widespread clearing in the Transitional Rainfall Zone has significantly altered the landscape hydrology and, as a consequence, rising saline water tables have caused or are threatening many remnants of native ecosystems with an estimated 400 plant taxa in risk of extinction including a number of ***Acacia*** (Greg Keighery[3], personal communication).

Changed fire regimes

In the Mediterranean climate of south-west W.A., vegetation is prone to burning in the dry summer months and it is hypothesised that fire has been a force of evolutionary significance in many plant groups (Gill 1981). Indeed, studies in the region have revealed taxonomically diverse groups of plant species that exhibit morphological, phenological and functional characteristics which suggest a commonality in evolutionary response to recurrent fire, but other explanations cannot be ruled out (Gill 1981; Bell ***et al***. 1984; Whelan 1995; Bond and van Wilgen 1996). These include fire survival characteristics (Gill 1981; Bell ***et al***. 1984) and fire related germination cues (Bell ***et al.*** 1984; Dixon ***et al.*** 1995) with recruitment in many taxa being restricted to the first winter following fire (Cowling and Lamont 1987; Enright and Lamont 1989). In many temperate and Mediterranean climate ***Acacia*** species, the most common environmental cue for breaking seed dormancy is fire and this disturbance is a significant driver of population dynamics (McCaw 1988; Auld and O'Connell 1991). In agricultural landscapes where most of the native vegetation has been cleared, landscape fires may no longer develop because of fire suppression and low fuel loads. As a consequence, plants that occur in small fragments and that rely on fire for recruitment may have fewer opportunities for regeneration (Yates ***et al***. 1994; Yates and Broadhurst 2002). If regeneration occurs by the seed bank and the fire interval exceeds the longevity of both the plants and the seed bank, local population decline and even extinction is likely (Burgman and Lamont 1992; Whelan 1995; Bond and van Wilgen 1996).

RARITY AND THREAT IN *ACACIA* IN WESTERN AUSTRALIA

The biogeography of ***Acacia*** in many ways reflects the patterns of plant diversity for Australia as a whole. Of the described taxa 772 occur in W.A., the greatest diversity occurred in the Transitional Rainfall Zone (Maslin and Stirton 1997; Beard ***et al***. 2000). Currently, 22 ***Acacia*** taxa are listed as threatened taxa (Declared Rare Flora) under the Western Australian Wildlife Conservation Act 1950 and the Commonwealth Environmental Protection and Biodiversity Conservation Act 1999. Of these, twelve are ranked as Critically Endangered, seven Endangered and three Vulnerable (Table 1). Another 183 ***Acacia*** taxa are considered to be rare and poorly known (Priority Flora), although their conservation status has yet to be determined accurately and many are likely to be under threat of extinction.

The Transitional Rainfall Zone, where ***Acacia*** diversity is highest, has been largely cleared for agriculture and is now occupied by the W.A. Wheatbelt. Not surprisingly, high numbers of rare and threatened taxa in ***Acacia*** occur there. The Wheatbelt includes three administrative regions of the Department of Conservation and Land Management – the Midwest, the Wheatbelt and the South Coast. In these regions 77% of rare and threatened taxa in ***Acacia*** are present (Wheatbelt 31%, Midwest 25% and South Coast, 21%; Fig. 1).

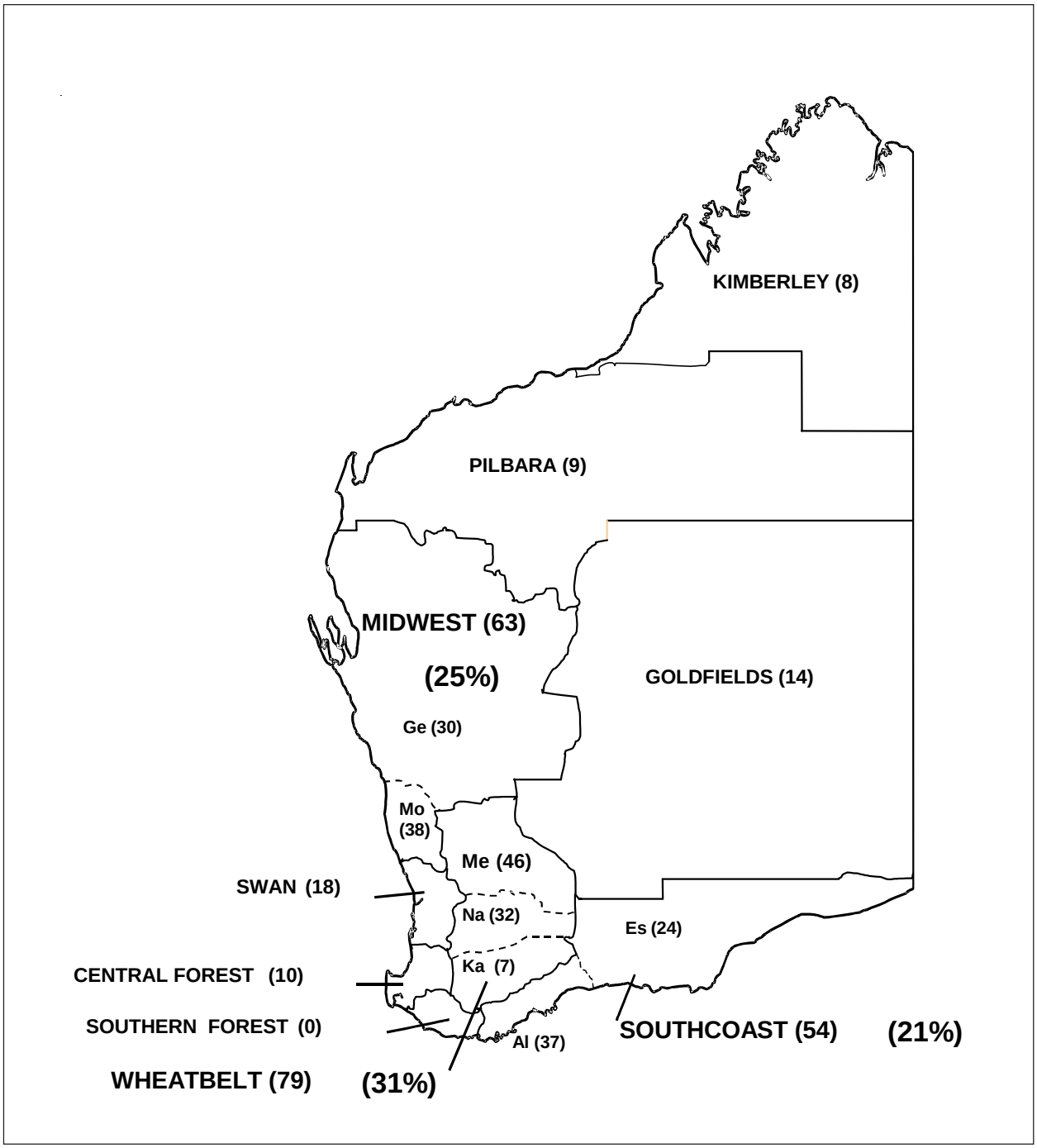


Figure 1. Western Australia showing regions administered by the Department of Conservation and Land Management. The numbers of Rare and Threatened Acacia taxa are identified in these regions of the Kimberley, the Pilbara, the Goldfields, the Midwest, the Wheatbelt and the Southcoast. The regions of the Midwest, Wheatbelt and Southcoast demonstrate the areas of highest concentration of Rare and Threatened Acacias, the percentage of the total also shown in brackets. These three regions are broken into districts of Geraldton (Ge) and Moora (Mo) for the Midwest, Merredin (Me), Narrogin (Na) and Katanning (Ka) for the Wheatbelt, and Esperance (Es) and Albany (Al) for the Southcoast.

When comparing the percentage of Threatened and Priority ***Acacia*** taxa to the total Threatened and Priority Flora of Western Australia, differences are apparent (Table 2). There is a higher percentage of Critically Endangered and Extinct ***Acacia*** taxa, and the proportion of Endangered and Vulnerable taxa is well below the percentage for the total flora. Thus, ***Acacia*** species in Western Australia, when they are rare, tend to be more threatened compared with the threatened flora as a whole.

As so many rare and threatened taxa in ***Acacia*** are found in the Wheatbelt, where competing land uses are common, land tenure (conservation reserve, road reserve, private property etc.) on which threatened species populations are found, is often an important factor determining conservation status and for setting conservation priorities. It is, therefore, useful to examine the distribution of numbers of plants and numbers of populations of threatened taxa across land tenures (Table 3). Most threatened ***Acacia*** taxa occur on private property (30%), conservation reserves (25%) and water reserves (22%). Smaller numbers of plants occur on non-vested Crown land (10%), local authority lands (5%), main roads (2%), Westrail land (1%) and State forest (0.2%). In contrast, the proportion of plants across land tenures for threatened flora as a whole shows a different pattern, with the greatest proportion of plants, occurring on conservation reserves (45%). Of the remaining plants most are found on non-vested Crown land and, to a less extent, local authority land (11%) and private property (10%). These data suggest that, in terms of plant numbers, private property is extremely important for the conservation of threatened taxa in ***Acacia***.

The significance of land tenure in setting priorities for conservation of threatened flora can be assessed further by taking into account not only the number of plants, as discussed previously, but also the number of populations. In turn, the combination of number of plants and number of populations can be used to infer the threat of small population size on different land tenures. For example a large number of plants and small number of populations on a particular land tenure suggest that small population size may not be an issue. In ***Acacia*** most threatened taxa populations occur on private property (31%), but these are generally larger populations. Therefore, the threat of small populations size may be less than for other land tenures such as local authority lands where there is a low proportion of plants (5%), but a high proportion of populations (28%; Table 3). This trend for local authority land, in particular shire road reserves, is also reflected but less pronounced for Threatened Flora as a whole.

CONSERVATION BIOLOGY OF RARE AND THREATENED WESTERN AUSTRALIAN *ACACIA*

Understanding factors that cause rarity can provide critical information that will ensure conservation of the rare flora in the long term. Knowledge of the population biology, life history and genetic systems of rare and threatened species is often needed for developing appropriate conservation strategies and this knowledge is often lacking (Coates and Atkins 2001).

One useful approach to understanding rarity and constraints to population growth in rare and threatened taxa is to use a common relative for comparison as part of the study. This often identifies idiosyncratic features of rarity which may distinguish a rare organism from a common one (Fiedler 1987). The common relative has

TABLE 2
Percentage conservation flora of the total flora of Western Australia compared to the conservation flora within the *Acacia* taxa of Western Australia for each conservation status category.

	CRITICALLY ENDANGERED	ENDANGERED	VULNERABLE	PRIORITY	EXTINCT
Percentage of total flora *(n = 8451)*	1.3	1.5	1.2	24.4	0.2
Percentage of *Acacia* taxa (n = 772)	1.6	0.9	0.3	23.7	0.3

TABLE 3
The percentage number of plants and populations of the total Declared Rare Flora and Declared rare *Acacias* that occur on the various land tenures.

	PRIVATE PROPERTY	LOCAL AUTHORITY	CONSERV-ATION RESERVE	MAIN ROADS WA	WATER RESERVE	NON VESTED CROWN LAND	WESTRAIL	STATE FOREST
Total flora plants	9.5	10.5	44.9	1.1	1.4	28.2	0.4	1.5
Total flora populations	20.0	19.6	27.5	4.8	4.7	11.9	3.0	4.3
Acacia plants	29.1	5.4	25.3	2.1	22.2	10.3	0.9	0.3
Acacia populations	30.7	28.1	21.5	5.7	3.1	3.1	3.1	2.6

been shown to provide baseline biological data on a successfully persistent and widespread taxon to contrast with restricted and declining taxa. The following case studies on the threatened taxa ***A. lobulata***, ***A. sciophanes*** and ***A.*** sp. 'Dandaragan' used this comparative approach to investigate the population genetics, reproductive biology, seed bank dynamics, and factors limiting seed germination and seedling establishment. Single species studies are also presented on other threatened taxa (***A. anomala***, ***A. aprica***, and ***A. cochlocarpa*** subsp. ***cochlocarpa***), with the studies on ***A. aprica***, and ***A. cochlocarpa*** subsp. ***cochlocarpa*** investigating the stages and transitions of the plant's life cycle to determine limitations on population survival and growth (Fig. 2). The implications of the research for understanding rarity and recovering / managing threatened plant taxa are discussed.

Acacia lobulata

Acacia lobulata is an erect shrub occurring in open woodland, exclusively on the quartz gravel loam of decaying granite adjacent to granite outcrops. The species is known from three populations, approximately 20 km apart (Fig. 3). Two populations with large numbers occur in nature reserves. The third, a recently discovered population of 116 plants, occurs in a small remnant on a road reserve and private property surrounded by cleared land. ***Acacia lobulata*** has an extremely restricted geographical distribution, and is seemingly habitat specific. In contrast, its taxonomically closest relative ***Acacia verricula***, also an erect woody shrub, occurs across a broad geographical range on a wide variety of soil types. The two species are sympatric at the northern end of the distribution of ***A. verricula***. ***Acacia lobulata*** and ***A. verricula*** are morphologically similar, sharing a unique, distinctive pattern of reticulate venation on the phyllodes. However, recent phylogenetic studies based on restriction fragment length polymorphism (RFLP) analysis of chloroplast DNA suggest that this taxon represents an ancient evolutionary lineage when compared to ***A. verricula*** and is more likely a Pliocene relictual species which diverged possibly three million years ago (Byrne ***et al.*** 2001).

A comparative study is currently being undertaken investigating the reproductive biology and ecology of ***A. lobulata*** and ***A. verricula***. These investigations include comparisons of reproductive success, seed predation / dispersal, seed bank longevity, germination physiology, impact of edaphic factors on seedling growth and response to fire. The initial data show differences between the two taxa in reproductive output, post-fire growth rates and length of primary juvenile period (Fig. 4). Reproductive output studies suggest that ***A. lobulata*** has the ability to produce viable seeds but seed production is variable and sensitive to climatic conditions and rates of flower to seed ratios are less than in ***A. verricula***. Despite the variable seed production in ***A. lobulata***, both species have similar numbers of seed in the soil seed reserve per plant. Seed dispersal / predation rates were also found to be similar and the soil seed reserve appears to be persistent in both species. Seeds of the two species responded to heat shock treatments to break seed-coat dormancy in controlled conditions but ***A. lobulata*** was less tolerant of thermal shock than ***A. verricula***. Both species were killed by a hot

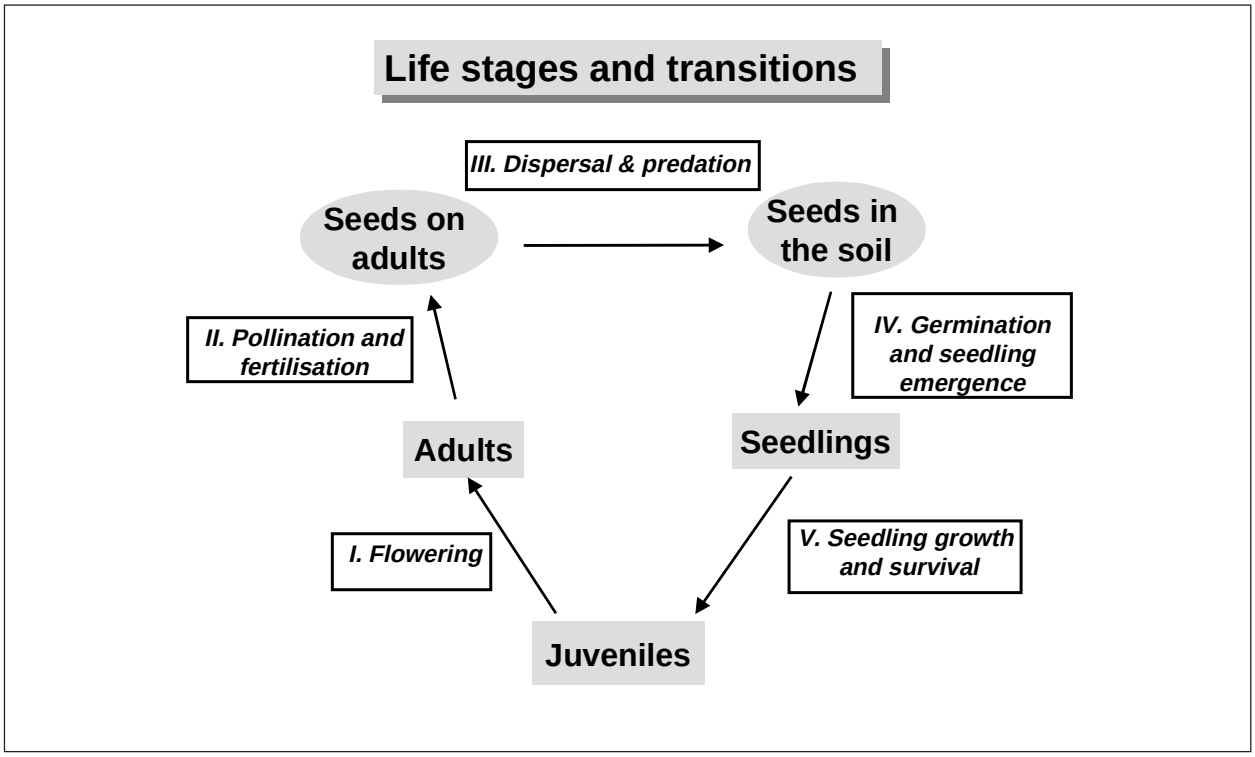


Figure 2. Life stages and transitions of plants.

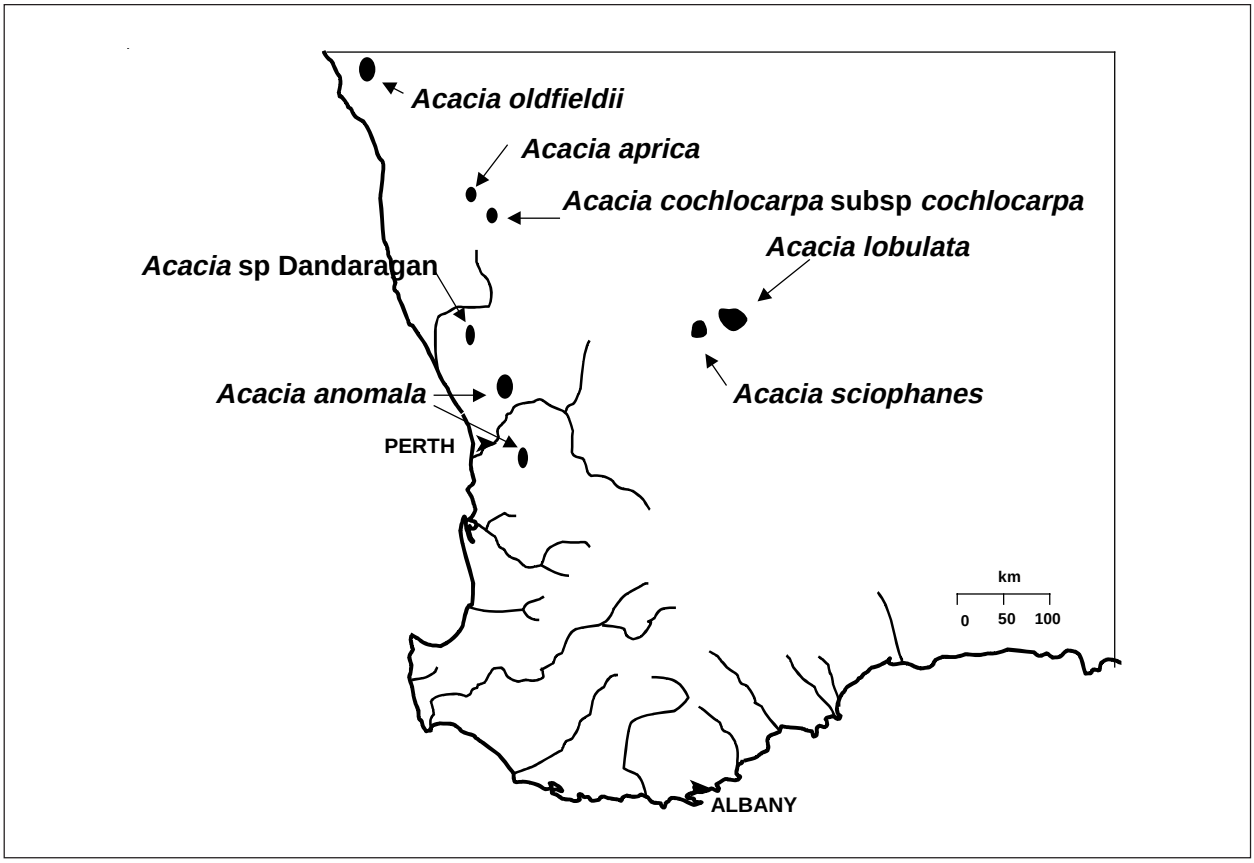


Figure 3. The south-west of Western Australian showing the distribution of Rare and Threatened Acacia ***taxa, referred to in the text.***

summer wildfire and similar rates of seedling recruitment were measured, but the common ***A. verricula*** grew faster and reached reproductive maturity earlier than ***A. lobulata***. These results suggest that ***A. lobulata*** may not be as competitive in the post fire environment and may be less resilient to fire than ***A. verricula***, but further research over a longer time period is needed before firm conclusions can be drawn.

The current distribution of ***A. lobulata*** on gravel loam in more mesic locations adjacent to granite outcrops suggests that the taxon is habitat-specific and may be adapted to past periods of higher rainfall. In contrast, ***A. verricula*** occurs over a wide geographical range on a range of soil types and land forms suggesting a much broader habitat preference under current circumstances. Interestingly however, glasshouse experiments investigating the role of soil type and soil moisture on seedling growth show no differences between the rare and common species. It should be noted, however, that the impacts of soil type and moisture availability could manifest themselves at other stages in the plant's lifecycle.

The relictual taxon ***Acacia lobulata*** shows some differences with its common congener ***A. verricula*** but for many of the parameters being measured no differences were observed. Explanations of the causes of rarity in ***A. lobulata*** may need to take into account the species' genetic system and age. Molecular clock techniques suggest that ***A. lobulata*** has been isolated from other ***Acacia*** species since before the Pleistocene (1.6 Ma) and possibly for 3 million years (Byrne ***et al***. 2001). In contrast, ***A. verricula*** is thought to have diverged from its closest relative more recently, c. 1.5 million years ago (Byrne ***et al***. 2001). It could therefore be argued that ***A. lobulata*** has had a greater opportunity to disperse across the landscape. The initial results of the comparative study suggest that ***A. lobulata*** is equally capable of dispersing and growing across a range of environments yet is highly restricted (Buist unpublished data).

An alternative explanation could be that ***A. lobulata*** is rare because it has been in the landscape longer and therefore been through many more population bottle-necks than ***A. verricula***. Of particular importance in this respect may be the influence of fire in a variable Mediterranean climate. Both ***A. lobulata*** and ***A. verricula*** are killed by fire and rely on seeds for persistence. Consequently both taxa have population dynamics that are susceptible to the effects of fire intervals and dependent effects such as post-fire rainfall (Bond and van Wilgen 1996). Fire intervals shorter than the primary juvenile period and droughts in the first winter or any winter following a fire before plants reach reproductive maturity can both result in localised population decline and extinction (Burgman & Lamont 1992). In south-western W.A. the earliest records of recurrent fire of uncertain frequency and intensity in the Transitional Rainfall Zone are for the period 2.62-2.51 Ma (Dodson and Ramrath 2001) and fire is likely to have continued to be a significant recurrent disturbance in the landscape as the climate

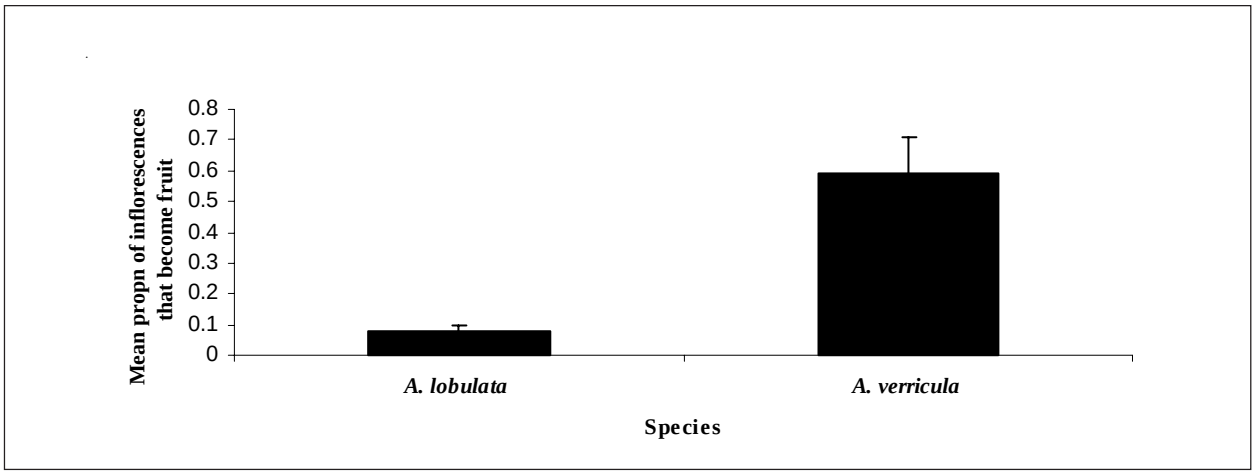


Figure 4a. Mean proportion of A. lobulata ***and*** A. verricula ***inflorescences that develop into fruit (from two years' data).***

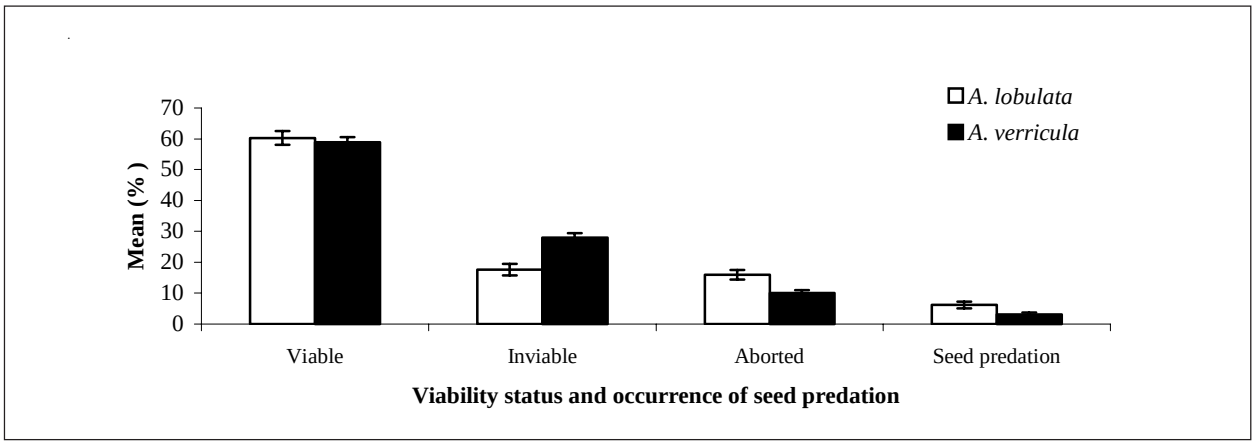


Figure 4b. Mean percentage of A. lobulata ***and*** A. verricula ***seeds that are viable, inviable, or aborted and have been affected by predation (from one year's data).***

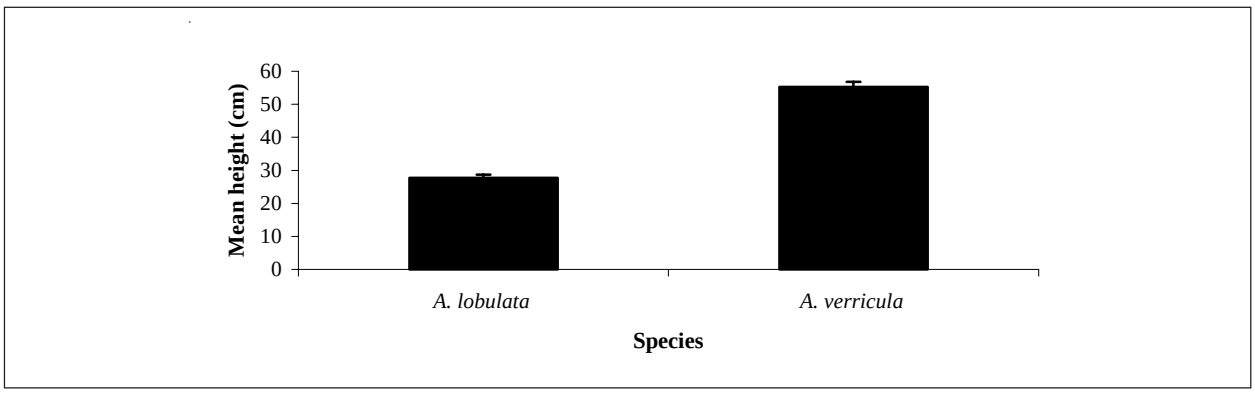


Figure 4c. Mean height of burn-recruited seedlings of A. lobulata ***and*** A. verricula***, two years after fire. Of 279*** A. verricula ***seedlings sampled, 9 were reproductive (3%). No*** A. lobulata ***seedlings were reproductive.***

became generally more arid to the present day. ***Acacia lobulata*** is therefore likely to have experienced more fire-related population bottle-necks than ***A. verricula***.

In conclusion, phylogenetic and ecological studies of the rare ***A. lobulata*** and common ***A. verricula*** show that the rare species has great conservation significance. Moreover, the research suggests that the interaction of habitat specificity, the species' fire life history and considerable age may account for its rarity, but further research is needed to confirm this hypothesis. The taxon's narrow geographical range, habitat specificity and fire sensitivity warrant its threatened status, and carefully managed fire regimes are needed to ensure its persistence. The small road verge population should also be recognised as essential to the taxon's persistence. This population needs to be managed for threats associated with road reserves including small population size, competition with invasive weeds and road work activities.

Acacia sciophanes

Acacia sciophanes is a tall, wispy shrub, known from two populations, covering a geographical range of only 7 km (Fig. 3). One population is located in a Nature Reserve with a total of 221 plants and the other is on private property with 114 plants. Its closest relative, ***A. anfractuosa***, is relatively common over a much wider geographical range of about 200 x 150 km. Both species grow on yellow sandy soil in floristically diverse low woodland and scrub heath communities. ***A. sciophanes*** can be defined as locally and geographically rare and a habitat generalist. Phylogenetic studies based on restriction fragment length polymorphism (RFLP) analysis of chloroplast DNA indicate that these are sister species and form a relatively recent evolutionary lineage (Byrne ***et al***. 2001).

A comparative study is currently being undertaken to investigate the reproductive biology and ecology of ***A. sciophanes*** and ***A. anfractuosa***. These investigations include comparisons of reproductive success, seed predation and dispersal, seed bank longevity, germination physiology, impact of edaphic factors on seedling growth, response to fire, mating systems and patterns of genetic variation (Fig. 5). In contrast to ***A. lobulata*** and ***A. verricula***, the initial data show few differences in ecology and reproductive biology between ***A. sciophanes*** and ***A. anfractuosa***. The reproductive output was similar, as was seed viability. Both taxa were found to possess a soil seed bank and germinate with heat shock to the seed coat. Seed dispersal and predation rates were similar and the seed bank appears to be persistent in both species. Seedlings of both taxa show similar post-fire growth rates.

In contrast to the ecological comparisons, genetic studies indicated differences in both the mating system and levels of genetic variation between ***A. sciophanes*** and ***A. anfractuosa***. Population estimates of genetic variation based on 14 allozyme loci showed that genetic variation measured by allelic richness, polymorphism and heterozygosity was lower, and gene diversity was significantly lower in ***A. sciophanes*** than in ***A. anfractuosa*** (Byrne ***et al.*** 2000). However, genetic variation in both species was relatively high compared to estimates for other Australian species of ***Acacia***, particularly those from eastern Australia, and higher than estimates for most long-lived woody angiosperms (Fig. 6).

Mating system analyses indicated that the multilocus outcrossing rate in the Wundowlin ***A. sciophanes*** population (tm = 0.61) was significantly lower than outcrossing rates for two ***A. anfractuosa*** populations (tm = 0.86, 0.85) and that the correlated paternity (probability that siblings shared the same father) in the ***A. sciophanes*** population (rp = 0.61) was higher than in either of the two ***A. anfractuosa*** populations (rp = 0.44, 0.36). Both these measures suggest that inbreeding is likely to be a more significant feature of the relatively small geographically restricted populations of ***A. sciophanes*** than the numerous, more widespread and generally larger populations of ***A. anfractuosa***. Whether this possible increase in inbreeding is associated with a reduction in fitness is unclear. To date, the ecological studies show no differences between ***A. sciophanes*** and ***A. anfractuosa*** in measures of fitness such as the level of seed production, and seedling establishment and growth. Further studies would be required to confirm that increased inbreeding is a feature of ***A. sciophanes*** populations over time and whether it is causally related to factors that may reduce population fitness.

With the few differences in the ecology of the two taxa, ***A. sciophanes*** seems to be able to compete adequately when compared with its successful, widespread congener. ***A. sciophanes*** has been found to have a relatively recent evolutionary origin and prior to land clearing probably had a wider geographical range. Despite its capacity to be equally capable reproductively as ***A. anfractuosa***, the extensive land clearing throughout its limited range has reduced this species to two small populations that persist in small fragmented remnants of vegetation. Highest priority for conservation of this Critically Endangered taxon will be achieved only by protection of its current locations and careful fire management to maintain or possibly increase the size of its two remaining populations.

Acacia sp. 'Dandaragan'

Acacia sp. 'Dandaragan' is known from one population in the Dandaragan-Badgingarra area of south-western W.A. (Fig. 3). It is currently undescribed and there has been uncertainty about its taxonomic status in relation to its common and widespread relative ***Acacia microbotrya.*** The single population is estimated to be as large as 25 000 reproductive plants and extends across three landforms: lateritic breakaway, colluvial slopes beneath the breakaway and alluvial flats at the base of the slope. Thus, the taxon is geographically restricted but locally widespread and occurs over a range of topographies and soil types (Elliott ***et al***. 2002).

Recent morphological and genetic (allozyme) studies show that ***A***. sp. 'Dandaragan' has close affinities with ***A. microbotrya*** but is sufficiently distinct to warrant recognition at least as a subspecies (Elliott ***et al***. 2002).

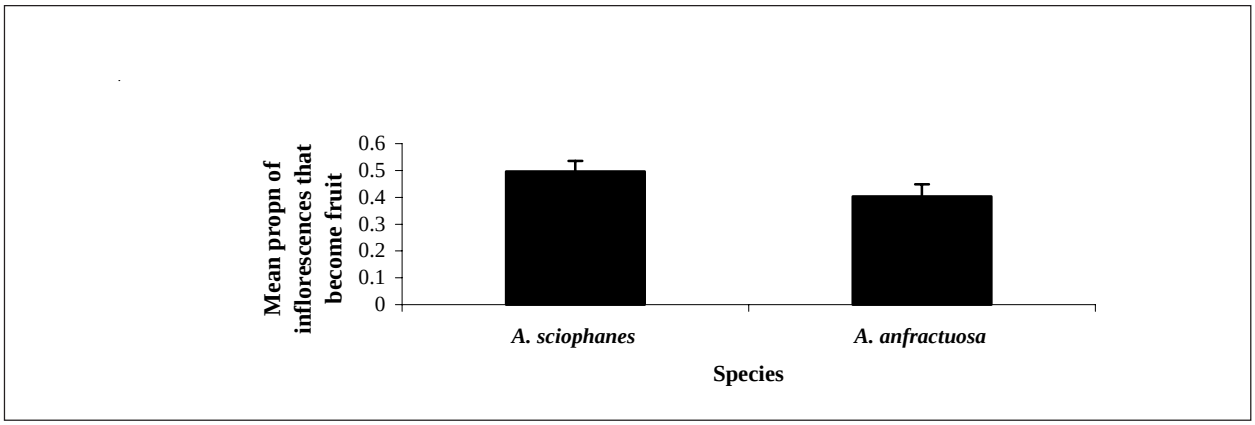


Figure 5a. Mean proportion of A. sciophanes ***and*** A. anfractuosa ***inflorescences that develop into fruit (from two years' data).***

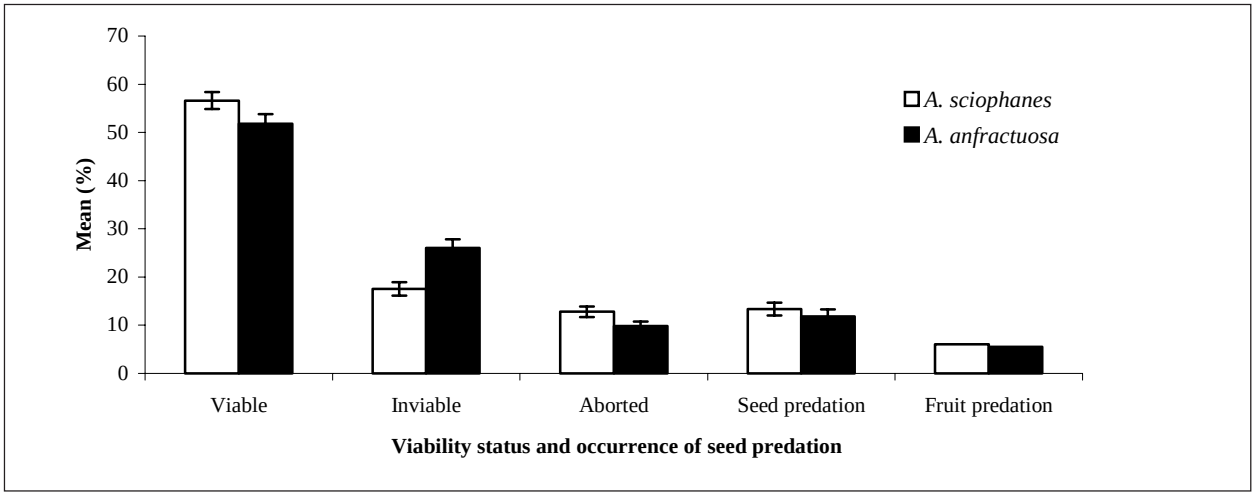


Figure 5b. Mean percentage of A. sciophanes ***and*** A. anfractuosa ***seeds that are viable, inviable, or aborted and have been affected by predation (from one year's data).***

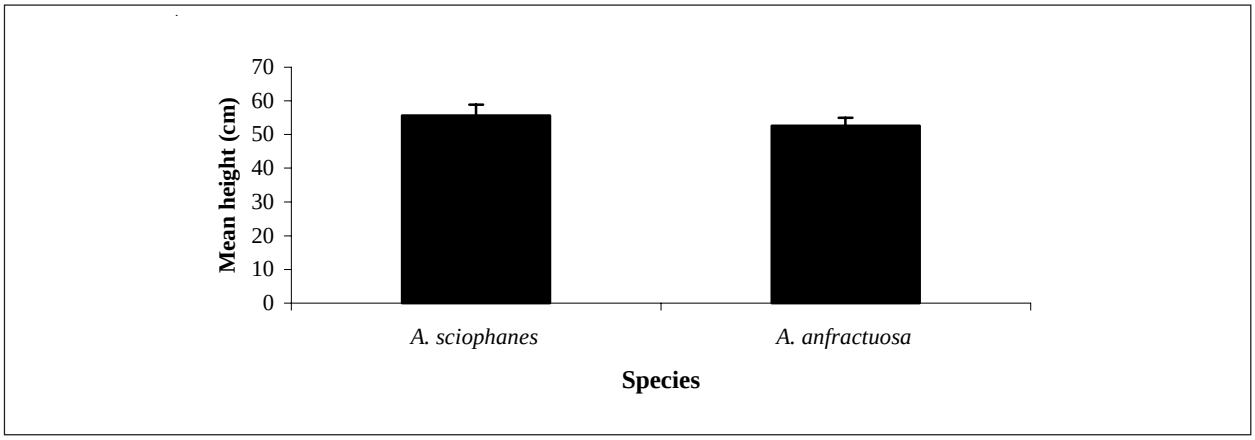


Figure 5c. Mean height of one-year-old, A. sciophanes ***and*** A. anfractuosa ***seedlings transplanted into the burnt habitat of*** A. anfractuosa.

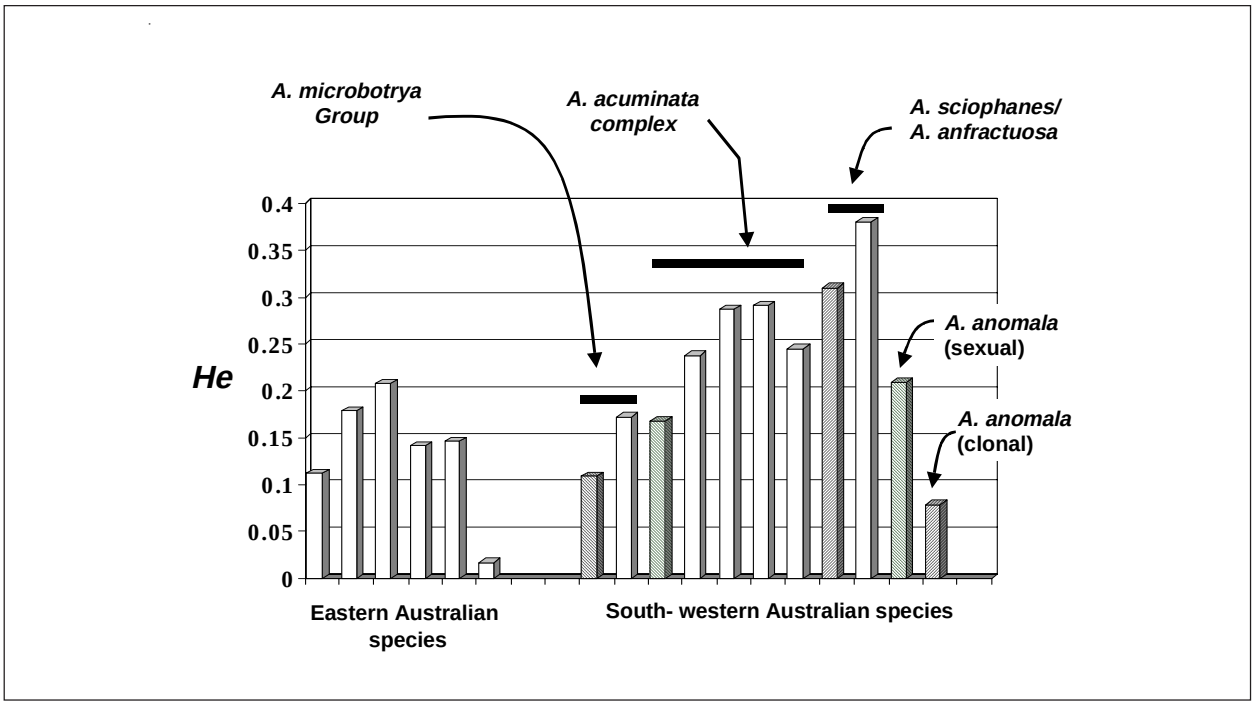


Figure 6. Population based estimates of genetic diversity (He) in eastern Australian and south-western Australian Acacia ***species. The eastern Australian species are from left to right*** A. aulacocarpa ***(McGranahan et al. 1997),*** A. mearnsii ***(Searle et al. 2000),*** A. melanoxylon ***(Playford et al. 1993),*** A. crassicarpa ***(Moran et al. 1989a),*** A. auriculiformis ***(Moran et al. 1989a),*** A. mangium ***(Moran et al. 1989b). The south-west Australian species are divided into common and rare geographically restricted taxa (shaded). Rare and geographically taxa are*** A. ***sp. 'Dandaragan' in the*** A. microbotrya ***group (Elliott et al. 2002),*** A. oldfieldii ***in the*** A. acuminata ***complex (Broadhurst and Coates 2002),*** A. sciophanes ***(Tischler 1998) and*** A. anomola ***(sexual and clonal population groups, Coates 1988).***

Morphological studies based on floral and phyllode characters clearly separate ***A***. sp. 'Dandaragan' and ***A. microbotrya***. Phylogenetic analyses of allozyme data also show that populations of ***A. microbotrya*** variants clustered separately from the single ***A***. sp. 'Dandaragan' population. Although genetically distinct, the level of divergence between ***A***. sp. 'Dandaragan' and ***A. microbotrya*** is not high and the occurrence of ***A***. sp. 'Dandaragan' in a single large population on the margins of the westerly range of ***A. microbotrya*** suggests relatively recent divergence from that species. This is supported by finding relatively low levels of genetic diversity in it compared to ***A. microbotrya***, despite the large size of the population (Ne = c. 25 000). It has been suggested that low levels of genetic variation in rare species may be due to founder events associated with recent divergence and speciation. Other explanations for the relatively low levels of genetic variation in ***A***. sp. 'Dandaragan', such as drift and inbreeding characteristic of small populations, seem unlikely given the current size of the population but cannot be ruled out if recent historical changes in population size were significant. Another explanation for low genetic variation could be partial clonality, although this is also known in ***A. microbotrya*** and is therefore unlikely to be a major contributing factor to the differences in genetic variability between these taxa.

Acacia sp. 'Dandaragan' was found to potentially recruit through both a soil seed bank and extensive root suckering, suggesting that it is resilient to fire. Demographic studies suggest that the population is stable and may be increasing in size primarily by vegetative means. The population size, structure and germination ecology indicate that ***A***. sp. 'Dandaragan' has no immediate management requirements. The single population occurs mainly on private property, however, has an extremely narrow geographical range, and is not afforded the same protection as it would receive in a conservation reserve.

Acacia anomala

Acacia anomala is a small herbaceous shrub known from 10 populations occurring in two disjunct areas, Chittering and Kalamunda, some 30 km apart (Fig. 3). Each population cluster covers only a few kilometres but both are found in Jarrah (***Eucalyptus marginata***), Powderbark (***E. accedens***) and Marri (***Corymbia calophylla***) woodlands on deep lateritic soils. Genetic divergence between the Chittering and Kalamunda population groups is high (D = 0.243) and is reflected in the level of differentiation among all populations (Coates 1988). Phylogenetic analyses based on either gene frequency data or genetic distance give identical tree topologies. They indicate that the Chittering and Kalamunda populations are distinct evolutionary lineages and should be treated as separate units for conservation and management. Significantly, this level of divergence is associated with a change from sexual

reproduction to vegetative reproduction (root suckering) and clonality. The northern populations at Chittering reproduce primarily by seed, and individuals within populations generally show different multilocus genotypes. In contrast, individuals in each Kalamunda population have identical multilocus genotypes with fixed heterozygosity at multiple loci. Clonality in this area appears to be extensive and a single clone may extend over 100 metres. Pollen sterility appears to be a feature of these plants and preliminary studies indicate that no seed is produced by these clones.

The disjunct distribution, significant genetic differentiation between the two population groups and contrasting modes of reproduction support the view that ***A. anomala*** has a remnant population structure that is probably due to the gradual extinction of intervening populations caused by Pleistocene climate change.

The presence of two conservation units with different reproductive systems necessitates quite different conservation strategies for ***A. anomala***. For example, a recommended strategy for the prioritisation of populations for conservation would be to give equal priority to all clonal populations in the Kalamunda area, but high priority to only a few larger populations in the Chittering area (Coates 1988).

Acacia aprica and *Acacia cochlocarpa* subsp. *cochlocarpa*

Acacia aprica is multi-stemmed shrub up to 2 m tall, known from six naturally occurring populations over 10 km in the Carnamah area of south-west W.A. (Fig. 3). Five of the extant populations occur on highly disturbed linear road reserves that have been invaded extensively by exotic grasses and broad-leaved herbs. Four populations consist of 15 or fewer plants. The sixth population, of 106 plants, occurs in relatively undisturbed scrub heath in a small remnant of native vegetation on private property.

Acacia cochlocarpa subsp***. cochlocarpa*** is a sprawling shrub to 0.7 m high recorded from a 20 km range in the Watheroo area and is currently known from a single extant population of 117 plants. This population occurs on a moderately disturbed road reserve and adjoining private property. Both taxa are described as geographically rare and locally rare and in may ways encompass the problems faced by many other threatened ***Acacia*** taxa in south-west W.A.

Recently, the population structure and ecology of these two Declared rare ***Acacia*** taxa have been investigated (Yates and Broadhurst 2002). Size class structure, levels of canopy death and an absence of juveniles indicate that all populations are in decline. Flowering intensity varied between populations and years in ***A. aprica*** and between years in ***A. cochlocarpa*** subsp. ***cochlocarpa.*** All populations were capable of producing viable seed but seed production varied considerably between years and between populations, although no thresholds in seed production associated with population size were identified. Seed bank analyses indicated that seeds were patchily distributed in the soil, while experimental fires demonstrated that such events could break seed dormancy and promote germination. Both taxa have similar germination physiologies and showed increased germination after seeds were exposed to heat or scarified, suggesting that seed reserves are persistent. The presence of a persistent soil seed reserve in both taxa may maintain population viability during years when seed production is low, or as adults decline in the standing vegetation.

Following emergence, however, competition with annual weeds had a negative impact on seedling growth and survival in both taxa. While vertebrate grazing had some influence, weeds were the major inhibitory influence on recruitment. Reduced fire frequencies since fragmentation may be responsible for population decline in both taxa but other factors such as weeds and grazing may affect the establishment of seedlings following fire. The availability of viable seeds does not appear to be responsible for the absence of recruitment. Rather, factors associated with seed germination and seedling establishment (the regeneration niche) appear to be a more likely explanation of population decline. Both taxa are hard seeded and rely on fire-related germination cues to break dormancy. Since habitat fragmentation, fires may no longer develop in the landscape and there may be fewer opportunities for recruitment. Maintenance of stable populations of both species will therefore require ***in situ*** management of the regeneration niche. This study has demonstrated that seedling establishment in the two taxa can be initiated through the careful use of fire to stimulate germination or by planting seedlings, both in association with weed control. The results of this study are relevant to other rare ***Acacia*** species and hard-seeded legumes that also rely on fire for recruitment and are restricted to isolated populations on road verges in south-west W.A.

CONCLUSIONS AND IMPLICATIONS FOR CONSERVATION OF RARE AND THREATENED *ACACIA* TAXA IN WESTERN AUSTRALIA

Rare, narrowly endemic plants are significant components of the diverse flora of Western Australia, particularly in the south-west. ***Acacia*** taxa provide clear illustrations of both this floristic diversity and the critical conservation status of a significant component of the flora. Twenty-six percent of the ***Acacia*** taxa in the State are either listed as threatened (Declared Rare Flora) or rare and poorly known (Priority Flora). The majority (77%) of rare and threatened taxa in ***Acacia*** occur in the Wheatbelt, the most cleared region in the State, where many small populations are restricted to small vegetation remnants, particularly in road reserves. A high proportion of rare and threatened populations of ***Acacia*** taxa are also found on private property and water reserves. The fragmented, isolated nature of many of these populations and the range of land tenures on which they occur make conservation of these species a complex task. Their conservation may involve a range of approaches such as land acquisition, ***in situ***

management of individual populations, translocations (Monks and Coates 2001, this volume), protection through legislation, and improved land management of the remnants and associated landscape.

Management and conservation of individual populations of rare and threatened ***Acac***ia taxa will inevitably require an understanding of ecological and reproductive factors that constrain population growth and persistence. In small populations, it is also useful to get some understanding of the effects that population size may have on genetic variation and inbreeding which, in both the medium and longer term, may be critical factors in the persistence of populations. The examples presented demonstrate the value of ecological, reproductive and population genetic studies in the development of management strategies that could be implemented as part of recovery programs for rare and threatened ***Acacia*** species.

The ***Acacia*** taxa investigated show different patterns of rarity based on their geographical distribution, abundance and habitat specificity (Table 4). For example, both ***A. lobulata*** and ***A***. sp. 'Dandaragan' are extremely localised geographically but occur as large populations. Phylogenetic studies indicate that they have very different evolutionary histories and habitat preferences. ***A. lobulata*** is considered to be a relictual taxon with specific habitat requirements associated with soil type. ***A.*** sp. 'Dandaragan' is thought to be a relatively recently diverged taxon restricted to a single population but occurring across a range of habitats and soil types. ***Acacia*** sp. 'Dandaragan' recruits successfully between fires from both its seed bank and through vegetative (clonal) reproduction and the population currently seems to be increasing. While the populations of ***A. lobulata*** appear to be stable their expansion is likely to be limited due to habitat specificity associated with soil type and its limited capacity to be competitive in a post-fire environment. Although fire is necessary for recruitment, specific factors are required for successful regeneration. Compared with other rare and threatened ***Acac***ia taxa such as ***A. aprica*** and ***A. cochlocarpa*** subsp**.** ***cochlocarpa***, land tenure of populations of these two taxa does not appear to be a significant issue at present. Both are partially protected on nature reserves, although one population of ***A. lobulata*** occurs on a road reserve and a significant proportion of ***A***. sp. 'Dandaragan' is on private property and seedlings may be subject to limited stock grazing.

Like ***A. lobulata*** and ***A.*** sp. 'Dandaragan', ***A. aprica*** and ***A. cochlocarpa*** subsp. ***cochlocarpa*** are geographically localised but, unlike those taxa, they occur in very small populations on narrow road reserves. Not only are ***A. aprica*** and ***A. cochlocarpa*** subsp. ***cochlocarpa*** extremely rare but they are Critically Endangered, surviving mostly in a few declining populations on degraded road reserves. Autecological studies have shown that in both taxa small population numbers are unlikely to have affected seed production but rather factors associated with the regeneration niche are more likely to be responsible for population decline. Indeed, maintenance of stable populations of both species will require ***in situ*** management of the regeneration niche, through either the careful use of fire to stimulate germination of the seedbank or planting seedlings, both in conjunction with weed control.

Acacia sciophanes, with two known populations, is

TABLE 4
Examples of *Acacia* taxa with their rarity defined, threats identified and the ecological and genetic factors which may limit their population growth.

RARE ACACIA	RARITY DEFINED	THREATS	ECOLOGICAL/GENETIC LIMITATIONS
A. lobulata	Geographically rare and locally abundant (+ one roadside pop.), narrow habitat preference, ancient evolutionary lineage.	Changed fire regimes (as for *A. aprica* and *A. cochlocarpa* ssp. cochlocarpa for roadside population).	Reproductive output?; fire response, post-fire growth and reproductivity; available habitat?; age of taxon
A. sciophanes	Geographically and locally rare, broad habitat preference, recent evolutionary lineage.	Continued destruction of habitat; small population size; changed fire regimes; land tenure.	Available habitat; genetic variation and gene diversity; reproductive attributes.
A. sp. 'Dandaragan'	Geographically rare and locally abundant, broad habitat preference, recent evolutionary lineage**.**	Continued destruction of habitat; changed fire regimes; land tenure.	Age of taxon; genetic variation.
A. anomala	Geographically rare and locally abundant, narrow habitat preference ancient evolutionary lineage.		Age of taxon; reproductive attributes.
A. aprica and *A. cochlocarpa* subsp. *cochlocarpa*	Geographically and locally rare, unknown habitat preference and evolutionary lineage.	Continued destruction of habitat; small population size; interactions with introduced weeds, herbivores and pathogens; altered landscape hydrology; changed fire regimes, land tenure.	Reproductive output; reduced fire occurrence

another taxon at risk. It competes adequately with its common counterpart reproductively and with seedling growth so is not declining through demographic factors. With only two relatively small populations, priorities for management must be as for the previous taxa, reducing threats and encouraging recruitment. In particular, the second population in a degraded, active gravel pit needs immediate action in cessation of habitat clearing removing standing plants.

It is generally assumed and theoretically predicted that rare plants, particularly in small isolated populations, will have lower levels of genetic variation and higher levels of inbreeding than more widespread species. These predictions are somewhat validated by population genetic studies on rare ***Acacia*** species. Both ***A. sciophanes*** and ***A*** sp. 'Dandaragan' have lower levels of genetic variation than their closely related widespread congeners, ***A. anfractuosa*** and ***A. microbotrya*** respectively. Another recently studied rare ***Acacia***, ***A. oldfieldii***, shows the same pattern with significantly less genetic variation than ***A. acuminata***, its closest widespread relative (Broadhurst and Coates 2002). Despite these findings, these rare Western Australian ***Acacias***, including ***A. anomala***, have higher levels of genetic variation than eastern Australian acacia species (Fig. 6) and other plants with similar life histories. In the short term it seems unlikely that the levels of genetic variation found in populations of these rare ***Acac***ia taxa will contribute to population decline, although theoretical predictions suggest that in the longer term they may be more important. Of far greater significance for short-term persistence of populations of rare ***Acac***ia taxa are those ecological and reproductive factors that may be limiting recruitment into their populations.

In conclusion, investigations of life histories, reproductive biology, seed bank dynamics, germination physiology, seedling establishment, fire responses, edaphic specialisation and genetic systems and diversity in rare and threatened ***Acacia*** taxa have provided important insights into rarity and guidance for managing threatening processes and recovering species.

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Personal communications

[1] Ms Robyn Phillimore, Department of Conservation and Land Management, Woodvale, W.A.

[2] Dr Brian Shearer, Department of Conservation and Land Management, Kennsington, W.A.

[3] Dr Greg Keighery, Department of Conservation and Land Management, Woodvale, W.A.

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The translocation of two critically endangered *Acacia* species

LEONIE MONKS[1] AND DAVID COATES[1]

[1]Science Division, W.A. Herbarium, Department of Conservation and Land Management,
Locked Bag 104, Bentley Delivery Centre, Western Australia 6983
Email: leoniem@calm.wa.gov.au; davidc@calm.wa.gov.au

SUMMARY

The successful recovery of critically endangered flora will rely increasingly on its translocation to secure sites where the amelioration of threats has been successful or where current threats such as weeds are absent. Translocations are both costly and time consuming and in many cases involve very small numbers of plants from critically endangered populations. Consequently it is important that effective, efficient methodologies are developed for the process and for monitoring success. Equally critical, as part of the same monitoring program, is the need to develop protocols for determining and predicting translocation success. Of the 28 *Acacia* species listed as threatened (Declared Rare Flora) 12 are critically endangered and all occur in agricultural areas where there has been extensive land clearing and habitat degradation. The Department of Conservation and Land Management has carried out 15 experimental translocations of critically endangered taxa as part of approved Interim Recovery Plans, including *Acacia aprica* and *Acacia cochlocarpa* subsp. *cochlocarpa*. Preliminary data are presented on the current status and success of experimental translocations of these two taxa of *Acacia*. Artificial watering and mulch had little effect on enhancing survival or growth of either taxon. Protection from grazing appears to be essential in ensuring translocation success. Continued monitoring is required to evaluate translocation success satisfactorily.

INTRODUCTION

A translocation is the deliberate transfer of plant material, such as seedlings, from one area to another for the purpose of conservation (Australian Network for Plant Conservation 1997). Translocations are rapidly becoming an important tool in the conservation of many critically endangered plants (Guerrant and Pavlik 1997). They can be undertaken to increase existing populations (augmentation), restore an extinct population (re-introduction) or establish a population where the species has not been recorded previously but where the habitat is similar to that of known populations (introduction) (Australian Network for Plant Conservation 1997). In an extreme case the translocation may be into an area where the species has never been recorded and where the habitat is different from that where the species occurs (conservation introduction) (Australian Network for Plant Conservation 1997).

Translocations should combine careful, detailed planning with a long-term commitment to monitoring. Planning involves decisions such as whether to translocate (will it assist the recovery of the species?); choice of propagule type (seed, seedling, cutting etc); evaluation of number and location of translocation sites (based on similarity to the natural sites, security of the site and absence of threatening processes), and design of the planting layout. A long-term commitment to maintaining and monitoring the translocation site is essential as the ultimate success will be determined only after many years (Sutter 1996).

Translocations with conservation objectives have been occurring for many years (Brookes 1981; Guerrant 1996; Ledig 1996; Mehrhoff 1996). In early translocations, however, there has been a lack of detailed records, a scientific approach, adequate control of threatening processes, long-term monitoring and a well-defined method of assessing the success or failure of the project. Coumbe and Dopson (2001) reviewed 335 translocations of 127 plant taxa in New Zealand between 1987 and 1999 and identified four aspects in which management of translocations could be improved: documentation, threat control, planned monitoring, and involvement of community groups.

Detailed records documenting every step of the translocation process are vital to ultimate success. A review of fifteen plant translocations undertaken for mitigation purposes in the USA found that many failed (Hall 1987). Lack of adequate documentation was a major factor in the failure of a third of the projects (Hall 1987). Very little value was gained from these projects because it was not known why they succeeded or failed. A good Western Australian example is the Mogumber Bell (*Darwinia carnea*), a critically endangered plant that occurs near Mogumber and Narrogin. It was propagated by a keen local horticulturist who in 1985 planted approximately 50 plants into a site believed to be the type locality for the species (Holland *et al.* 1997). Five years later a botanist

visited the area and could not locate a single plant. A local farmer believed that sheep had eaten the plants, but nobody really knew what had happened (Holland *et al.* 1997). Later, when the species was translocated in the Narrogin area, the project had to start with virtually no background information despite the previous translocation. Pavlik (1996) believes that even a 'good solid failure' can be useful in learning about a species as long as detailed records are kept.

Even if adequate records have been kept, success or failure cannot be accurately assessed in many cases because of poor experimental design. A rigorous scientific approach should be used, including assessment of the suitability of the site, investigations into the species' biology and testing of different methodologies (Jusaitis 1997). Guerrant (2001) used this approach when translocating Western Lily (*Lilium occidentale*). He tested the accuracy of a computer model which suggested that larger founding plants had a greater chance of long-term survival than smaller ones. His experimental translocations showed that, over the first four years, bulbs had higher survival than directly seeded plants. Of the directly seeded plants, those grown from old seed survived better in the first year than those grown from new seed (although this trend reversed in the following years). The bulbs also grew significantly more than direct-seeded plants, although there was little difference between the two seed types. At least initially, it appeared that using bulbs was the more successful way of establishing Western Lily. In most cases many aspects of rare species biology are unknown, and learning this may prove crucial to the ultimate success of the translocation.

Critical to the outcome of translocations is the presence of threatening processes, or the potential effect of threatening processes, at the translocation site. Secure translocation sites should be chosen where threats are either not present or action has been taken to eliminate them. Mehrhoff (1996) cautioned against translocating plants into area where threats have not been adequately controlled. He stated: 'It makes little sense to spend considerable time and resources to propagate transplants and then send these valuable transplants on a near-certain "death-march" back into the wild if the threats endangering the species have not been eliminated or controlled'. Pavlik *et al.* (1993) showed that control of annual grasses with herbicides had a significant beneficial effect on the size and reproductive output of translocated *Amsinckia grandiflora*. The control of herbivores increased the half-life survival of a population of *Hieracium pilosella* by 57% (Davy and Jeffries 1981). Herbivores were also found to have had a significant negative effect on the survival of translocated seedlings of *Vella pseudocytisus* (Sainz-Ollero and Hernandez-Bermejo 1979). Seedlings planted in 'jiffy' pots appeared to attract rabbits, mice and moles, which then uprooted the plants. Even after the threats have been identified, it may be difficult to quantify their effect during the translocation. Threats that appear to have only a small impact on the natural population may mean the difference between the success or failure of the translocation. An experimental approach can again be used to evaluate their impact.

The goal of translocation is to establish resilient, self-sustaining populations that retain the genetic resources necessary to undergo adaptive evolutionary change (Guerrant 1996). No translocation project should be complete without some form of assessing whether the action has been worthwhile. A goal or series of goals should be programmed into the translocation project at the beginning so that there is some means by which the success or failure of the action can be assessed. Pavlik (1996) advocated short- and long-term goals. Short term goals should assess the ability of the new populations to establish, reproduce and disperse. Long-term goals should use the natural population as a benchmark, and assess the ability of the translocated population to integrate fully into an ecosystem and adapt to a changing environment through evolution or migration. Pavlik (1996) also distinguished between biological and project success. He defined biological success as the performance of translocated individuals, populations and groups of populations (metapopulations) in assuming appropriate functions in the ecosystem. Project success has a much broader definition by contributing to our knowledge of the threatened species or facilitating the development of new management techniques. Fiedler (1991) assessed 46 translocation projects in California and expressed concern that 33% of the projects lacked criteria and consistency in evaluating success.

Sutter (1996) considered monitoring to be the foundation of success in a good translocation program. The purposes of monitoring are to:

- ascertain the status of particular populations or species (Davy and Jefferies 1981);
- check the initial survival, growth and flower and seed production;
- check recruitment and seedling growth;
- check the results against a reference population (Pavlik 1996).

Monitoring should meet four criteria (Sutter 1996):

- it should detect real changes in the population with an acceptable level of precision;
- the data collection techniques must be usable by many people;
- data must be collected over a long enough period to detect long-term trends;
- it must be cost effective and uncomplicated so that it can continue over a long period.

TRANSLOCATIONS IN WESTERN AUSTRALIA

Western Australia is world-renowned for its high plant species diversity and endemism, with around 80% of the estimated 12,000 species in the State restricted to the south-west corner (Hopper *et. al.* 1996). As a result of extensive land clearing and habitat degradation, however, more than 2000 plant taxa in Western Australia are currently listed as rare and threatened (Buist *et al.* this proceedings), and most occur in the South-West.

Rare and threatened plant species in Western Australia are assessed and ranked according to the level of threat. Species that have a high probability of becoming extinct in the next five to ten years, if threatening processes are not abated, are ranked as critically endangered. Currently, 106 plant taxa are listed as critically endangered. One of the key recovery actions recommended for many of the critically endangered species in Western Australia is translocation, which is considered when populations are small and declining, and seem unlikely to persist beyond a few years. Translocations are also used when all or most populations of the threatened species occur in areas that are extremely vulnerable to destruction. Currently there are Interim Recovery Plans for 71 critically endangered species. Translocation is recommended for 51 species, and 25 of these are already under way (Table 1).

The south-west of Western Australia is also world renowned as the centre of *Acacia* species diversity, where 33% (397 species) of the 1200 species worldwide occur. This diversity coincides with the area of highest human impact, so many species are considered rare and poorly known (161 species) or threatened (29 species). Of the 29 threatened species, 12 are considered at such a high risk of extinction that they have been listed as critically endangered (see Buist *et al.* this proceedings).

In 1998, two *Acacia* taxa considered critically endangered were targeted for translocation in an effort to have at least one population of each in a secure site. The first (*Acacia aprica*) is a spreading, open shrub to 2 m tall with slightly zigzag branches, terete phyllodes, and golden, globular flowers from June to August. Only six populations with approximately 220 individuals remain in the wild. Five of these populations occur on narrow, degraded road verges and the sixth in remnant vegetation on private property. The second (*Acacia cochlocarpa* subsp. *cochlocarpa*) is a sprawling shrub to 0.7 m tall and up to 3 m wide. The phyllodes are linear, incurved and erect. The flower heads are golden, sessile, and cylindrical and occur from June to July. Only one population, of 125 individuals, is known on a narrow road verge, extending into the adjacent farmland. Threats to the survival of both taxa are similar and are listed as accidental destruction, weed encroachment, spray and fertiliser drift from adjoining agricultural areas and small population size (Stack and English 1999a and b).

TABLE 1
Summary of the status of plant translocations in Western Australia.

SPECIES	PRESENT CONSERVATION RANK	TRANSLOCATION STATUS
Acacia aprica	Critically endangered	Survival good, plants reproducing
Acacia cochlocarpa subsp. *cochlocarpa*	Critically endangered	Survival good, plants reproducing
Banksia cuneata	Critically endangered	Survival excellent, plants reproducing, second generation present
Brachysema papilio	Critically endangered	Survival good
Darwinia sp. *Williamson*	Critically endangered	Survival moderate
Darwinia carnea (Mogumber form)	Critically endangered	No plants survive
Darwinia carnea (Narrogin form)	Critically endangered	Survival good, plants reproducing
Daviesia bursarioides	Critically endangered	Survival reasonable, plantsreproducing
Dryandra ionthocarpa	Endangered	Survival reasonable
Eremophila nivea	Critically endangered	Survival poor, seed yet to germinate
Eremophila scaberula	Critically endangered	Seed yet to germinate
Eucalyptus rhodantha	Endangered	Survival very poor, a few plants flowering, no second generation
Grevillea calliantha	Critically endangered	Survival good, plants reproducing
Grevillea dryandroides	Critically endangered	No plants survive
Grevillea maccutcheonii	Critically endangered	Survival good, plants reproducing, second generation present
Grevillea scapigera	Critically endangered	Survival good, plants reproducing, second generation present
Lambertia echinata subsp. *echinata*	Critically endangered	Survival poor, plants reproducing
Lambertia echinata subsp. *occidentalis*	Critically endangered	Survival good, plants reproducing
Lambertia orbifolia subsp. *orbifolia*	Critically endangered	Survival excellent, plants reproducing, second generation present
Lasiopetalum pterocarpum	Critically endangered	Survial good, plants reproducing
Lechenaultia laricina	Endangered	Survival moderate, plants reproducing
Petrophile latericola	Critically endangered	Survial moderate
Rulingia sp. Trigwell Bridge	Critically endangered	Survival excellent, plants reproducing, second generation present
Verticordia fimbrilepis subsp. *fimbrilepis*	Critically endangered	Survival poor, plants reproducing
Verticordia spicata subsp. *squamosa*	Critically endangered	Seedling survial excellent, plants reproducing Seed yet to germinate

MATERIALS AND METHODS

Seed of *A. aprica* was sourced from a bulked collection from 60 plants in the largest population. Seed of *A. cochlocarpa* subsp. *cochlocarpa* was sourced from a bulk collection from 30 plants in the only known population. Seed of both species was pretreated by soaking overnight in near-boiling water, placed on agar plates and incubated at 15°C with 12 hours light and 12 hours dark until germination. At radical emergence germinants were transferred to the nursery at Kings Park, Botanic Gardens and Parks Authority, where they were grown in sterilised potting mix until ready for planting into the translocation site.

Translocation sites were selected by surveying areas around the natural populations, specifically targeting areas reserved for conservation purposes. Sites were evaluated for suitability based on similarity of soil type, associated vegetation type and structure to the natural populations. Sites were also evaluated for the presence of threatening processes. After a search of four reserves around Carnamah, one site was chosen for *A. aprica*, in a shire reserve. The site was in a disused gravel pit of red-brown gravelly clay loam, surrounded by eucalypt woodland. The gravel pit was deep-ripped prior to planting. Although weed invasion was evident in the surrounding woodland and had the potential to impact at the translocation site, the site was still considered the best of the few available in the surrounding highly cleared landscape. Two sites were chosen for *A. cochlocarpa* subsp. *cochlocarpa* in a nature reserve. Both sites were disused gravel pits, which were deep-ripped prior to planting. The soil type (red-brown clay loam) and surrounding vegetation (low scrubland) matched those of the natural population. None of the processes threatening the natural population was evident at the translocation sites.

In 1999, 180 plants of *A. aprica* were planted at the translocation site. Four blocks of 16 m x 5 m were measured. In one block 48 seedlings were planted, whilst the remaining blocks were each planted with 44 seedlings. Within each block, half the seedlings were assigned randomly to the mulched treatment, but the remainder were not mulched (Table 2). The mulch consisted of tree loppings ground into small (>10 cm) pieces and sterilised with methyl bromide to eliminate insect pests, weed seeds and other pathogens (e.g. *Phytophthora cinnamomi*). Each plant was then surrounded by a wire fence 90 cm in height (mesh dimension 4 cm), which was secured to the ground using two steel tent pegs 25 cm long. After planting each seedling was tagged with an individually numbered aluminium tag.

In 2000 the effects of grazing by kangaroos and rabbits on *A. aprica* seedlings were investigated. A total of 362 seedlings was planted at the translocation site. These were planted in five blocks with 72 seedlings in each block (with the exception of block 4 with 71 seedlings). Within each block half the seedlings were assigned randomly to the fenced treatments and the remainder were assigned to the unfenced treatment (Table 2). In the fenced treatment seedlings were planted in a block of four rows with seedlings planted at one metre intervals. Each block was surrounded by a fence of 16 m x 5 m in size (Table 2). Seedlings assigned to the unfenced treatment were planted around each fenced block, spaced c. 1 metre apart, each with an individually numbered aluminium tag.

In 1999 344 seedlings were raised of *A. cochlocarpa* subsp. *cochlocarpa*. These were assigned randomly to five blocks of 68 seedlings (except block five with 72 seedlings). Blocks measured 18 m x 5 m and seedlings were planted in four rows of 17 with 1 m between each seedling. One batch of 235 seedlings was 9 months old and one of 109 was 18 months old (Table 2). Half the plants in each age group were then assigned randomly to the watered treatment whilst the remaining plants were not watered (Table 2). Water was applied once a week, gravity-fed from a 4500 litre storage tank controlled by a solar-powered electronic valve system. But because there was little slope on site the gravity fed system could not deliver a precise quantity to each plant. Thus the watering treatment is simply defined as plants given water. Plants were watered from the start of December to the end of April to test whether watering over the first summer enhances survival. Each block of seedlings was surrounded by a wire fence (mesh dimension 4 cm) of 90 cm in height. Each seedling was tagged with an individually numbered aluminium tag.

In 2000, 370 seedlings of *A. cochlocarpa* subsp. *cochlocarpa* were raised to investigate the effects of grazing by kangaroos and rabbits. These were randomly assigned to one of five blocks (73 seedlings in block 1, 72 in block 2, 66 in block 3, 81 in block 4, 78 in block 5). Within each block seedlings were assigned to the fenced treatment (21 seedlings in block 1, 20 in block 2, 19 in block 3, 28 in block 4, 29 in block 5) and the remainder were assigned to the unfenced treatment (Table 2). In the fenced treatment seedlings were planted c. 1 m apart in a group of four rows. Each block was surrounded by a fence of 16 m x 5 m. For the unfenced treatment seedlings were planted c 1 m apart around each fenced block. Each seedling was tagged with an individually numbered aluminium tag.

Monitoring was undertaken at planting, approximately six months after planting and annually thereafter. Data included the number of surviving plants, height, width of the crown in two directions (for *A. cochlocarpa* subsp. *cochlocarpa* only), reproductive state, number of inflorescences and pods (although due to the time of flowering floral bud data were obtained only for *A. aprica*), whether second-generation plants were present and general health of the plants.

All growth and reproductive data were analysed for treatment and block effect using two- or three-way analysis of variance. One-way analysis of variance was used to test for treatment and block effect for survival data. Percentage data were arcsin transformed prior to analysis.

TABLE 2
Description of experimental treatments.

TREATMENT	DESCRIPTION OF TREATMENT
Younger plants	Seedlings planted after being grown in the nursery for nine months.
Older plants	Seedlings planted after being grown in the nursery for 18 months.
Control (not watered)	Plants not watered during summer.
Watered	Plants watered with c. 1 litre of water once a week .
Control (not mulched)	Plants not mulched.
Mulched	A layer of mulch, c. 2.5 cm deep and 1 m wide, placed around the plant.
Control (unfenced)	Plants not fenced.
Fenced	Plants surrounded by a wire fence (mesh dimension 4 cm) 90 cm high, secured to the ground using two 25 cm long steel tent pegs.

TABLE 3
Monitoring data for translocated *Acacia aprica* seedlings planted in 1999.

	2000		2001	
	MULCHED	UNMULCHED	MULCHED	UNMULCHED
% survival	88.7	92	88.7	87.5
Mean height (m)	0.90	0.95	0.93	0.99
Mean no. floral buds	78.5	70.4	N/A	N/A

RESULTS

Survival of *A. aprica* seedlings planted in 1999 was high over the two monitoring periods regardless of whether plants were mulched or unmulched (Table 3). There was no significant difference in survival ($P = 0.9716$), growth ($P = 0.3308$) or floral bud production ($P = 0.4561$) between the two treatments in 2000. There was also no significant difference at the 2001 monitoring period between mulched and unmulched plants in either survival ($P = 0.6901$), or growth ($P = 0.4566$). Block effect in 2001 was only significant for height ($P = 0.0203$) and number of buds ($P < 0.0001$).

More *A. aprica* seedlings survived when protected from herbivory (Table 4) although survival was not significantly enhanced ($P = 0.1021$). Growth was not significantly different between fenced and unfenced plants ($P = 0.9527$) (Table 4). There was no significant effect of block for height ($P = 0.2408$) or survival ($P = 0.7469$).

TABLE 4
Monitoring data for translocated *Acacia aprica* seedlings planted in 2000.

	FENCED	UNFENCED
% survival	62	38
Mean height (m)	0.57	0.57

In 2001 seedlings of *A. cochlocarpa* subsp. *cochlocarpa* that were not watered had a level of survival similar to those given water ($P = 0.3338$) (Table 5). There was also no difference in survival between those seedlings planted at 9 months compared to those planted at 18 months of age ($P = 0.7258$). There was a significant difference between differently aged seedlings for mean width ($P < 0.001$) in 2001, but no difference in plant height ($P = 0.1589$). No significant difference was shown between the watered and unwatered plants for either height ($P = 0.5184$) or width ($P = 0.2781$) in 2001. There was a clear

TABLE 5
Monitoring data for *Acacia cochlocarpa* subsp. *cochlocarpa* seedlings planted in 1999.

MONITORING PERIOD	TREATMENT	SEEDLING AGE	% SURVIVAL	MEAN HEIGHT (M)	MEAN WIDTH (M)	MEAN NO. BUD, FLOWERS AND FRUIT
2000	Control	9 months	93.8	0.28	0.50	37.1
	Control	18 months	87.0	0.32	0.96	77.2
	Water	9 months	96.8	0.26	0.51	50.1
	Water	18 months	100	0.30	0.95	101.7
2001	Control	9 months	92.2	0.32	0.65	N/A
	Control	18 months	88.2	0.33	1.04	N/A
	Water	9 months	93.1	0.27	0.77	N/A
	Water	18 months	96	0.34	1.07	N/A

difference between the ages in 2000 for the number of flowers (P = 0.0144). Again there were no significant differences between watered or unwatered plants (P = 0.0908) for the number of flowers. On average, however, watered plants produced more flowers than unwatered plants (Table 5). Significant differences between blocks were shown only for height (P = 0.0112), mean width (P = 0.0004) and number of buds (P < 0.0001).

Seedlings of *A. cochlocarpa* subsp. *cochlocarpa* had significantly greater survival when protected from herbivores (P = 0.0093), although canopy height (P = 0.5887) and width (P = 0.1760) were not significantly reduced by grazing (Table 6). There was no significant effect of block for height (P = 0. 4395) or survival (P = 0.8194).

TABLE 6
Monitoring data from June 2001 for *Acacia cochlocarpa* subsp. *cochlocarpa* seedlings planted in 2000.

	FENCED	UNFENCED
Percentage survival	74.6	30.7
Mean height (m)	0.26	0.27
Mean width (m)	0.34	0.30

DISCUSSION

Using an experimental approach to the translocation of *A. aprica* and *A. cochlocarpa* subsp. *cochlocarpa* has allowed us to investigate several techniques. Fencing seedlings immediately after planting clearly enhances success, as seedlings of both *Acacia* taxa were more likely to survive when protected from herbivores. Growth was not significantly reduced by grazing for either species. However, this is probably because plants that were not heavily grazed were the only ones to survive.

In environments where water is limited, leaf litter is believed to enhance seed germination and seedling survival by reducing evaporation of soil moisture from around the plant (Hamrick and Lee 1987; Enright and Lamont 1989; Facelli *et al.* 1999). In contrast in this study the use of mulch appeared to have little effect on the survival or growth of the translocated *A. aprica* seedlings. The reasons for this are unknown, but may be a result of age of founder plants. Seedlings were approximately 18 months of age when planted and the root system may have been sufficiently well developed to tap quickly into deeper water supplies. This may have reduced any effect of mulching.

The availability of water in the first summer after germination is often found to be one of the most important factors limiting seedling survival in Mediterranean climates (Lamont *et al.* 1993). However, in the case of the translocated *A. cochlocarpa* subsp. *cochlocarpa* seedlings there was very little difference in survival or growth between plants given water and those not watered. There are several possible reasons for this. The translocation site was formerly a gravel pit and there may have been little competition for the available water, reducing any effect from the watering treatment. Or, as mentioned previously, the founder plants may have been old enough to have reasonably well developed root systems which allowed them to establish quickly before the summer drought.

Long-term survival of translocated plants may be influenced by the age of the founding individuals. Guerrant (1996) used computer models to compare long-term survivorship between different aged founder groups for a range of long-lived perennial species. Death rates declined significantly as the age of the founder group increased and, after ten years, population size increased significantly as age of the founder group increased (Guerrant 1996). Initially there does not appear to be such a clear trend for *A. cochlocarpa* subsp. *cochlocarpa*. A significant difference was found in the first year growth between the two ages but this would appear to be a function of the size at planting. This difference reduced in the second year, indicating that 9-month-old plants are actually more vigorous than 18-month-old plants. In addition the 9-month-old plants appear healthier, greener and have a denser canopy than 18-month-old plants. Long term monitoring should enable the progress of the different aged seedlings to be followed and give a better idea of what is the ideal seedling age for translocation.

The preliminary results from this study indicate that a number of the techniques investigated to maximise seedling establishment, survival and growth are important for translocation success. Monitoring to date also shows that criteria for short-term success, particularly in seedling survival and reproductive capability, have been met. Many translocation projects have also reported such success in the short term (e.g. Olwell *et al.* 1987; Gordon 1996; Bowle and McBride 1996; Johnson 1996). For example, translocation of *Abronia umbellata* subsp. *breviflora* (Nyctaginaceae) appeared to be successful just two years after the initial planting (Kaye *et al.* 1999). Survival of the transplants was high, transplants flowered and produced viable seed, second generation plants were recorded and the experimental approach helped refine many translocation techniques.

The long-term and biological success criteria proposed by Pavlik (1996) have yet to be determined for these two acacias. It is not yet possible to determine whether the populations are self-sustaining or whether sufficient genetic diversity has been retained (Guerrant 1996). Even for annual species, authors have hesitated to evaluate long-term success (Brookes 1981; Guerrant and Pavlik 1997). For example, ten years after translocating the annual *Stephanomeria malheurensis* (Asteraceae), long-term monitoring is still recommended (Guerrant and Pavlik 1997). In one of the earliest documented conservation translocations, that of the sedge *Schoenus ferrugineus* (Cyperaceae), monitoring continued for over 30 years – but there was no evaluation of the long-term success (Brookes 1981). Despite indications that these two acacias can flower and set fruit after three years, they must be monitored for at least another three years before a realistic determination of the long-term success of the translocations can be made.

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Wattle I plant for wildlife?

B.M.J. (PENNY) HUSSEY

Land for Wildlife Coordinator, Department of Conservation and Land Management,
Locked Bag 104, Bentley Delivery Centre, Western Australia 6983
Email: pennyh@calm.wa.gov.au

SUMMARY

Wattles (*Acacia* spp) are an important component of most Australian ecosystems and, as a group, are one of the most widely recognised native plants. However, there is surprisingly little recorded about the relationship between wattles and fauna. This paper looks at the ways in which wattles can provide resources for native fauna, brings together published records relating to acacias and fauna in the south-west of Western Australia, and discusses what this means for revegetation.

INTRODUCTION

In the south-west of Western Australia, most vegetation communities contain some wattle (*Acacia*) species. It is generally accepted that in this region there are about 8000 vascular plant taxa, of which some 500 are wattles. In the Wheatbelt the number of taxa is around 3500, of which some 12% (417 taxa) are wattles. Their contribution to the biomass of local ecosystems may be very much higher than may appear from species diversity figures, as they often appear *en masse* in the years immediately following a fire or other disturbance, when the pioneer species grow quickly and dominate the regrowth. After a few years they die off, remaining as seeds in the soil seed bank until another disturbance stirs them into growth once more. Some species, however, are much longer lived.

As an integral part of the vegetation community, wattles provide several ecosystem services, including effects on various stages in the water cycle. The roots of most species host nitrogen-fixing organisms and so contribute usable nitrogen to the soil–they are probably especially important in replacing nitrogen lost to the atmosphere during fire. In the rapid phase of regrowth that occurs after a disturbance, they may act as shelter for slower-growing plants. In addition, they provide resources such as food and shelter for fauna. This paper looks at the relationship between wattles (in both remnant and revegetated areas) and native fauna in the south-west of Western Australia, that is, the developed agricultural area, west of the State Barrier Fence, then discusses this information in the light of current and proposed revegetation practice.

RESOURCES NEEDED BY NATIVE FAUNA

Since a stated aim of much remnant protection and revegetation in the agricultural area is to 'provide fauna habitat', 'create a bush corridor' or just generally to 'maintain biodiversity', it is important to consider what this implies. Animals require resources such as food, water, space and shelter as well as the possibility of meeting an appropriate mate and so reproducing more of their kind. Whether considering the survival of native fauna in general, or of one species in particular, it is necessary to consider food webs, the cycling of nutrients and water, the ability to cope with predators, disease and major changes in the physical environment such as fire and drought, and finally the population size needed for long-term survival (Hussey and Wallace 1993). These needs are, of course, supplied by the entire ecosystem, of which wattles are just a part.

There are surprisingly few published records of fauna using wattles in Australia, and most of what has been written refers to species in eastern Australia or the Mulga zone (see New 1984 for a summary to that date). Details of those south-west Western Australian records that I have been able to locate are given in Table 1. The following sections highlight data for various animal groups.

TABLE 1
Use of *Acacia* species by native fauna in the south-west of Western Australia. Personal communications are indicated by the name of the individual, without date.

Name	Fauna group	Genus, species	Notes	Authority
A. aciphylla	Insecta	bees; *Hyaleus* sp., *Leioproctus*		Houston (2000)
A. acuaria	Bird	Blue-breasted Fairy-wren, *Malurus pulcherrimus*	nest	M Brooker
A. acuminata Jam	Mammal	Dalgyte, *Macrotis lagotis*	eat bardi grubs from roots	Friend (2001)
	Mammal	Grey Kangaroo, *Macropus fuliginosus*	graze foliage,shelter	F Falconer
	Bird	thornbills	use planted corridors	A Baxter
	Gastropoda			Majer *et al.* (2001)
	Arachnida	Arachnida		Majer *et al.* (2001)
	Arachnida	Pseudoscorpiones		Majer *et al.* (2001)
	Arachnida	Acari		Majer *et al.* (2001)
	Malocostrata	Isopoda		Majer *et al.* (2001)
	Diplopoda	Polyxenida		Majer *et al.* (2001)
	Collembola	Arthropleona		Majer *et al.* (2000)
	Collembola	Symphypleona		Majer *et al.* (2000)
	Insecta	Thysanura		Majer *et al.* (2000)
	Insecta	Odonata		Majer *et al.* (2000)
	Insecta	Blattodea		Majer *et al.* (2000)
	Insecta	Mantodea		Majer *et al.* (2000)
	Insecta	Isoptera		Majer *et al.* (2000)
	Insecta	Dermaptera		Majer *et al.* (2000)
	Insecta	Orthoptera		Majer *et al.* (2000)
	Insecta	Phasmatodea		Majer *et al.* (2000)
	Insecta	Psocoptera		Majer *et al.* (2000)
	Insecta	Hemiptera	large numbers	Majer *et al.* (2000)
	Insecta	Thysanoptera		Majer *et al.* (2000)
	Insecta	Neuroptera	adults & larvae	Majer *et al.* (2000)
	Insecta	Coleoptera	adults & larvae	Majer *et al.* (2000)
	Insecta	Mecoptera	adults	Majer *et al.* (2000)
	Insecta	Diptera	adults & larvae	Majer *et al.* (2000)
	Insecta	Trichoptera		Majer *et al.* (2000)
	Insecta	Lepidoptera	adults & larvae	Majer *et al.* (2000)
	Insecta	Hymenoptera	ants	Majer *et al.* (2000)
Majer *et al.* (2001)	Insecta	Hymenoptera	bees, wasps	Majer *et al.* (2000)
	Insecta	bees; *Leioproctus* sp.		Houston (2000)
	Insecta	Bag Shelter Moth, *Ochrogaster lunifer*	defoliates, builds shelters	Tommerup & Bougher (1999)
	Insecta	parasitic fly	eggs seen on head capsule of *Ochrogaster lunifer*	Tommerup & Bougher (1999)
	Insecta	bardi grubs - borer larvae	root/stem borer	Friend (2001)
A. aestivalis Summer Wattle	Mammal	Grey Kangaroo, *Macropus fuliginosus*	graze foliage, shelter	BMJ Hussey
*A. aneura*Mulga	Insecta	ants	harvest seed	V Mischker
	Insecta	ants; *Melophorus* sp., *Pheidole* sp.	harvest seed	Davidson & Morton (1984)
A. aprica	Insects	11 spp	collected on flowers	Prescott (2000)
A. blakelyi	Insecta	bees; *Ctenocolletes* sp.; *Leiproctus* sp		Houston (2000)
A. campylophylla	Bird	Splendid Fairy-wren, *Malurus splendens*	nest	BMJ Hussey
A. celastrifolia Shining Wattle	Bird	Common Bronzewing, *Phaps chalcoptera*,	take seed from ground	BMJ Hussey
	Bird	Port Lincoln Parrot, *Barnardius zonarius*, Red-capped Parrot, *Purpureicephalus spurius*,	take developing seed	BMJ Hussey
	Bird	Silvereye, *Zosterops lateralis*	pollinator?	Brown *et al.* (1997)

TABLE 1 (continued)

Name	Fauna group	Genus, species	Notes	Authority
A. cochlearis	Arachnida	many types		V Mischker
A. cochlocarpa subsp. *cochlocarpa*	Insecta	10 spp		Prescott (2000)
A. colletioides Wait-a-while	Bird	thornbill	nest	H Adamson
A. congesta	Bird	Port Lincoln Parrot, *Barnardius zonarius*	eat seed	BMJ Hussey
	Arachnida	Christmas Spider *Gasteracantha minax*, and other orb-weavers	habitat	BMJ Hussey
A. cyclops Red-eyed Wattle	Mammal	Southern Bush-rat, *Rattus fuscipes*	may eat seed	Gill (1985)
	Mammal	Brush-tail Possum, *Trichosurus vulpecula*	eat seed, digest seed stalk, seeds pass into scats; eats exudate	J Dewing P Mawson
	Mammal	Ring-tailed Possum, *Pseudocheirus peregrinus*	eats phyllodes	P Mawson
	Bird	Pink Cockatoo, *Cacatua leadbeateri*	major seed predator	Gill (1985)
	Bird	Port Lincoln Parrot, *Barnardius zonarius*	eat immature seeds and pods	Powell (1990)
	Bird	silvereye, *Zosterops lateralis*	eat seed stalks, disperse seeds	Gill (1985), Powell (1990)
	Bird	Red Wattlebird, *Acanthochaera carunculata*	eat seed stalks, disperse seeds Powell (1990)	Gill (1985),
	Bird	Grey Currawong, *Strepera versicolor*	eat seed stalks, disperse seeds	Gill (1985)
	Bird	Singing Honeyeater, *Meliphaga virescens*	eat seeds	Gill (1985)
	Bird	Brush Bronzewing, *Phaps elegans*	eat seeds	Gill (1985)
	Bird	Australian Magpie, *Gymnorhina tibicens*	eat seeds	Gill (1985)
	Insecta	ant-longicorn beetle	Larva burrows into twigs, adults on flowerheads	Powell (1990)
	Insecta	ants, *Iridiomyrex* sp.	moved seed + aril	Gill (1985)
	Insecta	ants, *Campanotus* sp.	moved seed + aril	Gill (1985)
	Insecta	ants, *Melophorus* spp (2 spp)	carryed seed + aril or removed aril	Gill (1985)
	Insecta	ants, *Monomorium* sp.	removed arils	Gill (1985)
	Insecta	ants, *Pheidole*, sp	moved seed + aril, or removed arils	Gill (1985)
	Insecta	ants, *Rhytidoponera* (2 spp)	moved seed + aril	Gill (1985)
	Insecta	shield bug, *Coleotichus ?costatus*	eats developing seed	Gill (1985)
	Insecta	Alylidid bug, *Riportus* sp.	eats developing seed	Gill (1985)
	Insecta	Pentatomid bug, *Dictyotus* sp.	red & khaki nymphs eat developing seeds	Gill (1985)
	Insecta	weevil, *Melanterius* spp	larvae eat developing seeds	Gill (1985)
	Insecta	lepidoptera, *Xerometra crocina*	larvae eat developing seeds	Gill (1985)
	Insecta	shield bug, *Adrisa* sp.	eats seed on ground	Gill (1985)
	Insecta	Cosmopterygidae	mines foliage + young pods	New (1984)
	Insecta	Lepidoptera, 26 spp		New (1984)
	Insecta	88 spp		New (1984)
A. dentifera	Bird	Red-capped Parrot, *Purpureicephalus spurius*	eat developing seeds	BMJ Hussey
	Bird	Port Lincoln Parrot, *Barnardius zonarius*	eat seeds	J Seabrook
A. erinaceaWattle	Bird	Blue-breasted Fairy-wren, *Malurus pulcherrimus*	nest	M Brooker
A. extensa Wiry Wattle	Mammal	Grey Kangaroo, *Macropus fuliginosus*	selectively graze	BMJ Hussey
	Insecta	ants, 9 spp, incl. *Rhytidoponera inornata* and *Melophorus* sp.	harvest seeds	Majer (1982)
A. fragilis	Insecta	bees; *Lasioglossum* sp.; *Leioproctus* sp.		Houston (2000)
	Bird	Blue-breasted Fairy-wren, *Malurus pulcherrimus*		nest M Brooker
A. hemiteles Tan Wattle	Mammal	Grey Kangaroo, *Macropus fuliginosus*	shelter	F Falconer
	Bird	Crested Pigeon, *Ocyphaps lophotes*	nest	F Falconer
	Bird	Blue-breasted Fairy-wren, *Malurus pulcherrimus*	nest	M Brooker

TABLE 1 (continued)

Name	Fauna group	Genus, species	Notes	Authority
A. jacksonioides	Bird	Blue-breasted Fairy-wren, *Malurus pulcherrimus*	nest	M Brooker
A. jutsonii	Bird	Blue-breasted Fairy-wren, *Malurus pulcherrimus*	nest	M Brooker
A. lasiocarpa var *sedifolia*				
Wandoo Prickly Moses	Arachnida	Christmas Spider, *Gasteracantha minax*, other orb-weavers		BMJ Hussey
A. leptopetala	Insecta	bees; *Hyaleus* sp., *Leioproctus* sp., *Nomia* sp.		Houston (2000)
A. ligulata	Insecta	bees; *Chalicodoma* sp., *Ctenocolletes* sp., *Leioproctus* sp.		Houston (2000)
	Insecta	ants; *Iridomyrmex purpureus*; *Pheidole* sp.	seed dispersal	Davidson & Morton (1984)
	Bird	Singing Honeyeater, *Lichennostomus virescens*; Spiny-cheeked Honeyeater *Acanthegenys rufogularis*	seed dispersal	Davidson & Morton (1984)
A. ligustrina	Insecta	Ants	harvest seeds (red aril)	BMJ. Hussey
A. merinophthora Zigzag Wattle	Bird	Red-capped Parrot, *Purpureicephalus spurius,* (in garden outside plant's natural range)	squeeze developing seed out of pod, eat	BMJ. Hussey
A. microbotyra Manna Wattle	Mammal	Grey Kangaroo, *Macropus fuliginosus*	shelter	F Falconer
	Bird	Major Mitchell Cockatoo, *Cacatua leadbeateri*	eat seeds	F Falconer
A. nyssophylla	Bird	White-winged Fairy-wren, *Malurus leucopterus*	good habitat	A Doley F Falconer
	Bird	Variegated Fairy-wren, *Malurus lambertii*	good habitat	F Falconer
	Bird	White-fronted Chat, *Epthianura albifrons*	good habitat	A Doley
	Insecta	locusts	eat foliage	A Doley
A. oncinophylla Hills Minniritchi	Bird	Red-capped Parrot, *Purpureicephalus spurius*	take unripe seed	BMJ Hussey
A. pulchella Prickly Moses	Mammal	Grey Kangaroo, *Macropus fuliginosus*	graze, eliminate seedling regrowth after fire	Shepherd *et al.* (1997), BMJ Hussey
	Mammal	Black-gloved Wallaby, *Macropus irma*; tammar wallaby, *Macropus eugenii*	graze	Shepherd *et al.* (1997)
	Bird	fairy-wrens, and other small birds	shelter	J Dewing
	Bird	Silvereye, *Zosterops lateralis*	pollinator?	Brown *et al.* (1997)
	Bird	Splendid Fairy-wren, *Malurus splendens*	nest - use both live or, after fire, dead plants	Brooker (2001)
	Insecta	ants, *Rhytidoponera inornata*	harvest seed	Majer (1982)
	Insecta	scarab beetle, *Diphucephala* sp.	pollinator?	Brown *et al.* (1997)
	Insecta	bees, *Hyaleus* sp., *Lasioglossum* sp., *Leioproctus* sp.		Houston (2000)
A. redolens Scented Wattle	Bird	fairy-wren	saline reveg planting, supported nest in fifth year of growth	K Vaux
A. restionaceae	Bird	Red-capped Parrot, *Purpureicephalus spurius*	eat developing seed - removed each individually	BMJ Hussey
A. rostellifera Summer Scented Wattle	Mammal	Tammar, *Macrotis eugenii*	forage beneath thickets	Powell (1990)
	Mammal	Quokka, *Setonix brachyurus*	forage beneath thickets, eat seeds	Powell (1990)
	Insecta	bag shelter moth	defoliate, make bag shelters	Powell (1990)

TABLE 1 (continued)

Name	Fauna group	Genus, species	Notes	Authority
A. saligna Golden Wreath Wattle	Mammal	Brush-tail Possum, *Trichosurus vulpecula*	love eating blossom	Nannup Wildlife Carers
	Mammal	Grey Kangaroo, *Macropus fuliginosus*	shelter	F Falconer BMJ Hussey
	Bird	Brown Honeyeater, *Lichmera indistincta*	pollinator?	Brown *et al.* (1997)
	Bird	Splendid Fairy-wren, *Malurus splendens*; Yellow-rumped Thornbill, *Acanthiza chrysorrhoa*	nest	M Brooker
	Collembola	3 spp		Majer (1978)
	Arachnida	17 spp		Majer (1978)
	Insecta	ants	carry seed into their nests, eat seed stalks, disperse seeds, use phyllode nectaries, may deter other herbivores	Majer (1978) listed 9 spp of ants Powell (1990)
	Insecta	92 spp		Majer (1978)
	insecta	*Castiarina rufipennis*	larvae bore through stem, sever it to exit	Powell (1990)
	Insecta	weevil	cause galls	Powell (1990)
	Insecta	weevil, *Melanterius* sp.	eat developing seeds	New (1983)
	Insecta	weevil, *Diethusa* sp.	eat developing seeds	New (1983)
	Insecta	borers in *Uromycladium* (fungal) galls		New (1984)
	Insecta	Cosmopterygidae, *Labdia* sp.	phyllode miner	New (1984)
	Insecta	Lepidoptera, 36 spp		New (1984)
	Insecta	Coleoptera, Lepidoptera, Hemiptera, 131 spp		New (1984)
A. sessilis	Bird	Splendid Fairy-wren, *Malurus splendens*	nest	M Brooker
A. sp. Dandaragan	Insecta	15 taxa incl: fly, midge, parasitic wasp, brown wasp, honeybee, hoverfly, beetle	collected on flowers; muscid and syrphid flies eat pollen and may be pollinators	Prescott (2000)
	Insecta	caterpillars and other larvae	among florets, but not collected	Prescott (2000)
A. stenoptera, wing-fruited wattle	Mammal	Black-gloved Wallaby, *Macrotis eugenii*	occasionally graze	Wann & Bell (1997)
A. strigosa	Insecta	ant, *Melophorus* sp.	harvests seed, removes elaiosome	Majer (1982)
A. tetragonophylla Kurara	Bird	Singing Honeyeater, *Lichennostomus virescens*; Spiny-cheeked Honeyeater *Acanthegenys rufogularis*	seed dispersal	Davidson & Morton (1984)
	Bird	White-browed Babbler, *Pomatostomus superciliosus*	nest	BMJ Hussey
	Insecta	bees; *Chalicodoma* sp., *Ctenocolletes* sp., *Leioproctus* sp.		Houston (2000)
	Insecta	ant; *Rhytidoponera mayri*; *R. metallica*; *Melophorus* sp.	seed dispersal	Davidson & Morton (1984)
A. ulicina	Insecta	locusts	eat stem, phyllodes	A Doley
A. urophylla	Insecta	ants, *Rhytidoponera inornata*	harvests seed	Majer (1982)
A. victoriae Bardi Bush	Mammal	Dalgyte, *Macrotis lagotis*	eating bardi grubs	Friend (2001)
	Insecta	ants; *Rhytidoponera mayri*; *R. metallica*; *Iridiomyrmex purpureus*	seed dispersal	Davidson & Morton (1984)
	Insecta	bardi grubs	stem/root borers	Friend (2001)
A. xanthina White-stemmed Wattle	Insecta	jewel beetles, *Agrilus australasiae*, *Cisseis* sp., *Melobasis terminata*.	in flowers, taking pollen	Powell (1990)
	Insecta	ants, *Crematogaster* sp.	harvest secretions from phyllode glands	Powell (1990)
	Insecta	native bees	in flowers	Powell (1990)
	Insecta	parasitic wasps	examine foliage for moth larvae	Powell (1990)
	Insecta	long-horned beetle (2 spp)		Powell (1990)

WATTLES AND MAMMALS

Many wattles are palatable and young foliage may be grazed preferentially by marsupials, including Brush-tailed Possums (*Trichosurus vulpecula*). Those known to be grazed by kangaroos include wattles often used in revegetation–*A. acuminata*, *A. aestivalis*, *A. brumalis*, *A. microbotrya* and *A. saligna*, but almost certainly large numbers of others are also taken, especially when young.

Preferential grazing by macropods can alter the composition of a plant community regenerating after fire or other disturbance. This is especially important in a small area. For example, on a small block in the Helena Valley, 93% of *A. pulchella* seedlings that germinated after a regeneration fire in autumn 2000 were removed by Western Grey Kangaroos (*Macrotis lagostis*) during the subsequent very dry summer. A similar effect probably occurs in other vegetation communities. For example, there are far fewer young wattles on Nangeen Hill Nature Reserve where, since 1982, fox control has allowed the Black-flanked Rock Wallaby (*Petrogale penicillata*) to build up to large numbers, in contrast to nearby rock nature reserves where there are no wallabies.

In eastern Australia, there are records of Sugar Glider (*Petaurus breviceps*) deliberately tapping acacias and drinking the sugary sap which is thereby exuded (Smith 1992). *Acacia microbotrya* is known as Manna Gum because of the way it weeps sap, and older settlers record that Brush-tailed Possums were often seen in this shrub. Were they, too, eating the sap? Perhaps, as fox control enables possums to return to their former range, someone will find out.

Wattle seed has not been recorded as a food source for native mammals in the wheatbelt, though native rodents probably utilise it. Gill (1985) hypothesised that *Rattus fuscipes* is an important agent of seed dispersal for *A. cyclops* on the south coast. It is not known whether animals such as Gilbert's Potoroo (*Potorus tridactylus*) and Woylie (*Bettongia penicillata*) which utilise large numbers of soil fungi in their diet, also eat wattle seed. The oily elaiosome of some species might contribute vital nutrients not obtained elsewhere.

Apart from direct consumption of the plant, some mammals may feed on the invertebrates attracted to it. If any wattles are within their range, phascogales and antichinuses probably hunt on them and historical references to the Dalgyte (*Macrotis lagotis*) record that it digs to remove bardie grubs (larvae of longicorn beetles or other borers) from *Acacia* roots (Friend 2001).

In common with other shady shrubs, wattles provide shelter for macropods, and kangaroos frequently make resting scrapes under them. On Garden Island Tammar (*Macropus eugenii*) and on Rottnest Island Quokka (*Setonix brachyurus*) rest during the day under the shade of shrubs such as *A. rostellifera*.

WATTLES AND BIRDS

Wattle flowers do not seem to attract nectar-eating birds, but many insectivores work the plants, taking insects that are attracted to them. A mixed aggregation of thornbills, honeyeaters, silvereyes and wrens will work their way along a hedge, taking small insects from flowers and foliage. Red Wattlebirds (*Anthochaera carunculata*) will take orb-weaving spiders and Pied Butcherbirds (*Cracticus nigrogularis*) the small skinks that prey on the insects.

Many wattles produce a large quantity of nutritious seed and granivorous birds take advantage of this, especially Bronze-wing Pigeons (*Phaps chalcoptera*) and Malleefowl (*Leipoa ocellata*), though the latter has perhaps changed principally to wheat. Many parrots consume the seed, commonly when it is still green. Red-capped Parrots (*Platycercus spurius*) will carefully peck seeds individually from pods of *Acacia celastrifolia*, *A. dentifera* and *A. oncinophylla* and, in a garden, have been observed on *A. merinthophora*, pulling the pods crosswise through their beak, presumably popping the tiny seeds into their mouth. Some seeds may survive ingestion by birds and germinate in their droppings, making this an important method of seed distribution (Gill 1985).

The architecture of a shrub is an important factor in determining which bird will build a nest in it. Some birds, such as fairy-wrens, like dense low bushes, and acacias often are a suitable shape. On Gooseberry Hill, Kalamunda, 31% of nests of Splendid Fairy-wren (*Malurus splendens*) were in *A. pulchella*, including dead bushes (Brooker 2001). At Wyalkatchem, 25% of nests of Blue-breasted Fairy-wren (*Malurus pulcherrimus*) were in wattles, primarily *A. acuaria* and *A. erinacea*, though four other species have been used (M.Brooker, pers. comm.). At Bolgart, Splendid Fairy-wrens nested in *A. campylophylla*, a fiendishly prickly low plant. In salt-land revegetation at Ongerup, fairy-wrens nested in planted *A. redolens* by the fifth year after planting (K.Vaux, pers. comm.).

Taller shrubs are utilised by other birds, but the most popular architecture remains dense growth, a wide, strong branch structure and, really importantly, prickly. One presumes that the prickliness deters predators. In the northern and eastern wheatbelt a widely used plant is Kurara, *Acacia tetragonophylla*. A clear example of this was seen on an excursion to a 140 ha reserve near Perenjori. Fifteen small bird nests (eight of them active) were noted in only one site, a clump of six Kurara bushes. The aptly-named Wait-a-while, *A. colletioides*, native to most of the wheatbelt, is also a favoured nesting site.

Mistletoes growing on wattles are important nesting sites for many species which build in or on top of the mistletoe clump, even if it has died. They provide nesting sites in species of *Acacia* (e.g. Jam, *A. acuminata*) which the plant itself may not provide. Birds using this resource include Yellow-rumped Thornbills (*Acanthiza chrysorrhoa*), Whiteface (*Aphelocephala leucopsis*) and Zebra Finch (*Poephila guttata*) (M.Brooker, pers. comm.).

Further mention of wattles and birds in south-western Australia may be found in journals such as *Emu* and other specialist publications. This literature is huge, however, and is indexed by bird names, not plants or places, hence trawling it for other information would be a project in itself.

WATTLES AND REPTILES

Herbivores such as the Bobtail (*Tiliqua rugosa*) consume seeds and other edible material (Gill 1985) but most reptiles using wattles are insectivores. Bearded Dragons (*Pogona minor*) hunt and bask on logs and vegetation, including wattles. The Fence Skink (*Cryptoblepharus plagiocephalus*) has been observed consuming small insects on *Acacia dentifera* and *A. microbotrya*, and *Menetia greyii* forages in leaf litter, including under acacias. The Spiny-tailed Gecko (*Strophurus spinigerus*) rests during the day in shrubs, including *A. pulchella*, presumably hunting through them at night. This is probably true for many other arboreal reptiles.

WATTLES AND AMPHIBIANS

The Slender Tree Frog (*Littoria adelaidensis*) basks during the day on vegetation which is close to or overhangs a pond or creek, for example on *A. saligna* and *A. alata*. I have not seen any records of amphibians taking prey from wattles.

WATTLES AND INVERTEBRATES

Most investigations of the relationships between acacias and fauna concern invertebrates, principally arthropods.

Any casual observer would note that there are large numbers and many species of invertebrate animals associated with wattles, foraging in and on flowers, foliage and seeds, sucking sap and boring into stems and roots. There is also a wide suite of animals feeding on the herbivores. A summary of the use of acacias by arthropods on a world scale was given by New (1984), but he noted that overall the associations between insects and wattles in Australia have been little studied.

Bernhardt (1983) noted that many Australian acacia species have flowers producing only pollen, thus are not likely to attract honey bees, unless they are males collecting pollen, but Houston (2000) stated that, in Western Australia, Mimosaceae is the sixth most attractive family to native bees. He recorded 18 genera of bees on *Acacia* but many species are not yet identified.

Where specific wattles have been investigated, large numbers and a high diversity of invertebrates have been recorded, for example 130 species from *A. saligna* (Majer 1978), and 25 taxa and a mean of 1268 invertebrates per tree on Jam wattle (Majer *et al.* 2001). Prescott (2000) studied three endangered *Acacia* species in the wheatbelt and recorded 10-15 insect taxa on each.

Many acacias may show very high levels of defoliation, presumably by insects but, though this markedly affects growth and vigour, it does not generally kill the plant. This is noticeable in remnant vegetation, but particularly so in monospecific plantings such as alleys of *A. saligna*, and could have a severe effect on production for stock fodder. As always in revegetation, a mixed stand is likely to promote a more balanced regime.

One insect, the Bag-shelter Moth (*Ochrogaster lunifer*), can completely defoliate large wattles (van Schagen *et al.* 1992). It seems to occur more commonly along road verges than in larger patches of remnant vegetation, and this may be related to a dearth of predators such as insectivorous birds in these linear strips.

Wattle seeds often have structures, called elaiosomes, designed to encourage collection by seed predators, often ants. For example, *Acacia ligustrina* has shiny black seeds enclosed in a bright red cup-shaped structure, and it is easy to watch the procession of ants carrying seeds down the plant and across the ground to their nest. Presumably the ants eat the elaiosome and discard the seed underground, as *A. ligustrina* is one of the species that regenerates after fire in clumps from a subterranean seed store. Majer (1982) discussed this ant-plant inter-relationship in the northern Jarrah forest, finding that nine species of ant consistently collect seed.

Seed predation by insects can be quite high; the author has noted that, on 12 local wattle species in a seed orchard west of York, an average of one in five pods contains larvae, presumably of weevils (New 1983). However, one non-local plant, *A. congesta*, planted to provide seed for revegetation elsewhere, has never been observed to contain larvae. It does get heavily smothered in spider webs–could there be a relationship?

OTHER INTER-RELATIONSHIPS

Wattles are important hosts for semi-parasitic plants such as Sandalwood (*Santalum spicatum*) and Quandong (*Santalum acuminatum*) and their role in supporting mistletoes (*Amyema* and *Lysiana*) has already been mentioned. Mistletoe foliage is heavily grazed by brush-tailed possums, many birds take nectar from the flowers, and others utilise the seeds. The larvae of the wood white butterfly (*Delias aganippe*) feed exclusively on these hemiparasites.

Since wattles usually set good seed crops (at least the seeders do; resprouters, as is often the case with this regeneration strategy, consistently produce fewer seed) they are presumably being pollinated, though the pollinator has not often been identified. Brown *et al.* (1997) noted that very little is known about *Acacia* pollination, and a great deal more work must be done. This comprehensive pollination database for Western Australia lists only 21 records of pollinators on 12 identified *Acacia* species, plus 10 on *Acacia* 'sp.' Of these records, only five refer to the south-west of Western Australia!

WATTLES IN REVEGETATION AND LANDSCAPE RECONSTRUCTION

To survive, all animals require resources such as food, space and shelter. They need to escape predators and survive disease outbreaks and disasters, natural or unnatural. Finally, to reproduce they need a mate. In Australia's fragmented agricultural landscape, the quality, quantity and availability of these resources are vastly different from those in uncleared land, favouring some species of plants and animals but disadvantaging others. Introduced organisms also complicate the picture. The result is that, if we wish to conserve indigenous biodiversity, we need to look beyond a simple strategy of maintaining conservation reserves to redesigning the total landscape for the benefit of both production and conservation. The techniques to do this are known (Hussey and Wallace 1993; Lefroy *et al.* 1993) although reliable commercial options based on perennials have not yet been proven.

Conserving biodiversity in a landscape which needs to be reconstructed is hampered by lack of knowledge of both past and present organisms, especially of invertebrates and the microcomponent of soil flora and fauna. In this respect the work of Inez Tommerup and her associates in CSIRO on fungi in wheatbelt remnants (Tommerup and Boucher 1999), and of Jonathan Majer and his associates at Curtin University on insects in paddock trees and in revegetation (Majer *et al.* 2000; Majer *et al.* 2001) are filling in some obvious gaps, but there are still many interactions about which little is known.

Reconstruction ecology therefore looks at groups of species that perform similar functions and can, in a changing environment, take over from each other to carry out critical ecosystem functions. Main (1992) called this 'functional substitutability' and listed four important functions that should be maintained. They are: to fix carbon and nitrogen; to provide an architectural structure or habitat; to interact with other species so that one or several do not dominate the use of resources; and to recycle the resources so that the net loss from the system is minimised. Wattles are useful in all these areas.

As an example, consider nitrogen fixation in a wheatbelt woodland. Apart from contributions from lightning and free-living or micro-organisms of the soil crust, a large amount of nitrogen comes via the activity of micro-organisms in the root nodules of certain plants. Acacias have the ability to form nodules, so do plants in the pea family (Fabaceae) and sheoaks (Casuarinaceae). In many Western Australian woodlands a major nitrogen fixer, appearing in huge numbers after a disturbance, is one of the poison peas (*Gastrolobium* spp.). These plants contain sodium monofluoroactetate, better known as 1080. Eating this substance kills stock but, through co-evolution, many native fauna have developed tolerance to it, and seed-eating fauna such as the Bronze-wing Pigeon may rely heavily on plants that contain it. Many farmers deliberately eradicated poison plants from their property, without replacing them with a plant having a similar ability to fix nitrogen. When revegetating, there are several wattles that could be used as substitutes.

Studies of birds in feeding guilds have noted how important the structural diversity of habitat–especially understorey habitat–is for feeding, foraging, perching or shelter to maintain a wide suite of birds (e.g. Recher and Davis 1998). Creating an architectural structure in a reconstructed habitat that will favour a wide diversity of fauna requires a change in the traditional pattern of revegetation. Currently, for reasons of speed and economy, most revegetation projects use seedlings planted mechanically. This generates a series of rows of trees, or trees and large shrubs, with paddock grasses or weeds as a ground layer. This does not accurately mimic the previous diversity of habitat sufficiently to provide resources for a diverse suite of fauna. Lower shrubs (especially prickly ones) and a more natural ground layer are also required.

Almost all revegetation projects now incorporate at least one large wattle, usually *A. saligna* or *A. acuminata*. Landholders like them because they grow fast and so show that something is happening, as well as providing stock shelter or emergency stock feed. These plants have an average life expectancy in a wheatbelt situation of about 15 years, after which they tend to collapse. Their seeds remain in the soil seed bank, however, until the next fire or other disturbance, and their seeds are large enough to cope with the heavy weed infestations likely to occur on such sites.

Smaller wattles are a different matter. Revegetators are often reluctant to replant these species, precisely because they are small, and so do not provide an immediate buzz of satisfaction at having done something. They are also perceived to be short-lived and so a waste of scarce time and financial resources. Considerably more public information and extension must be done to counteract these perceptions, and explain the plants' role in overall ecology. Direct seeding can reintroduce this structural diversity, even onto difficult sites.

Take the example of the wandoo (*E. wandoo*) woodland studied by Recher and Davis (1998). This study was undertaken in a conservation reserve, but there are many similar woodland remnants in farmland, where a long history of grazing has removed all or most of the native understorey which these authors found to be so important for bird diversity. But wandoo woodland is not easy to revegetate, as the tree is strongly competitive for resources and even allelopathic. Several wattles grow well in this situation, however, and one, *A. lasiocarpa* var. *sedifolia*, the Wandoo Prickly Moses, is easy to collect seed from; direct seeds well, growing even directly under the crown of mature Wandoo; and is relatively long-lived, persisting in such a revegetated site at York for 15 years so far.

The study of birds in road verges undertaken by Newbey (2000) shows that, in linear strips, a good structural diversity and a wide variety of species–whether remnant or revegetated–are factors that make them more likely to be utilised by birds. Over the last 20 or so years, Main Roads Western Australia has demonstrated that, if fauna needs are considered at the time of planting, excellent long-term fauna habitat can be created. Many individual landholders have also demonstrated this but the fact remains that it is necessary to plan for fauna needs at the time of undertaking the project. If the revegetation consists principally of commercial species, then a landholder can incorporate the needs of fauna by creating habitat islands among the commercial plantation (Hussey 1998). The use of land to create these habitat islands should not be considered as a financial loss, but as a long-term investment leading to long-term gains. These gains, in water-table management, erosion control, shelter and, most especially, pest insect control, should not be ignored just because they are difficult to quantify (Smart 1997).

In the south-west of Western Australia, most plant communities are extremely diverse (and, on the evidence of the few detailed studies yet completed, so are the invertebrate communities that depend upon them) and the diversity can vary widely over relatively short distances. This means that, for every revegetation site a suite of wattles may be selected to fill habitat criteria for each different soil and topographic position. As an example, consider revegetation of a 2.5 ha property in the Helena Valley. Seven wattles occur naturally on this site, of which four are prolific seeders, easy to collect and easy to grow, which between them produce the structural elements of habitat for all the soil types on the property (Table 2). The larger the property and the more diverse the landscape, the wider will be the choice of wattles to include in the revegetation mix.

It is therefore suggested that all revegetation projects in the south-west of Western Australia include a minimum of five species of *Acacia* for each soil type or topographic position. They should be selected to cover as wide as possible a range of size, architecture and prickliness. Larger species could be introduced as seedlings, but in every project at least some areas should be direct-seeded with low or medium shrubs and ground covers, some of which will be wattles.

SUMMARY

It is clear that wattles provide resources for numerous animals throughout the south-west of Western Australia, and that they are a vital component of natural ecosystems. It is equally clear that that a great deal more research into the inter-relationships between wattles and fauna needs to be undertaken before we can clearly delineate the role of wattles in ecosystem functioning. Nevertheless, it can be seen that wattles can and should be included in multi-purpose revegetation projects throughout the agricultural area, to provide a multitude of benefits to both production and conservation.

Wattle I plant? Wattlever I can!

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TABLE 2
Species of *Acacia* native to a 2.5 ha property in Helena Valley, Western Australia.

A. alata	Medium upright shrub, seeder, alluvial soil or on water-gaining site among granite rocks, grows in dense shade, short-lived, regenerates by seed after fire, relatively soft 'foliage' heavily attacked by invertebrate herbivores
A. dentifera	Large shrub, regenerates by seed after fire, grows on clay derived from dolerite dykes or on alluvium, can tolerate shade, huge seed crop important for seed-eating birds and ants
A. ericifolia	Small shrub, under wandoo, lignotuberous resprouter after fire, flowers seldom and seeds never recorded on this property
A. oncinophylla	Medium to large shrub, grows among granite rocks, lignotuberous resprouter after fire, flowers sparsely, few fruit produced and these are heavily predated by red-capped parrots, no mature seed recorded on this property
A. pulchella	Small to medium shrub, prickly, grows on all rocky areas, short-lived, regenerates from seed after fire, seed crop used by fauna
A. saligna	Very large shrub, grows on alluvium and among granite, regenerates from seed after fire, short-lived, seed crop important for seed-eating birds
A. willdenowiana	Very small shrub, grows under wandoo, short lived, regenerates from seed after fire

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Flora and vegetation of Burnerbinmah Station: a study of the plant communities in the Mulga shrublands of the Murchison Region, Western Australia

SUSAN PATRICK[1]

[1]Science Division, Department of Conservation and Land Management, W A Herbarium,
Locked Bag 104, Bentley Delivery Centre, Western Australia 6983
Email: suep@calm.wa.gov.au

SUMMARY

A study was undertaken of the flora and plant communities of Burnerbinmah Station in the Murchison Region of Western Australia. The station lies at the head of the Mongers Lake drainage system, with associated calcrete valley fills and platforms, alluvial plains, sandplains, granite exposures and breakaways.

Thirty- four quadrats were used to define nine community types that were correlated with soil types and topography. A total vascular flora of 551 species was recorded from the station, of which 494 were native and 57 were introduced. *Acacia* is represented by 32 species, Mulga (*A. aneura*) being dominant in many communities. Nine taxa listed on the Department of Conservation and Land Management's priority flora list were found on the station.

INTRODUCTION

Burnerbinmah Station was purchased by the Department of Conservation and Land Management in 1995, when the pastoral lease was transferred to the Department.

The Station covers about 59 908 hectares and is situated approximately 70 km south-west of Mount Magnet and 270 km due east of Geraldton in Western Australia. It lies within in the Shire of Yalgoo between Yalgoo, Mount Magnet and Paynes Find. This is within the Murchison Region, part of the Eremaean Botanical Province (Beard 1990), and lies on the boundary between the Yalgoo and Murchison Bioregions (Thackway and Cresswell 1995). It has an arid climate of unpredictable summer and winter rainfall but is close to the eastern margin of the South-western Botanical Province (Fig. 1).

Based on figures recorded at Yalgoo (c. 70 km to the north-west), the average annual rainfall is about 250-280 mm (Beard 1976). At Burnerbinmah the mean annual rainfall between 1980 and 1994 was 251 mm. In February 1995, cyclonic storms brought heavy rain to the area and the annual rainfall for Burnerbinmah in that year was 451 mm (Brand 1999).

HISTORY

The pastoral lease was taken up in 1878, and with seven adjoining leases make the lease as it is today. About 1884 a mud brick home was built at the head of Mongers Lake and is incorporated in the present day homestead. The Station was grazed, mainly with sheep, and some cattle and horses, from the 1890s until de-stocked in 1995.

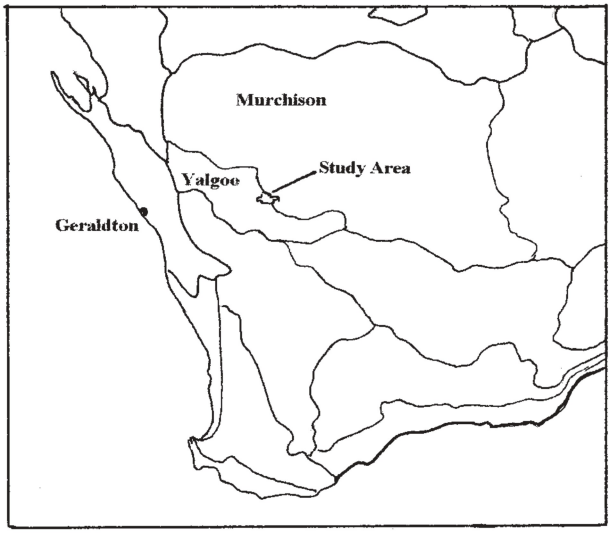


Figure 1. Location of the study area and its position within the Austin Bioregion.

A few plant collections were made by R.A.Saffrey in 1969, when some specimens were taken as vouchers for *Arid Shrubland Plants of Western Australia*, 2nd edn (Mitchell & Wilcox 1994). J.S.Beard made some collections in 1973 during fieldwork for the vegetation survey of the region (Beard 1976). A.L.Payne and A.M.E.Van Vreeswyk made further collections in 1993 during fieldwork for the inventory and condition survey of the Sandstone-Yalgoo-Paynes Find area (Payne *et al.* 1998). Voucher specimens for regeneration monitoring trials of Sandalwood (*Santalum spicatum*) have been taken by J.E.Brand since 1996, as part of ongoing work on Sandalwood at Burnerbinmah (Brand 1999; Patrick *et al.* 1997/8).

GEOLOGY

Mongers Lake runs southwards through the station, roughly bisecting it. Calcrete is deposited along the northern section of this drainage line and along another on the south-western corner of the station. Surrounding the lake are alluvial deposits of sand and clay deposited in drainage channels and on floodplains. The land rises from the lake floor at 300 m to 378 m on the eastern side and 358 m on the western side. Alluvial and colluvial deposits of transported clay, sand and lithic fragments occur mainly on the western side. Yellow sandplain is found throughout the station, with some red colluvial sand on plateau remnants. There are also smaller areas of residual deposits, sand, clay and duricrust and deposits of laterite on top of breakaways. Granitoid rocks also provide relief. There are large outcrops of adamellite to granodiorite rocks, particularly on the south-western side, and smaller outcrops of adamellite and granite throughout (Baxter *et al.* 1983).

VEGETATION AND LANDFORMS

There have been few detailed botanical studies of specific areas in the Murchison Region. Davies (1970) published a list of c. 200 taxa for Mileura Station which is situated c. 250 km north of Burnerbinmah. The terrain there is flat with some laterite breakaway scarps and granite tors. The vegetation is less diverse, mainly Mulga (*Acacia aneura*) shrubland, with some saltbush on floodplains but with no spinifex sandplains.

Eighty taxa were listed in an annotated list of the angiosperms of Lakeside Station (Kenneally 1968) which lies 120 km north of Burnerbinmah, with a similar annual rainfall. The vegetation is predominantly Mulga, with a larger range of species on breakaways.

The vegetation on Burnerbinmah Station is mainly representative of the arid zone flora but it is close to the eastern limit of the South-West Botanical Province. The vegetation of the Murchison Region is predominantly Mulga low woodland on plains, reduced to scrub on hills (Beard 1990). Low woodlands of Mulga, often rich in ephemerals, dominate the vegetation of the Murchison Bioregion, and the Yalgoo Bioregion has open woodlands and scrub of Mulga, *Callitris-Eucalyptus salubris* and bowgada (*Acacia ramulosa* var. *linophylla*) (Thackway and Cresswell 1995).

The predominance of the Mulga association through the station is reflected by a rich assemblage of *Acacia* species, at 32 taxa the largest number for any genus recorded there.

The vegetation map for the Murchison (Beard 1976) shows that the station lies across a rainfall boundary, approximately the 250 mm isohyet. Beard recorded Mulga woodland predominating on the drier eastern side and mixed *Acacia* scrub with scattered Mulga on the western side. This major division is also reflected in the area being the south-western edge of the distribution of most species of *Triodia*.

Eight land types are represented with a total of twelve component land systems (Payne *et al.* 1998) (Table 1). The upper reaches of the Mongers Lake wetland complex form a broad valley. Other landforms include breakaways, granite hills and exposures, salt lakes and calcareous plain. One gorge has permanent freshwater and there are areas of sandplain. A wide range of plant communities results from this diversity, including Mulga low woodlands in the broad valleys and, less commonly, mallee woodlands. *Acacia* shrubland occurs on shallow soils associated with granite exposures. Spinifex sandplain on the eastern side of the station is replaced by mixed spinifex and sedgelands on the red sandplains of the western side. There are freshwater and saline wetlands. Open Mulga with bluebush (*Maireana* spp) and saltbush (*Atriplex* spp) and also bluebush, saltbush and samphire (*Halosarcia*) shrublands are associated with the salt lakes.

WILDLIFE MANAGEMENT PROGRAMS FOR RARE AND POORLY KNOWN FLORA

The work was undertaken as part of a wildlife management program for rare and priority (poorly known) flora in the Department of Conservation and Land Management (CALM) Geraldton District.

The district runs inland nearly 600 km, and thirty seven Threatened Flora and 264 Priority Flora are recorded for it. Most of the Threatened Flora occur on the wetter coastal strip, and in the inland pastoral section where many species of Priority Taxa occur there were no conservation reserves until the purchase of Burnerbinmah. It was therefore important to determine which Threatened and Priority Taxa occur on Burnerbinmah and to learn more about the vegetation of the area.

In 1996 the opportunity arose to survey the flora on Burnerbinmah as part of a Landscope Expedition. These expeditions are offered by the CALM publication *Landscope*, in association with The University of Western Australia's Extension Program. They provide expedition members with an opportunity to work on CALM research projects, to promote wider co-operation in addressing conservation and land management challenges in Western Australia.

METHODS

Participants

Three Landscope Expeditions worked on the Station, in September 1996, August 1997 and October 1998 with a total of 29 participants. An expedition with the Western Australian Naturalists' Club at Easter, March 1997, also gathered information. In total, twenty two days were spent on the work.

TABLE 1
Land types and systems of the Sandstone-Yalgoo-Paynes Find Rangeland Survey (Payne *et al.* 1998), represented on Burnerbinmah Station, with quadrats established on each system.

Land Type 4.	Breakaways, stony plain and sandy surfaced plain on granite with Mulga shrubland and minor halophytic shrubland quadrats	
She –Sherwood	Breakaways, kaolinised footslopes and extensive gently sloping plains on granite	A4 A5 A6 B3 B5 C3 C4 C5
Wag –Waguin	Undulating sandy plain and stripped surface with small breakaways on laterite and granite	A1 C7
Land Type 6.	Plain with gritty surface and low tors and domes on granite with acacia shrubland	
Chl –Challenge	Gently undulating plain with occasional hills, tors and low breakaways on granite	no quadrats established
Land Type 12.	Sandplain with grassy acacia shrubland	
Kal –Kalli	Level to gently undulating plain of red sand over laterite	A3 A9 A11 B2 B10 C2 C10
Land Type 13.	Wash plain on hardpan with Mulga shrubland	
Ham –Hamilton	Plains on hardpan and granite with narrow, incised drainage lines	A12
Tin –Tindalarra	Very gently inclined wash plain with narrow saline drainage tracts	B11 C11
Wod –Woodline	Nearly level sandy surfaced plain over hardpan	A8 B7 C8
Land Type 14.	Wash plain and sandy tracts on hardpan, with Mulga and wanderrie grasses	
Yng –Yanganoo	Wash plain with concentrated drainage zones and sandy tracts	No quadrats established
Land Type 17.	Alluvial plain with saline soil and predominantly halophytic shrubland	
Ero –Ero	Tributary flood plain on hardpan	A7 B4 C6
Land Type 18.	Calcreted drainage plain with mixed halophytic and non-halophytic shrubland	
Cun –Cunyu	Calcrete platform, narrow drainage floor, and fringing wash plain	A2 B1 C1
Mil –Mileura	Calcrete platform and alluvial plain with saline soil	B6 B8
Land Type 20.	Salt lakes and fringing alluvial plain with halophytic shrubland	
Car –Carnegie	Salt lake with fringing alluvial plain, kopi dunes and sandy banks	A10 B9 C9

Quadrats and land systems

It was considered most effective to set up permanent 20 x 20 metre quadrats and to sample them according to the methods of Bushland Plant Survey (Keighery 1994). This provided a method of collecting a larger range of species than might otherwise be obtained by opportunistic collections alone, when some, particularly very small ephemeral species, might be overlooked. The method of thorough sampling also provided a record of all Priority taxa present, some of which might have been missed by opportunistic sampling. It also provided a permanent record for specific sites which could be monitored in the future when the effects of reduced grazing might become more apparent. The size of quadrats was increased from the 10 x 10 metres recommended in Bushland Plant Survey which is designed for recording in the South West Botanical Province. The larger quadrat size, 20 x 20 metres, was required to record sufficient species in the more arid conditions of the Eremaean Botanical Province where plants are more widely spaced.

Quadrats were established in three types of plant community at each site, by selecting localities where a range of plant communities was present on one land system (Fig. 2). Six land types were sampled in this way, and ten land systems.

In September 1996, 28 quadrats were established. In 1997, 25 of the 28 quadrats were resampled during summer. In August 1997, all were resampled and 6 more quadrats were established. Another opportunity to collect further data arose in October 1998, when a third Landscope Expedition combined astronomy and botany. The range of recording times from early to late spring and in summer increased the opportunity of finding a larger range of species in flower. On each visit the group worked in three teams, denoted as A, B or C. Quadrats completed by each were then numbered consecutively so that each quadrat had a unique name.

As a result 22 days were spent establishing quadrats, in resurvey and opportunistic collections. Thirty four quadrats were established over two years, 28 in 1996, and of these 25 were sampled four times and four three times. The six quadrats, which were established in 1997, were sampled twice.

As the terrain was not generally very rugged, most study locations were reached by vehicle along tracks, but two land types were not sampled by quadrat establishment, each of which has only one land system represented on the Station. Yanganoo is poorly represented, as is Challenge, which in addition is rugged and difficult to access. General botanical collection was undertaken at other localities apart from those where the quadrats were set up, and Challenge was sampled in this way, by traverse on foot.

Quadrat recording

All quadrats were set up using an optical square to ensure correct corner angles and were permanantly marked with four steel fence droppers. Position of each quadrat was recorded by using a global positional system (GPS) unit.

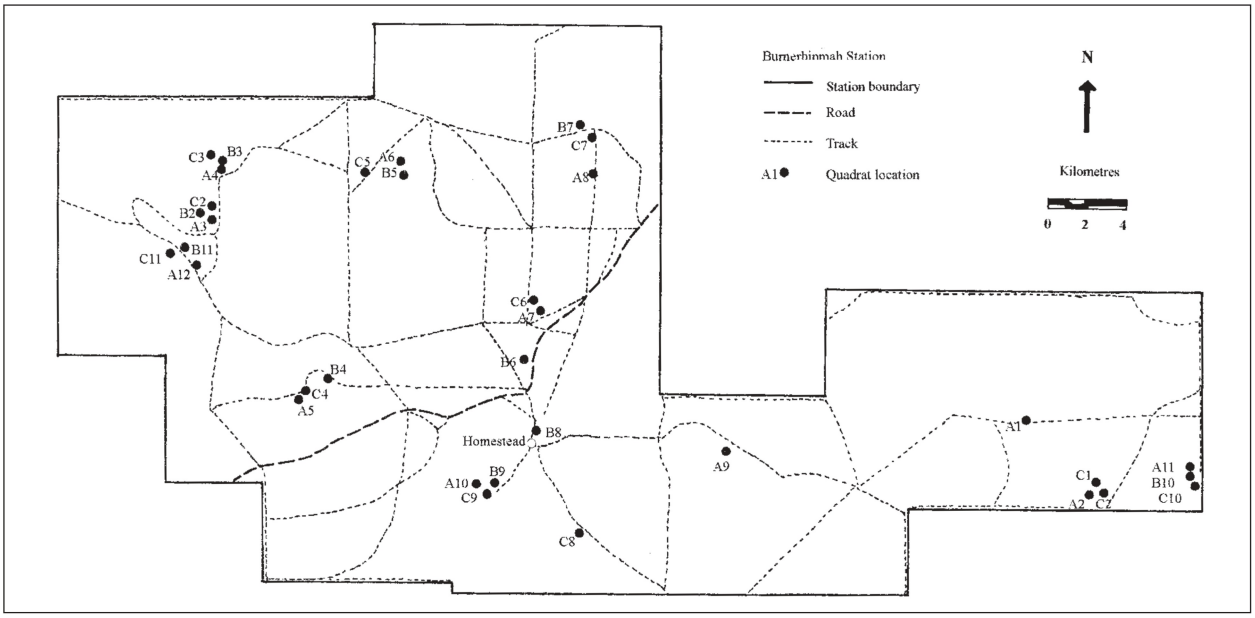


Figure 2. Study area showing location of survey sites.

Distance on ground from nearest landmark was also recorded. Photographic records were made at each visit using fixed points. During recording at each quadrat, lengths of rope were placed between the corner pegs to mark the boundaries, then removed at the conclusion of recording.

All taxa found flowering within each quadrat were collected as well as those from the surrounding area not represented within. Soil descriptions were recorded in 1998 by W.M.McArthur (unpublished), at all but two of the quadrats. Quadrat location, site data, vegetation structure (Muir 1977; Aplin 1979), cover and site condition were obtained, with a list of species for each stratum. At the end of each day specimens were pressed for later identification.

In addition, a manilla folder was used at each quadrat to fix a small piece of each species under plastic tape. After identification these specimens provide a quick reference so that on later visits only those species were collected that had not been found in flower previously.

Thirty nine further sites were sampled opportunistically.

The site and species classifications used the Czekanowski coefficient and 'unweighted pair-group mean average' fusion method (UPGMA; Sneath and Sokal 1973) using the PATN software package (Belbin 1993).

Nomenclature follows Paczkowska and Chapman (2000) and current usage at the Western Australian Herbarium (PERTH).

RESULTS

A list of taxa (species, subspecies and varieties) for the station was compiled from the specimens collected on these expeditions. With the aid of three volunteers, 612 voucher specimens were added to the collections of the Western Australian Herbarium and a reference herbarium was assembled for the station. The work also extends other monitoring programs in the region, and provides a data set for future assessment of grazing reduction on the vegetation.

Floristic analysis

A total of 551 taxa was recorded on Burnerbinmah station. The list was compiled from taxa found within and near the 34 quadrats, from opportunistic collections and from confirmed records held in PERTH. Of these 494 (89·6%) were native and 57 introduced (Appendix 1).

The largest families represented were the Asteraceae (78 native taxa, 6 introduced), Chenopodiaceae (49 native taxa, 2 introduced) and Mimosaceae (32 taxa). Several other families were represented by large numbers of taxa (Table 2). The most common genera were *Acacia* (32 taxa), *Eremophila* (25 taxa), *Maireana* (14 taxa), *Ptilotus* (13 taxa) and *Rhodanthe* (12 taxa).

TABLE 2

Largest flora families represented on Burnerbinmah.

FAMILY	NO. OFNATIVE TAXA	NO. OFINTRODUCED TAXA
Asteraceae	78	6
Chenopodiaceae	49	2
Mimosaceae	32	0
Poaceae	31	14
Myoporaceae	25	0
Myrtaceae	22	0
Brassicaceae	10	7
Papilionaceae	15	1
Amaranthaceae	15	0
Goodeniaceae	14	0
Proteaceae	13	0
Cyperaceae	12	0
Solanaceae	11	1
Malvaceae	10	1
Aizoaceae	8	2

Rare and Priority species

One of the aims of the work was to find Declared Rare and Priority taxa on the station. The decision to set up quadrats proved successful in that several very small, poorly known species listed as Priority taxa (Atkins 2001) were collected in the quadrats, and these may well have been overlooked had collecting been limited to opportunistic searches.

Nine priority taxa were found on the station (Table 3). For all except *Dicrastylis linearifolia* these were the first records on conservation lands. Those for *Dicrastylis linearifolia*, *Myriocephalus nudus* and *Goodenia neogoodenia* were south of their previously recorded ranges, whilst that of *Hyalosperma stoveae* extended its known range to the west, that of *Lepidium merrallii* to the north and that of *Myriocephalus nudus* to the south. *Gunniopsis rubra* was added to the Priority list in 1997 as Priority 1, after its discovery on the Station brought to attention its poorly known status. *Hyalosperma stoveae* was listed as Priority 1 in 1996, its discovery on Burnerbinmah was the fifth collection for the species, and the second in Western Australia. *Lepidium merrallii* was also listed as Priority 1 in 1996, the collection on Burnerbinmah station being the fifth collection for the species, and the first in the Geraldton District. *Phlegmatospermum drummondii* was gazetted as Rare when discovered here in 1997, but this discovery and a collection from north of Kalbarri in 1995 showed that this small, annual species was much more widespread than originally thought and it is now listed as Priority 3. *Goodenia pusilliflora* was listed as Priority 1 in 1996, but several recent collections, including five populations found on Burnerbinmah have resulted in its removal from the Priority List.

TABLE 3
Priority Flora found during the survey indicating the number of populations located.

TAXON	PRIORITY LISTING	NO. OF POPULATIONS	QUADRATS
Cryptandra imbricata	3	4	B7, B10, C10
Dicrastylis linearifolia	3	1	-
Euryomyrtus patrickiae	3	1	A3, C2
Goodenia neogoodenia	4	4	A7
Gunniopsis rubra	3	3	A1, B5, C5
Hyalosperma stoveae	*2*	*1*	B2, C8
Lepidium merrallii	2	1	-
Myriocephalus nudus	1	1	B4
Phlegmatospermum drummondii	3	1	A11

Biogeographical plant occurrences of significance

The location of the station close to the boundary of the Eremaean and South-west Botanical Provinces is reflected in the large number of taxa which are represented on the station at or near the limit of their ranges in Western Australia (Appendix 1).

Forty eight taxa were found at or near the south-western limit of their known range and 11 taxa were found on the station as a south-western extension of their known range. Similarly, the records of 51 taxa were at or near the north-eastern limit of their range and those of 16 taxa were an extension of their range to the north-east. Nine taxa were at the northern limit of their range and six taxa were a northern extension of their range, whilst 20 taxa were at the southern limit of their range and six taxa were southerly extensions of their range. Only four taxa were at the easterly limit of their range, but 17 taxa were at the westerly limit of their range and three taxa were westerly extensions of their range. Records of three taxa were at the north-western limit of their range and those of five were an extension of their range to the north-west. However, the record of only one taxon was a range extension to the south-east. This was of *Paracaleana lyonsii* ms, previously known only from an area some 300 km to the north-west of Burnerbinmah, in the southern Carnarvon Basin.

The lack of previous botanical collections in the area is reflected by the large number of range extensions recorded, for 48 taxa, of which 10 are introduced taxa.

Introduced species

Fifty six taxa of introduced plants were recorded on the station. Previous lack of collections of introduced taxa in this area is indicated by the large proportion which were found to be range extensions, 11 (23%) of the 48 range extensions, whereas of the total list recorded, only 10.3% were introduced taxa.

Eighteen of the 74 families included introduced taxa. Most of these were grasses, 14 of the 45 taxa of Poaceae being introduced. All nine taxa of Caryophyllaceae on Burnerbinmah were introduced. Asteraceae had the highest number of taxa recorded, 84, of which only 6 were introduced. Similarly, Brassicaceae was represented by 17 taxa of which 7 were introduced.

Of these introduced taxa, 15 were recorded only once. Several of these occurred here as extensions to the north west of their known ranges: *Micropterum papulosum*, *Brassica rapa*, *Hornungia procumbens*, *Raphanus raphanistrum*, *Silene nocturna*, *Spergula arvensis*, *Spergula pentandra*, *Chenopodium album*, *Plantago coronopus* subsp. *commutata* and *Zaluzianska divaricata*.

Twenty taxa were at or near the north-eastern limit of their known ranges. *Spergularia media* had not previously been recorded in Western Australia, *Elytrigia repens* was recorded for the second time, whilst *Alopecurus pratensis* and *A. geniculatus* had both been recorded only twice previously in W.A. *Spergularia salina* had been recorded previously only once in the Eremaean Botanical Region.

The introduced annual grass *Pentaschistis airoides* occurred most frequently, and was recorded in 22 of the 34 quadrats. *Cuscuta epithymum*, a parasitic twining annual, occurred in 21 quadrats, another annual grass, *Rostraria pumila*, in 15 and a rosetted annual or perennial, *Hypochaeris glabra*, in 14.

Pentaschistis airoides is a common, widespread weed particularly on granite rocks, in woodlands, shrublands and on disturbed sites in the south west of the state, from Carnarvon to Kalgoorlie and Balladonia. Burnerbinmah is on the north-western edge of its known range. *Cuscuta epithymum* occurs from north of Kalbarri to Busselton with a few scattered records further inland. *Rostraria pumila* is a common weed of grazed semi-arid woodlands and shrublands from Shark Bay to Eucla. *Hypochaeris glabra* is a common weed of roadsides, agricultural areas and bushland throughout the South-West (Hussey et al. 1997) (Florabase, Western Australian Herbarium (1998).

Frequency of introduced species was lowest on sandy soils, none being recorded in quadrats B2 and C2, in the sedgeland of *Chrystrix distigmatosa* with *Triodia tomentosa* on yellowish red or reddish brown sand, on the western side of the station. A third quadrat in this sedgeland, A3, on brown sand, had 2% of introduced species. Two quadrats on a sand dune at the eastern end of the station, C10 and B10, on yellowish red fine sand, also had 2%, which was a similar level at B7 in Mulga shrubland on yellowish red sandy loam. A11 in the same area as C10 and B 10 had a higher level of weeds, 7%.

Quadrats in Mulga shrubland generally had lower levels of introduced species as did those around and on granite outcrops. Particularly high levels were recorded in all wet areas and above 20 % in a wash area by a claypan at Corrialgo Pool, in the bottom of the gorge and reaching 30% at A12 on a creekline.

Vegetation

In the 34 quadrats established on Burnerbinmah Station, 460 taxa were recorded. For the floristic analysis, species occurring in only one quadrat were excluded. As a result the final data set consisted of 295 taxa in 34 sites, of which 132 were perennials. Species richness ranged from 35 to 79 taxa per site, with individual taxa occurring in two to 27 of the 34 sites. The high numbers of taxa recorded are a reflection of the repeated sampling of the quadrats during the spring months, August to October, when the highest numbers of annual species were present. The two-way table (Appendix 2) shows these taxa as 17 groups, A-Q. Taxa in species group L include a high number of annuals and grasses and this group is well represented in most of the community types for this reason.

The dendrogram shows the five major community types recognised in the analysis (Fig. 3) which also shows further subdivision to nine community types.

Community type 1 occurs on the shallow soils of c. pH 6 on rocky areas, breakaways and granite outcrops. Taxa in species group L are typical of community type 1, including *Acacia tetragonophylla*, *Ptilotus obovatus*, *P. gaudichaudii* and a wide range of annual herbs and grasses, including *Brachyscome ciliaris*, *B. ciliocarpa*, *Rhodanthe maryonii*, *Helipterum craspedioides*, *Velleia rosea*, *Pogonolepis muelleriana*, *Crassula colorata*, *Erodium cygnorum*, *Pentaschistis airoides* and *Calandrinia eremaea*. This community occurs largely on land type 4, primarily on the Sherwood land system, with one quadrat A4 at the base of a breakaway, on Waguin.

Community 1a was confined mainly to shallow soils of brown clay loam, sandy clay loam or light brown clay on weathered laterite and weathered granite surfaces. It was less species-rich than 1b, with an average of 49 species per quadrat, but also contained species from group N, including *Acacia aneura*, *A. ayersiana*, *Maireana georgei*, *M. glomerifolia*, *Micromyrtus sulphurea*, *Mirbelia rhagodioides*, *Philotheca brucei*, *Micropterum papulosum*, *Gunniopsis rubra* and *Levenhookia leptantha*.

Community 1b contained an average of 57 species per quadrat and occurs mainly on large granite outcrops on gritty, loamy sands of reddish brown or yellowish red over granite. Taxa in species groups I and J are typical of community 1b, these include: *Acacia acuminata*, *A. burkittii*, *A. quadrimarginea*, *Dodonaea inaequifolia*, *Malleostemon tuberculatus*, *Borya sphaerocephala*, *Goodenia berardiana*, *Tricoryne elatior*, *Caladenia incensa*, *Pterostylis* sp. inland, *Prasophyllum gracile* and *Drosera macrantha* ssp. *eremaea*.

Two quadrats which fall into this community type are atypical. They occurred on flat Mulga plain, with red sandy loam soil over hard pan. However, both had a similar number of species per quadrat, higher than other Mulga sites on the station, and were characterised by a species-rich understorey. C11 on shallow soil of 35 cm depth had 49 taxa, in tall shrubland with a rich representation of grasses and annual herbs. C8 on deeper soil had 56 taxa and had an open cover of shrubs over 1m, with a species rich understorey of shrubs under 1m tall, and of annual herbs and grasses. *Acacia aneura*, *Senna artemisioides* subsp. *filifolia*, *Maireana thesioides*, *Sida atrovirens* and *Monachather paradoxus* were species more typical of the community in these quadrats than in others of type 1 community. These two sites are on the western side of the station, which experiences a higher rainfall than the eastern side where the other Mulga sites were sampled and, presumably for this reason, have a more species-rich understorey.

Community type 2 is confined to Mulga shrubland on flat red, reddish brown, yellowish red sandy loams over hardpan with a pH of 6-6.5. The term 'Mulga' is used here to include not only *Acacia aneura* but other species in the complex, *A. ayersiana* and *A. minyura* (Pedley 2001).

The average species richness in community type 2 was 44 taxa per site. Taxa in species groups L, M and N are characteristic of this community type, including *Acacia aneura*, *A. ayersiana, A. minyura*, *A. ramulosa*, *Eremophila glandulifera* ms, *Ptilotus obovatus*, *Pentaschistis airoides*, *Monachather paradoxus*, *Rhodanthe maryoni*, *Brachyscome ciliocarpa*, *Waitzia acuminata*, *Goodenia occidentalis*, *Calandrinia eremaea* and *Crassula colorata*.

Quadrat A9 is an atypicial site within type 2 including species group P, dominated by *Callitris glaucophylla* and *A. minyura* and including *Acacia exocarpoides*, *Santalum spicatum*, *Scaevola spinescens*, *Olearia pimeleoides*,

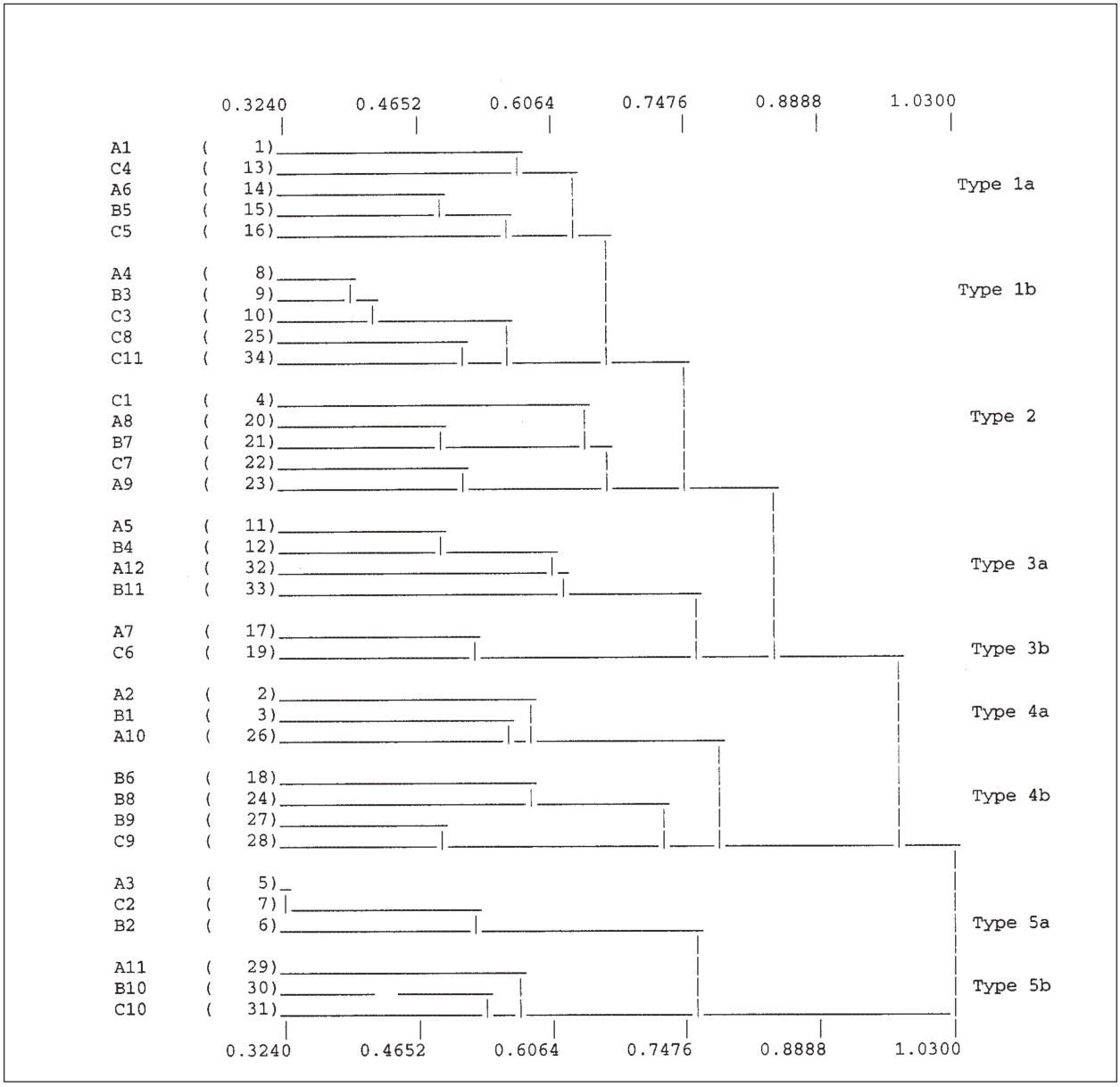


Figure 3. Dendrogram of the sites on Burnerbinmah Station showing the nine group level classification.

Enchylaena tomentosa, *Sclerolaena densiflora*, *Chenopodium gaudichaudianum*, *Maireana suaedifolia*, *Tetragonia cristata*, *Thysanotus manglesianus*, *Goodenia pusilliflora*, *Angianthus tomentosus*, *Gnephosis tenuissima* and *Plantago drummondii* which are not found in community type 2 apart from within this site. It is similar to other sites of this community in the good representation of species group M. It was more species rich, with 50 taxa, the other sites having a mean of 42.5 taxa. The soil was more acidic, a clayey fine sand, of pH 5.5.

Community type 3 occurs on wet areas and has a mean of 62 taxa per quadrat. It includes two subgroups, communities of wet drainage lines and of claypans. High numbers of introduced taxa are present in this community: *Sonchus oleraceus*, *Emex australis*, *Anagallis arvensis*, *Erodium cicutarium*, *Hordeum glaucum*, *Centaurea melitensis*, *Silene gallica*, *Pentaschistis airoides*, *Cuscuta epithymum* and *Hypochaeris glabra* being represented in both subcommunities. Some introduced taxa were found only in the communities of drainage lines, *Polycarpon tetraphyllum*, *Avena fatua* and *Osteospermum clandestinum*. Others, including *Acetosa vesicaria*, *Sisymbrium erysimoides* and *Spergularia rubra*, were found mainly around claypans.

Community type 3 species as a whole is characterised by shrubland with *Acacia tetragonophylla*, *Exocarpos aphyllus*, *Dodonaea viscosa* and *Pittosporum phylliraeoides* over *Ptilotus obovatus*, and a number of annual species found in species group L, *Rhodanthe maryonii*, *Brachyscome ciliocarpa*, *Crassula colorata*, *Calotis multicaulis*, *Helipterum craspedioides*, *Velleia rosea*, *Calotis hispidula*, *Cephalipterum drummondii*.

Community type 3a occurs on drainage lines on brown gritty sand, of pH 6.5 where recorded. It includes species groups B, I and L, including *Solanum lasiophyllum*, *Atriplex semilunaris*, *Cyperus gymnocaulos*, *Eriachne pulchella*, *Wahlenbergia gracilenta*, *Nicotiana occidentalis* subsp. *hesperis*, *Calandrinia ptychosperma*, *Haloragis trigonocarpa* and *Trachymene ornata*.

Community type 3b around claypans on reddish brown sandy loam over clay of pH 9 includes taxa in species group C, D and F. The community has open shrubland with *Acacia victoriae*, *A. tysonii*, *Exocarpos aphyllus*, *Melaleuca uncinata*, *Scaevola spinescens*, *Senna artemisioides* subsp. *filifolia*, *Rhagodia eremaea*, *Solanum orbiculatum*, *Pimelea microcephala*, *Maireana pyramidata*, *Atriplex amnicola*, *Eremophila maculata*, *Bergia perennis* subsp. *exigua*, *Marsilea drummondii* and many annuals, *Spergularia rubra*, *Plagiobothrys plurisepalus*, *Brachyscome lineariloba*, *Agrostis avenacea*, *Peplidium* sp. C, *Ranunculus pentandrus*, *Rhodanthe propinqua*, *R. stricta* and *Schoenia cassiniana*.

Community type 4 occurs on yellowish red sandy or clayey loams with a high pH of 8.5-9.5, sometimes associated with calcrete or gypsum. The vegetation is generally more salt tolerant than that of community 3 and is associated with the main drainage channels of Mongers Lake. The sites had a mean of 44 taxa. It separates into two groups: type 4a on low rises around lakes and type 4b on the flats of drainage zones.

Community type 4a has a very open shrub storey with a rich assemblage of annual herbs and grasses. Species groups A, E, F and L were well represented in this community. Perennial species include *Eremophila pantonii*, *Eriochiton sclerolaenoides*, *Zygophyllum fruticulosum*, *Enchylaena tomentosa*, *Senna artemisioides* subsp. *filifolia*, *Ptilotus divaricatus*, *Sclerolaena densiflora*, *Abutilon malvifolium* and *Ptilotus obovatus*. Annual species include *Ptilotus exaltatus*, *Bromus arenarius*, *Brachyscome ciliaris*, *Goodenia mimuloides*, *Erodium cygnorum*, *Cephalipterum drummondii*, *Angianthus tomentosus* and *Euphorbia drummondii*.

In community type 4b *Acacia victoriae*, *A. tysonii*, *Maireana trichoptera*, *Zygophyllum compressum*, *Z. auranticum*, *Frankenia fecunda*, *Solanum orbiculatum*, *Rhagodia preissii*, *Didymanthus roei*, *Halosarcia halocnemoides*, *H. indica* subsp. *bidens*, *H.pterygosperma* subsp. *denticulata* and *Sclerostegia tenuis* were more typical of the perennial species, including species of group Q.

Community type 5 occurs on sand plains and dunes and had a mean of 39 taxa per quadrat. Perennial species of this community type include *Acacia ramulosa*, *A. jamesiana*, *Micromyrtus flaviflora*, *Aluta aspera*, *Amphipogon caricinus*, *Stylidium induratum*, *Brunonia australis* and *Thysanotus manglesianus*. Common annual species include *Erodium cygnorum*, *Goodenia occidentalis*, *Lawrencella davenportii*, *Velleia hispida*, *Bellida graminea* and *Gnephosis tenuissima*. The community divides into two subgroups. Type 5a, on the western side of the station grows on gentle sloping areas, of loose brown, reddish brown or yellowish red sand over clayey sand over hard pan with pH 5.5. Species in group O largely define this type. It has perennial species including *Acacia coolgardiensis* subsp. *coolgardiensis*, over *Anthotroche pannosa*, *Euryomyrtus patrickiae*, *Keraudrenia integrifolia*, *Euryomyrtus maidenii*, *Chrysitrix distigmatosa*, *Triodia tomentosa* and *Thysanotus rectantherus*.

Type 5b occurs on the eastern side of the station, on reddish brown to yellowish red fine sand over hardpan with ph 5.5-7. In this area the sand forms dunes. Perennial species of this community are mainly in species group P. Typical species include *Eucalyptus hypochlamydia*, *Callitris glaucophylla*, *Acacia ligulata*, *Bossiaea walkeri*, *Cryptandra imbricata*, *Rhagodia preissii*, *Triodia rigidissima*, *Ptilotus obovatus* and *Solanum lasiophyllum*.

DISCUSSION

Acacia species occurred in 10 of the 17 species groups. They occurred most frequently on the shallow soils of granites and breakaways and in Mulga shrubland on sandplains and dunes. They also occurred less frequently on drainage lines and claypans, but were less frequent or absent on saline soils.

The current list of 551 taxa recorded for the station has improved knowledge of the Yalgoo and Murchison Bioregions. Asteraceae, Chenopodiaceae and Mimosaceae were the largest families represented and *Acacia* was the most common genus. This reflects the predominance of Mulga and mixed *Acacia* shrubland across the station, with halophytic shrubland on saline soils.

The results of the work on priority taxa shows the lack of previous botanical survey in the area. None had been found before on the station. Six of the nine taxa found are small annual species. Two of these were found at more than one locality on the station and they are all relatively widespread in their distribution, but poorly collected. The three shrub species are also relatively widespread in distribution and one was found at more than one locality on the station. Three of the species found were downgraded in their priority status as a result of the work, which has also resulted in removal of a tenth, *Goodenia pusilliflora*, from the Priority list.

The high number of records of biogeographical significance indicates not only the position of the station near the boundary of the Eremaean and South-West Botanical Provinces, but also the lack of previous plant collections in this area, of both native and introduced species.

The number of weeds recorded for the area was higher at 10.3% of the total list than that of 4.1% found during flora and vegetation studies of the southern Carnarvon Basin (Keighery *et al.* 2000). However, the same families–Poaceae, Caryophyllaceae, Brassicaceae and Asteraceae–had the highest number of weed species and, similarly, the highest levels were found in wet areas along creek lines and around claypans.

The community groups of the study area correlate well with substrate and topographical positions. Briefly, community type 1 occurred on shallow soils of rocky areas, large granite exposures and breakaways and was species-rich.

Community type 2 was less species-rich, occurring on sandy loams over hardpan in Mulga shrubland. Two of the quadrats in Mulga shrubland were more species rich, occurring on the wetter western side of the station and were more closely allied with community type 1.

Community types 3 and 4 both occurred in damp areas. Type 3 included freshwater creekline and claypan communities and was very species-rich, whilst type 4 had fewer species and included claypan communities and sites around Mongers Lake on more saline soils.

Community type 5 occurred on red/brown sands, and was the least species-rich. *Triodia* species are part of the community, which occurs both on the eastern and western sides of the station, but this separation results in two sub communities.

Thorough sampling within quadrats provided information on many small, poorly collected plants which might have been overlooked during general collecting. This method of sampling also increased the number of Priority taxa that were found during the survey, as six of the nine species were small and may not otherwise have been found.

The four visits at different seasons produced significant numbers of new records, with plants in flower at each visit which had not been identified previously.

A comparison of the five major community groups identified in the study, with the land types and component land systems defined by Payne *et al.* (1998) is shown in Table 4. The quadrats covered six of the eight land types represented on the station and ten of the twelve component land systems. The five major community types were represented by between one and four of the six land types. Community types four and five gave best correlation with the ten land systems. This classification also describes fifty major habitat types split into ten habitat groups. The other three community types showed better correlation on comparison with the ten habitat groups and component thirty four major habitat types represented on the station.

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The former lessees, Don and Rhonda Anderson, living at the homestead as manager/caretakers, provided much advice from their extensive knowledge of the area.

TABLE 4
Comparison of the five major community types identified in the study with the land types and component land systems defined by Payne *et al.* (1998).

LAND TYPE/ LAND SYSTEM	SITE GROUPS				
	1	2	3	4	5
Mulga shrublands and halophytic shrublands on breakaways, stony and sandy surfaced plains on granite					
Sherwood	7		1		
Waguin	1	1			
Grassy Acacia shrublands on sandplains					
Kalli		1			6
Mulga shrublands on wash plains on hardpan					
Hamilton			1		
Tindalarra	1		1		
Woodline	1	2			
Halophytic shrublands on alluvial plains with saline soils					
Ero			3		
Mixed halophytic and non-halophytic shrublands on calcreted drainage plains					
Cunyu		1		2	
Mileura				2	
Halophytic shrublands around saltlakes and fringing alluvial plains					
Carnegie				3	

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APPENDIX 1

Flora list for Burnerbinmah Station

This list includes all taxa from the sampling quadrats, the opportunistic collections and unconfirmed records from the Western Australian Herbarium (PERTH). Nomenclature follows Paczkowska and Chapman (2000) and current usage at PERTH.

(ms denotes a manuscript name, * indicates an introduced taxon).

Family: Adiantaceae	
Cheilanthes adiantoides	poorly collected, 2nd record for W.A.
Cheilanthes austrotenuifolia	
Cheilanthes lasiophylla	
Cheilanthes sieberi subsp. *sieberi*	
Family: Aizoaceae	
Gunniopsis quadrifida	
Gunniopsis rodwayi	
Gunniopsis rubra	Priority 3 species, north-eastern limit of range
Gunniopsis septifraga	
**Mesembryanthemum nodiflorum*	northern limit of main range
**Micropterum papulosum*	northern extension of range
Tetragonia cristata	southern limit of range
Tetragonia eremaea	western range extension
Tetragonia moorei	poorly collected, western range extension
Tetragonia tetragonioides	north-western range extension
Family: Amaranthaceae	
Alternanthera nodiflora	
Gomphrena sp. 'Belele' (D.W.Goodall 3215)	poorly collected
Ptilotus chamaecladus	south-western limit of main range
Ptilotus divaricatus	
Ptilotus drummondii	
Ptilotus exaltatus	
Ptilotus exaltatus var. *villosus*	
Ptilotus gaudichaudii	
Ptilotus gomphrenoides	southern extension of range
Ptilotus grandiflorus var. *grandiflorus*	
Ptilotus macrocephalus	near southern limit of range
Ptilotus obovatus	
Ptilotus polystachyus	south-western extension of range
Ptilotus schwartzii	
Ptilotus sp. S.Patrick 2787	undescribed species
Family: Anthericaceae	
Arthropodium curvipes	north-eastern range extension
Arthropodium dyeri	
Dichopogon capillipes	north-eastern limit of range
Laxmannia arida	western limit of range
Thysanotus manglesianus	
Thysanotus pyramidalis	
Thysanotus rectantherus	north-eastern limit of range
Tricoryne elatior	north-eastern range extension
Family: Apiaceae	
Daucus glochidiatus	
Hydrocotyle pilifera var. *glabrata*	near northern limit of range
Trachymene ceratocarpa	
Trachymene cyanopetala	
Trachymene ornata	
Trachymene pilosa	north-eastern limit of range
Family: Asclepidaceae	
Marsdenia australis	south-western limit of range
Rhyncharrhena linearis	
Family: Asphodelaceae	
Bulbine semibarbata	
Family: Asteraceae	
Actinobole uliginosum	
Angianthus tomentosus	
**Arctotheca calendula*	north-eastern limit of range
Asteridea athrixioides	
Bellida graminea	
Brachyscome cheilocarpa	
Brachyscome ciliaris	
Brachyscome ciliocarpa	
Brachyscome lineariloba	
Brachyscome perpusilla	
Brachyscome pusilla	northern limit of range
Calocephalus ?knappii	southern limit of range
Calocephalus multiflorus	
Calotis hispidula	
Calotis multicaulis	
**Centaurea melitensis*	
Cephalipterum drummondii	
Ceratogyne obionoides	
Chthonocephalus pseudevax	
**Cotula bipinnata*	north-eastern limit of range
Cotula cotuloides	near north-eastern limit of range
Cratystylis subspinescens	
Dielitzia tysonii	
Erymophyllum ramosum	
Gilberta tenuifolia	
Gilruthia osbornei	
Gnephosis angianthoides	near north-eastern limit of range
Gnephosis arachnoidea	near southern limit of range
Gnephosis brevifolia	
Gnephosis tenuissima	
Helipterum craspedioides	near south-western limit of range
Hyalochlamys globifera	north-eastern limit of range
Hyalosperma glutinosum subsp. *venustum*	
Hyalosperma glutinosum subsp. *glutinosum*	north-eastern limit of main range

APPENDIX 1 (continued)

Hyalosperma stoveae	Priority 2 species, 5th collection, 2nd in W.A.
**Hypochaeris glabra*	near north-eastern limit of range
Isoetopsis graminifolia	near western limit of range
Kippistia suaedifolia	western limit of range
Lawrencella davenportii	
Lawrencella rosea	
Lemooria burkittii	near south-western limit of range
Millotia myosotidifolia	
Millotia perpusilla	
Minuria cunninghamii	
Myriocephalus guerinae	
Myriocephalus nudus	Priority 1 species, 5th collection.
Myriocephalus oldfieldii ms	
Myriocephalus pygmaeus	
Myriocephalus rudallii	near south-western limit of range
Olearia pimeleoides	
**Osteospermum clandestinum*	near north-eastern limit of range
Pluchea dentex	southern limit of main range
Podolepis canescens	
Podolepis capillaris	
Podolepis kendallii	
Podolepis lessonii	
Podotheca gnaphalioides	
Pogonolepis muelleriana	
Pogonolepis stricta	
Quinqueremulus linearis	near southern limit of range
Rhodanthe battii	
Rhodanthe chlorocephala subsp. *splendida*	
Rhodanthe citrina	
Rhodanthe haigii	near western limit of range
Rhodanthe heterantha	northern extension of range
Rhodanthe humboldtiana	near southern limit of range
Rhodanthe laevis	
Rhodanthe maryonii	
Rhodanthe polycephala	near north-eastern limit of range
Rhodanthe propinqua	near south-western limit of range
Rhodanthe pygmaea	
Rhodanthe stricta	
Schoenia cassiniana	
Senecio glossanthus	
Siloxerus multiflorus	near north-eastern limit of range
* *Sonchus oleraceus*	
Sondottia connata	
Streptoglossa cylindriceps	south-western limit of range
Tietkensia corrickiae	south-western extension of range
Trichanthodium exile	
Trichanthodium skirrophorum	
Triptilodiscus pygmaeus	near western limit of range
Waitzia acuminata	
Waitzia nitida	
Family: Boraginaceae	
Omphalolappula concava	
Plagiobothrys plurisepalus	2nd collection in WA Herbarium
Family: Boryaceae	
Borya sphaerocephala	north-eastern limit of range
Family: Brassicaceae	
**Brassica rapa*	near north-eastern limit of range
**Brassica tournefortii*	
Harmsiodoxa brevipes	poorly collected, north-eastern limit of range
**Hornungia procumbens*	north-eastern extension of range
Lepidium merrallii	Priority 2 species, 3rd collection in W.A., north-eastern extension of range
Lepidium muelleri-ferdinandii	near south-western limit of range
Lepidium oxytrichum	near south-western limit of range
Lepidium phlebopetalum	
Menkea australis	
Phlegmatospermum drummondii	Priority 3 species, 6th collection, north-eastern limit of range
**Raphanus raphanistrum*	north-eastern extension of range
**Sisymbrium erysimoides*	
**Sisymbrium irio*	
**Sisymbrium orientale*	
Stenopetalum anfractum	near south-western limit of range
Stenopetalum filifolium	
Stenopetalum lineare	near western limit of range
Family: Caesalpiniaceae	
Senna artemisioides subsp. *filifolia*	
Senna artemisioides subsp. *petiolaris*	
Senna sp. 'Austin' (A.Strid 20210)	
Family: Campanulaceae	
Wahlenbergia communis	
Wahlenbergia gracilenta	
Wahlenbergia preissii	north-eastern limit of range
Wahlenbergia tumidifructa	
Family: Caryophyllaceae	
**Polycarpon tetraphyllum*	near north-eastern limit of range
**Silene gallica* var. *gallica*	near north-eastern limit of range
**Silene nocturna*	north-eastern extension of range
**Spergula arvensis*	north-eastern extension of range
**Spergula pentandra*	north-eastern extension of range
**Spergularia diandra*	
**Spergularia media*	1st record for W.A.
**Spergularia rubra*	
**Spergularia salina*	2nd record for Eremaean Botanical Province, otherwise limited to south-west
Family: Casuarinaceae	
Casuarina obesa	
Family: Centrolepidaceae	
Centrolepis eremica	
Centrolepis polygyna	north-eastern extension of range

APPENDIX 1 (continued)

Family: Chenopodiaceae	
Atriplex amnicola	
Atriplex bunburyana	
Atriplex codonocarpa	
Atriplex holocarpa	
Atriplex semilunaris	
Atriplex vesicaria	
**Chenopodium album*	northern extension of range
Chenopodium curvispicatum	south-western limit of range
Chenopodium gaudichaudianum	near southern limit of range
Chenopodium melanocarpum	
**Chenopodium murale*	
Chenopodium saxatile	south-western extension of range
Didymanthus roei	
Dysphania glandulosa	south-western extension of range
Einadia nutans	south-western extension of range
Enchylaena lanata	north-eastern limit of range
Enchylaena tomentosa	
Eriochiton sclerolaenoides	
Halosarcia fimbriata	
Halosarcia halocnemoides	undescribed subspecies
Halosarcia indica subsp. *bidens*	
Halosarcia pterygosperma	
Halosarcia pterygosperma subsp. *denticulata*	southern extension of range from Shark Bay
Halosarcia syncarpa	north-eastern limit of range
Maireana amoena	
Maireana carnosa	
Maireana convexa	near south-western limit of range
Maireana diffusa	northern extension of range
Maireana georgei	south-western limit of main range
Maireana glomerifolia	
Maireana planifolia	
Maireana planifolia × villosa	
Maireana pyramidata	
Maireana suaedifolia	western limit of range
Maireana thesioides	
Maireana trichoptera	
Maireana triptera	
Maireana villosa	near southern limit of range
Rhagodia drummondii	
Rhagodia eremaea	south-western limit of range
Rhagodia preissii subsp. *preissii*	
Salsola tragus	
Sclerolaena burbidgeae	
Sclerolaena densiflora	near south-western limit of range
Sclerolaena diacantha	
Sclerolaena eriacantha	south-western range extension
Sclerolaena eurotioides	
Sclerolaena gardneri	
Sclerolaena lanicuspis	near southern limit of range
Sclerolaena uniflora	
Sclerostegia moniliformis	north-western extension of range
Sclerostegia tenuis	poorly collected, north-western extension of range

Family: Chloanthaceae	
Dicrastylis linearifolia	Priority 3 species, southern extension of range
Spartothamnella teucriiflora	south-western extension of range
Family: Colchicaceae	
Wurmbea ?densiflora	
Family: Convolvulaceae	
Convolvulus erubescens	
Convolvulus remotus	
Porana ?sericea	
Family: Crassulaceae	
Crassula colorata	
Crassula colorata var. *acuminata*	
Crassula exserta	northern limit of range
Family: Cupressaceae	
Callitris glaucophylla	
Family: Cuscutaceae	
**Cuscuta epithymum*	
Family: Cyperaceae	
Chrysitrix distigmatosa	north-eastern limit of range
Cyperus alterniflorus	
Cyperus gymnocaulos	
Cyperus rigidellus	near southern limit of range
Cyperus squarrosus	south-western limit of range
Cyperus vaginatus	
Isolepis congrua	
Lepidosperma sp.	
Schoenus humilis	
Schoenus nanus	north-eastern limit of range
Schoenus subaphyllus	
Schoenus variicellae	
Family: Droseraceae	
Drosera bulbosa subsp. *major*	poorly recorded, 3rd record for W.A.
Drosera indica	south-western range extension
Drosera macrantha subsp. *eremaea*	poorly recorded
Family: Elatinaceae	
Bergia perennis subsp. *exigua*	southern limit of range
Family: Epacridaceae	
Leucopogon sp. 'Clyde Hill' (M.A.Burgman 1207)	north western limit of range
Family: Euphorbiaceae	
Euphorbia drummondii	
Euphorbia ?tannensis subsp. *eremophila*	near south-western limit of range
Pseudanthus intricatus ms	
Stachystemon sp.	
Family: Frankeniaceae	
Frankenia fecunda	
Frankenia ?glomerata	Priority 1 species, bridges range between north and south-west
Frankenia interioris var. *parviflora*	north-western extension of range

APPENDIX 1 (continued)

Frankenia laxiflora	
Frankenia pauciflora	
Frankenia sessilis	near western limit of range
Frankenia setosa	
Family: Gentianaceae	
Centaurium clementii	southern extension of range
Family: Geraniaceae	
**Erodium aureum*	
**Erodium cicutarium*	near north-eastern limit of range
Erodium cygnorum	
Family: Goodeniaceae	
Brunonia australis	
Dampiera roycei	western limit of range
Goodenia berardiana	
Goodenia havilandii	
Goodenia mimuloides	
Goodenia neogoodenia	Priority 4 species, southern extension of range
Goodenia occidentalis	
Goodenia pinnatifida	
Goodenia pusilliflora	northern limit of range
Scaevola chrysopogon × *restiacea*	
Scaevola spinescens	
Velleia glabrata	south-western limit of range
Velleia hispida	south-western limit of range
Velleia rosea	
Family: Gyrostemonaceae	
Gyrostemon ramulosus	
Family: Haloragaceae	
Gonocarpus nodulosus	
Haloragis odontocarpa	near south-western limit of range
Haloragis trigonocarpa	near south-western limit of range
Myriophyllum decussatum	near southern limit of range
Family: Hydrocharitaceae	
Ottelia ovalifolia	northern and inland extension of range
Family: Hypoxidaceae	
Hypoxis glabella	north-eastern extension of range
Family: Juncaceae	
**Juncus bufonius*	north-eastern limit of main range
Juncus flavidus	poorly collected, northern extension of range
Juncus pallidus	north-eastern extension of range
Family: Juncaginaceae	
Triglochin calcitrapa	
Triglochin centrocarpa	
Triglochin mucronata	
Triglochin nana	
Triglochin protuberans	poorly collected, 4th collection
Triglochin sp. A Flora of Australia (G.J.Keighery 2477)	
Triglochin sp. B Flora of Australia (P.G.Wilson 4294)	
Family: Lamiaceae	
Hemigenia sp. 'Edah' (J.W.Green 1601)	
Hemigenia sp. 'Paynes Find' (A.C.Beauglehole 49138)	
Prostanthera althoferi subsp. *althoferi*	
Prostanthera patens	eastern limit of range
Family: Lobeliaceae	
Isotoma petraea	
Lobelia heterophylla	
Lobelia winfridae	
Family: Loranthaceae	
Amyema fitzgeraldii	near southern limit of range
Amyema nestor	
Lysiana casuarinae	
Family: Malvaceae	
Abutilon cryptopetalum	south-western limit of range
Abutilon malvifolium	5th record for W.A., south-western limit of range
Abutilon oxycarpum	south-western limit of range
Alyogyne pinoniana	
Lawrencia glomerata	
Lawrencia helmsii	south-western limit of range
**Malva parviflora*	
Sida atrovirens ms	
Sida calyxhymenia	
Sida fibulifera	
Sida ?intricata	poorly collected
Family: Marsileaceae	
Marsilea drummondii	
Family: Mimosaceae	
Acacia acuminata	north-eastern limit of main range
Acacia acuminata subsp. *acuminata*	north-eastern limit of main range
Acacia aneura	near south-western limit of range
Acacia aneura × *craspedocarpa*	
Acacia assimilis subsp. *assimilis*	north-eastern limit of range
Acacia aulacophylla	
Acacia ayersiana	near south-western limit of range
Acacia burkittii	near south-western limit of range
Acacia coolgardiensis subsp. *coolgardiensis*	north-eastern limit of main range
Acacia coolgardiensis subsp. *effusa*	
Acacia ?coriacea	southern extension of range
Acacia craspedocarpa	south-western limit of range
Acacia eremaea	
Acacia exocarpoides	
Acacia fragilis	northern extension of range
Acacia grasbyi	near south-western limit of range
Acacia jamesiana	near south-western limit of range
Acacia ?kempeana	near south-western limit of range
Acacia ligulata	
Acacia longispinea	south-western limit of range

APPENDIX 1 (continued)

Acacia masliniana	
Acacia minyura	near south-western limit of range
Acacia murrayana	
Acacia quadrimarginea	
Acacia ramulosa	
Acacia ramulosa var. linophylla	near south-western limit of range
Acacia resinosa	northern limit of range
Acacia rhodophloia	near south-western limit of range
Acacia ?stowardii	
Acacia tetragonophylla	
Acacia tysonii	
Acacia victoriae	
Family: Myoporaceae	
Eremophila alternifolia	near south-western limit of range
Eremophila compacta	
Eremophila eriocalyx	
Eremophila forrestii	
Eremophila georgei	
Eremophila gibbosa	north-western extension of range
Eremophila glandulifera ms	
Eremophila granitica	
Eremophila ?jucunda	south-western limit of range
Eremophila latrobei subsp. *latrobei* ms	
Eremophila longifolia	
Eremophila mackinlayi	southern limit of range
Eremophila maculata	
Eremophila maculata subsp. *brevifolia* ms	
Eremophila miniata	
Eremophila muelleriana	
Eremophila oldfieldii subsp. *angustifolia* ms	
Eremophila oppositifolia subsp. *angustifolia*	
Eremophila pantonii	
Eremophila platycalyx	
Eremophila punicea	
Eremophila ?rostrata	Priority 1 species
Eremophila serrulata	
Eremophila shonae subsp. *shonae* ms	southern limit of range
Eremophila spuria ms	southern limit of range
Family: Myrtaceae	
Aluta aspera	
Callistemon phoeniceus	
Calytrix divergens	near southern limit of range
Darwinia capitellata	
Eucalyptus hypochlamydea	near northern limit of range
Eucalyptus kochii subsp. *amaryssia* ms.	north-western edge of range
Eucalyptus leptopoda subsp. *arctata*	
Eucalyptus oldfieldii	
Eucalyptus pileata	northern limit of range
Euryomyrtus maidenii ms	near western limit of range
Euryomyrtus patrickiae	Priority 3 species, near western edge of range
Homalocalyx thryptomenoides	
Malleostemon roseus	small-flowered form
Malleostemon tuberculatus	near north-eastern limit of range
Melaleuca eleuterostachya	near north-eastern limit of range
Melaleuca lateriflora subsp. *acutifolia* ms	
Melaleuca ?xerophylla	large south-western range extension
Micromyrtus flaviflora	
Micromyrtus sulphurea	
Thryptomene decussata	south-western limit of range
Thryptomene mucronulata	
Family: Nyctaginaceae	
Boerhavia ?coccinea	
Family: Ophioglossaceae	
Ophioglossum lusitanicum	
Family: Orchidaceae	
Caladenia hirta	
Caladenia incensa ms	
Paracaleana lyonsii ms	large south-eastern extension of range
Prasophyllum gracile	near north-eastern limit of range
Pterostylis sp. 'inland' (A.C.Beauglehole 11880)	north-eastern limit of range
Thelymitra sargentii	north-eastern limit of range
Family: Orobanchaceae	
**Orobanche minor*	north-eastern limit of range
Family: Oxalidaceae	
**Oxalis corniculata*	
**Oxalis pes-caprae*	north-eastern limit of range
Family: Papilionaceae	
Bossiaea walkeri	
Gastrolobium laytonii	
Glycine canescens	
Jacksonia arida ms	
Mirbelia ramulosa	
Mirbelia rhagodioides	
Swainsona affinis	
Swainsona campestris	large range extension from south-east W.A.
Swainsona gracilis	
Swainsona ?halophila	
Swainsona oroboides	near western limit of range
Swainsona ?paucifoliolata	
Swainsona perlonga	poorly collected, eastern limit of range
Swainsona rostellata	near south-western limit of range
Templetonia egena	
Family: Phormiaceae	
Dianella revoluta	
Family: Pittosporaceae	
Bursaria occidentalis	
Pittosporum phylliraeoides	
Family: Plantaginaceae	
**Plantago coronopus* subsp. *commutata*	north-eastern extension of range
Plantago debilis	near northern limit of range
Plantago drummondii	
Family: Poaceae	
Agrostis avenacea	
**Alopecurus geniculatus*	3rd record for W.A.
**Alopecurus pratensis*	poorly recorded, northern range extension

APPENDIX 1 (continued)

Amphibromus nervosus	
Amphipogon caricinus	
Aristida contorta	
Austrodanthonia caespitosa	
Austrostipa elegantissima	
Austrostipa flavescens	north-eastern limit of range
Austrostipa nitida	
Austrostipa scabra	
Austrostipa trichophylla	
**Avena fatua*	near north-eastern limit of range
**Briza minor*	north-eastern limit of range
Bromus arenarius	
Bromus ?rubens	north-eastern limit of range
Cymbopogon ambiguus	
**Ehrhartia longiflora*	near north-eastern limit of range
Enneapogon caerulescens	
Eragrostis dielsii	
Eragrostis eriopoda	south-western limit of range
Eragrostis falcata	near western limit of range
Eragrostis kennedyae	southern extension of range
Eragrostis lanipes	south-western limit of range
Eragrostis pergracilis	
Eriachne flaccida	near south-western limit of range
Eriachne helmsii	near south-western limit of range
Eriachne ovata	
Eriachne pulchella	south-western limit of range
**Hordeum glaucum*	
**Lamarkea aurea*	eastern limit of main range
Monachather paradoxus	
Paspalidium clementii	south-western limit of main range
**Pentaschistis airoides*	near north-eastern limit of range
**Polypogon monspeliensis*	
**Rostraria cristata*	north-eastern limit of range
**Rostraria pumila*	
**Schismus barbatus*	
Thyridolepis mitchelliana	near western limit of range
Thyridolepis multiculmis	near southern limit of range
Tragus australianus	
Triodia rigidissima	near western limit of main range
Triodia scariosa	
Triodia tomentosa	near western limit of range
**Vulpia muralis*	north-eastern limit of range
**Vulpia myuros* var. *myuros*	northern limit of range
Family: Polygalaceae	
Comesperma integerrimum	
Family: Polygonaceae	
**Acetosa vesicaria*	
**Emex australis*	
Muehlenbeckia florulenta	
Family: Portulacaceae	
Calandrinia disperma	2nd and 3rd records for W.A.
Calandrinia eremaea	
Calandrinia granulifera	
Calandrinia polyandra	
Calandrinia primuliflora	
Calandrinia ptychosperma	
Calandrinia sp. 'Bungalbin' (G.J.Keighery & N.Gibson 1656)	3rd record for W.A., southern range extension
Calandrinia sp. 'Coolcalalaya' (G.J.Keighery & N.Gibson 698)	3rd record for W.A., south-eastern range extension
Family: Primulaceae	
**Anagallis arvensis*	
**Anagallis arvensis* var. *caerulea*	
Samolus repens	
Family: Proteaceae	
Grevillea acacioides	near north-western limit of range
Grevillea deflexa	near south-western limit of range
Grevillea eriostachya	
Grevillea excelsior	near north-eastern limit of range
Grevillea hakeoides subsp. *stenophylla*	near eastern limit of range
Grevillea juncifolia	
Grevillea levis	near eastern limit of range
Grevillea obliquistigma	
Grevillea pityophylla	
Grevillea sarissa	near western limit of range
Hakea minyma	
Hakea preissii	
Hakea recurva	
Persoonia sp.	
Family: Ranunculaceae	
Ranunculus pentandrus var. *platycarpus*	western extension of range
Ranunculus sessiliflorus var. *sessiliflorus*	north-eastern limit of range
Family: Rhamnaceae	
Cryptandra imbricata	Priority 3 species
Family: Rubiaceae	
Psydrax latifolia	south-western extension of range
Family: Rutaceae	
Philotheca brucei	
Philotheca brucei subsp. *brevifolia*	
Philotheca tomentella	
Family: Santalaceae	
Exocarpos aphyllus	
Leptomeria preissiana	
Santalum acuminatum	
Santalum spicatum	
Family: Sapindaceae	
Alectryon oleifolius	bridges gap in range between populations of north-west and south-east

APPENDIX 1 (continued)

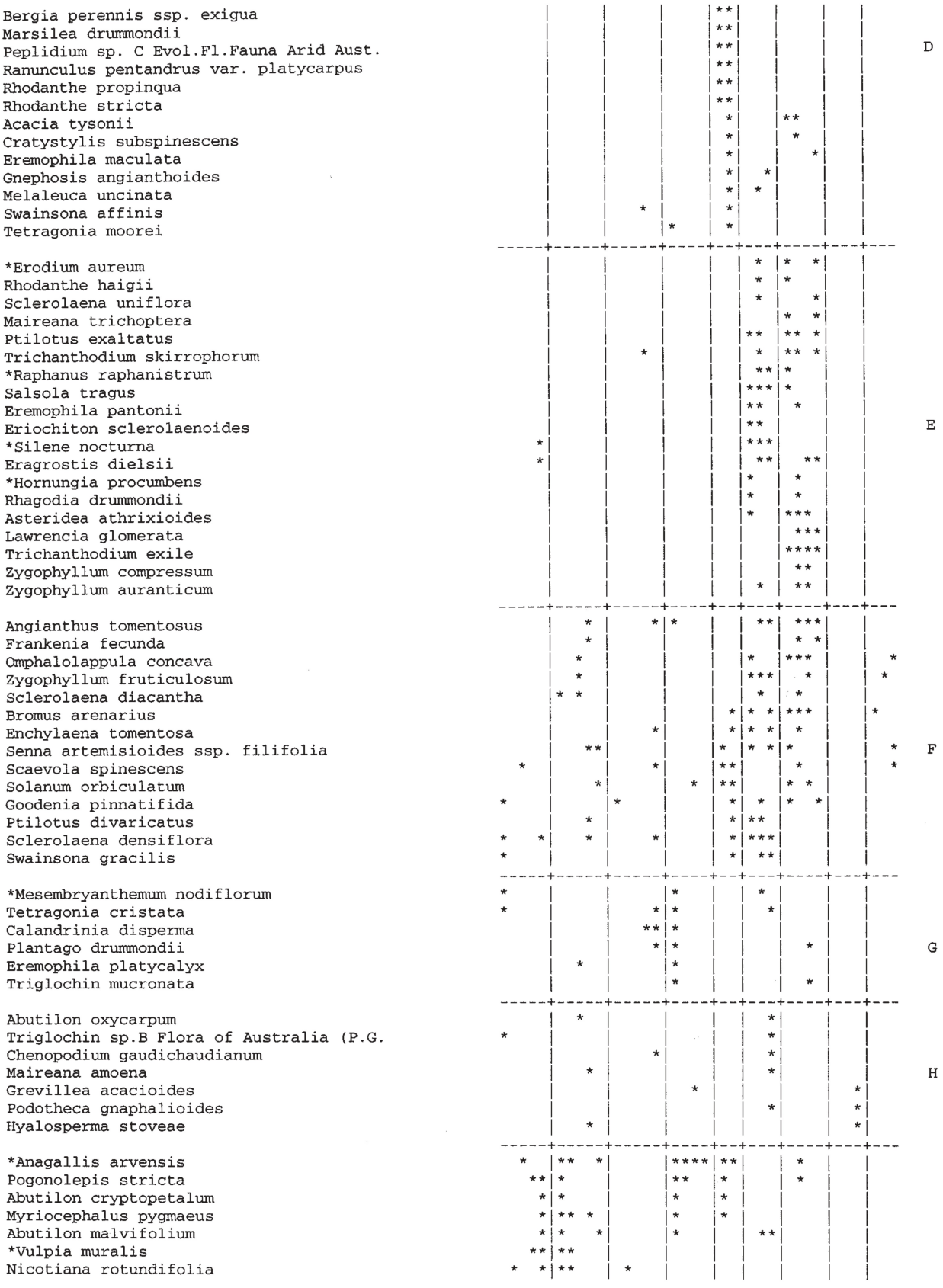
Dodonaea inaequifolia	
Dodonaea microzyga var. *acrolobata*	
Dodonaea viscosa	
Dodonaea viscosa subsp. *mucronata*	
Dodonaea viscosa subsp. *angustissima*	
Family: Scrophulariaceae	
Glossostigma diandrum	
Glossostigma drummondii	
**Parentucellia latifolia*	near north-eastern limit of range
Peplidium muelleri	southern limit of range
Peplidium sp. C Evol.Fl.Fauna Arid Aust. (N.T.Burbidge & A.Kanis 8158)	southern limit of range
**Zaluzianskya divaricata*	north-eastern extension of range
Family: Solanaceae	
Anthotroche pannosa	
Duboisia hopwoodii	
Nicotiana cavicola	
Nicotiana occidentalis subsp. *hesperis*	
Nicotiana occidentalis subsp. *obliqua*	
Nicotiana rosulata subsp. *rosulata*	
Nicotiana rotundifolia	
Solanum cleistogamum	
Solanum lasiophyllum	
**Solanum nigrum*	
Solanum orbiculatum	
Solanum orbiculatum subsp. *orbiculatum*	
Family: Sterculiaceae	
Brachychiton gregorii	
Keraudrenia integrifolia	
Rulingia luteiflora	
Family: Stylidiaceae	
Levenhookia leptantha	
Stylidium induratum	western limit of range
Stylidium longibracteatum	
Family: Thymelaeaceae	
Pimelea microcephala	
Family: Urticaceae	
Parietaria cardiostegia	
Family: Zygophyllaceae	
Zygophyllum auranticum	
Zygophyllum compressum	south-western limit of range
Zygophyllum eremaeum	
Zygophyllum fruticulosum	
Zygophyllum glaucum	
Zygophyllum ovatum	
Zygophyllum simile	

APPENDIX 2

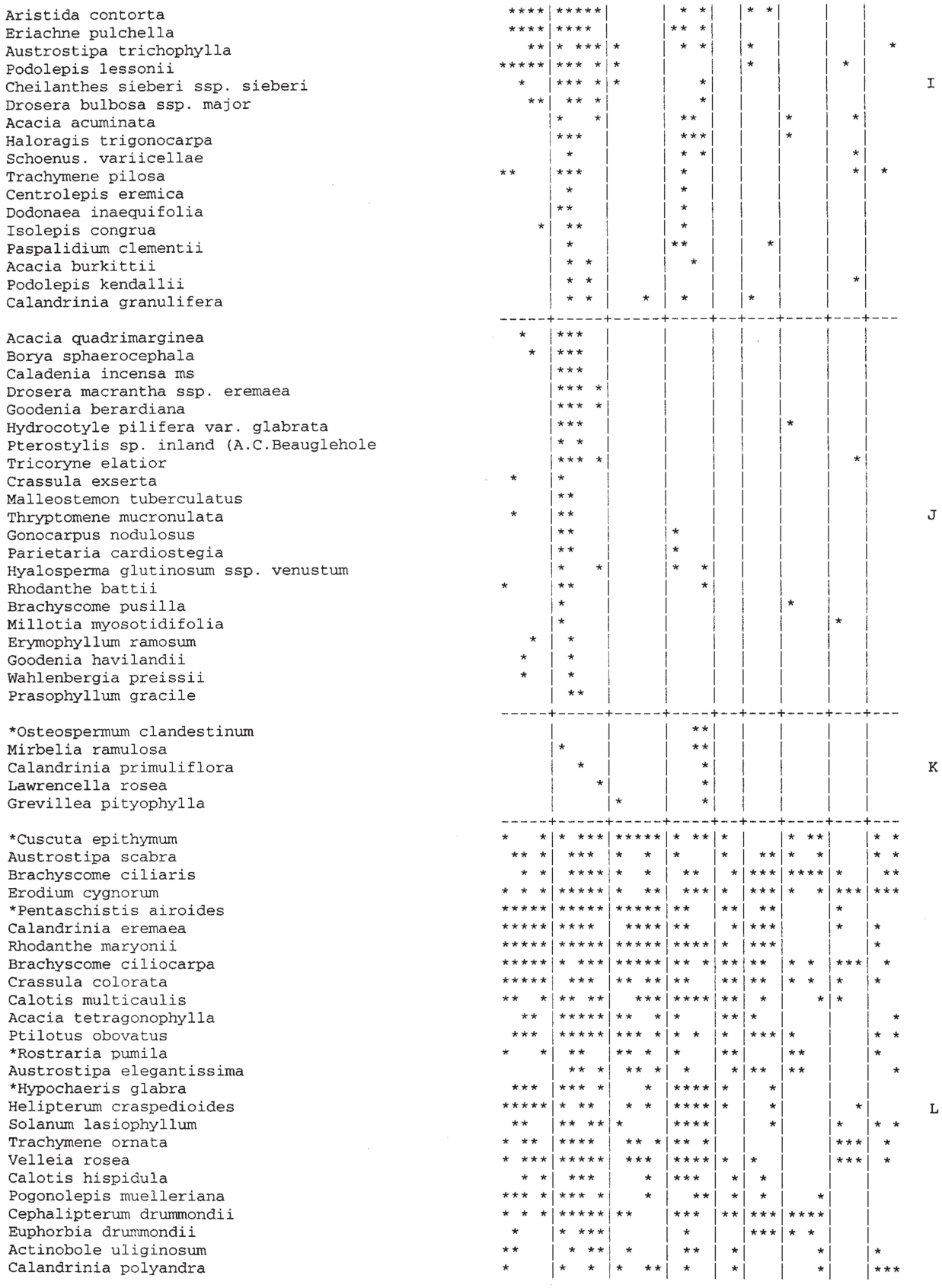
Sorted two-way table of the Burnerbinmah sites showing species occurrence (rows) by community type (site codes appear as columns).

	COMMUNITY TYPE									
	1a	1b	2	3a	3b	4a	4b	5a	5b	
										SPECIES GROUPS
	ACABC	ABCCC	CABCA	ABAB	AC	ABA	BBBC	ACB	ABC	
	14655	43381	18779	5411	76	211	6899	322	111	
		1		21		0			100	
*Sonchus oleraceus			*	****	**		* *			
*Erodium cicutarium			*	**	**		*			
*Emex australis				***	**	**				
*Hordeum glaucum				***	*	* *	**			A
Nicotiana occidentalis ssp. hesperis				** *		*	*			
Swainsona rostellata				* *	*	*	*			
Goodenia pusilliflora	**	*	*	*	**	*				
Senecio glossanthus	*			*	*		**		*	
*Arctotheca calendula				*	*					
Ptilotus macrocephalus				*	*					
*Centaurea melitensis				***	*					
*Silene gallica var. gallica				***	*					
*Cotula bipinnata				**	*					
Atriplex semilunaris				**		*				
*Polycarpon tetraphyllum				**						
Cyperus gymnocaulos				**						
Wahlenbergia communis				**						
*Avena fatua		*		**					*	
Daucus glochidiatus				**			*		*	
Hyalochlamys globifera				* *						
Wahlenbergia gracilenta			*	** *						
Rhodanthe chlorocephala ssp. splendida			*	* *				*		B
*Solanum nigrum	*			*						
Gnephosis brevifolia	* *			*						
Rhyncharrhena linearis			**	*						
*Vulpia myuros var. myuros	*		*	*						
Eriachne flaccida	*			* *						
Eriachne ovata	*			**						
Rhodanthe pygmaea	*			*						
Acacia exocarpoides			*	*						
Calandrinia ptychosperma		*		***						
Triglochin calcitrapa				* *						
Ptilotus chamaecladus				* *		*				
Chenopodium melanocarpum				**						
Cyperus alterniflorus				**						
Swainsona oroboides				**						
Sida fibulifera		*		*						
*Acetosa vesicaria					*		**			
Acacia victoriae					*		**			
Tetragonia eremaea					*		*			
Lepidium phlebopetalum	*				*		**			
*Sisymbrium erysimoides					*	**	*			
Rhagodia eremaea					*	*				
*Oxalis corniculata				*	*					C
Exocarpos aphyllus				*	**					
Myriocephalus oldfieldii ms				*	*					
Pimelea microcephala					*				*	
Dodonaea viscosa				*	*	*				
Pittosporum phylliraeoides				*	*	*				
Maireana pyramidata					*	*				
*Spergularia rubra	*				**					
Plagiobothrys plurisepalus	*				**					
Gnephosis arachnoidea	*				*					
Hyalosperma glutinosum ssp. glutinosum	* *				*					
Atriplex amnicola		*			**					
Brachyscome lineariloba			*		**					
Agrostis avenacea					**					

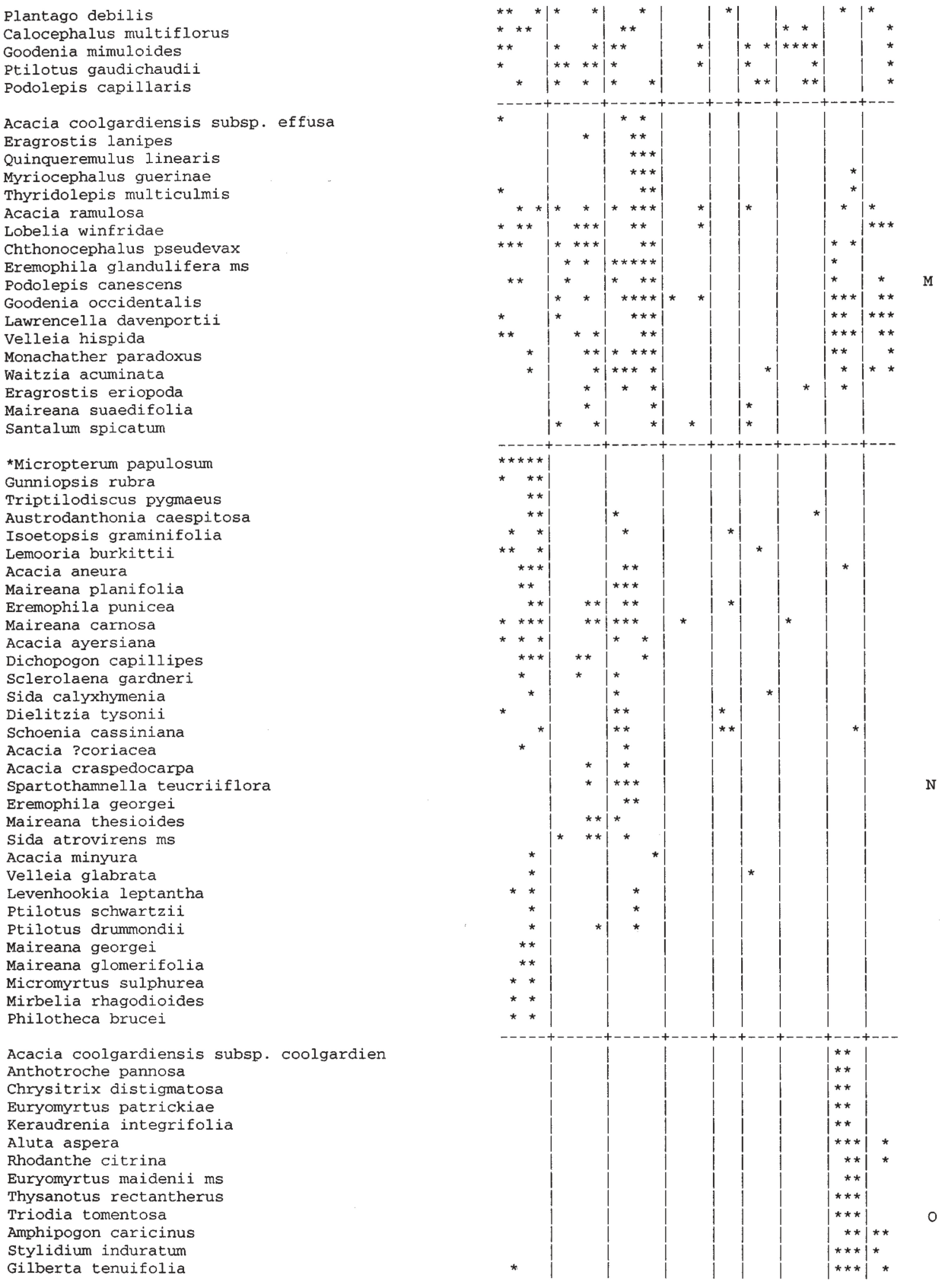
APPENDIX 2 (continued)



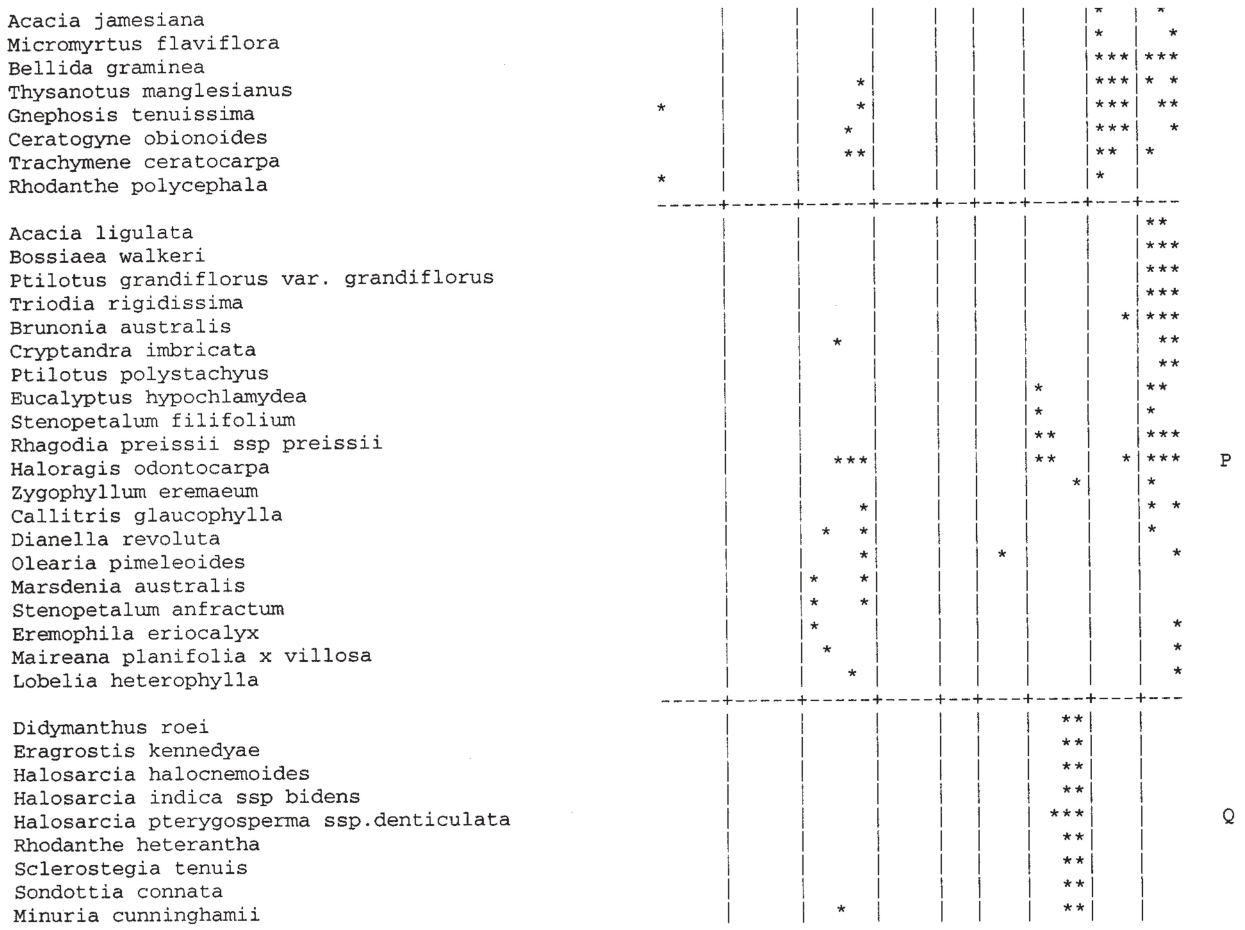
APPENDIX 2 (continued)



APPENDIX 2 (continued)



APPENDIX 2 (continued)



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Australian Plant Name Index

LINDY CAYZER, LAURIE ADAMS, KIRSTEN COWLEY,
BRENDAN LEPSCHI AND GREG WHITBREAD

Centre for Plant Biodiversity Research, GPO Box 1600, Canberra, Australian Capital Territory 2601

Summary

The Australian Plant Name Index (APNI), is a comprehensive database of published names of Australian vascular plants, now available on-line at: www.anbg.gov.au/apni .

The *International Code of Botanical Nomenclature* has strict rules on the publication and priority of plant names and must be very carefully considered in any revision involving new plant names and name changes. In Australia we have an enormous heritage of taxonomic literature in many languages and from many sources, and much of this literature is not readily available either here or overseas. To assist clients needing this information, the Australian Academy of Science Standing Committee for a Flora of Australia set up the Australian Plant Name Index project in 1973, supervised by Nancy T.Burbidge AM (1912-77). The first compiler was Penelope Hack, succeeded in 1974 by Arthur D.Chapman, but a number of botanists assisted especially during the early years. A four-volume, hard copy edition was published by the Australian Biological Resources Study [ABRS] in 1991 (Chapman, 1991). This contained the bibliographic and typification details for more than 60,000 Australian plant names.

Today, APNI provides comprehensive publication and type citations on-line for nearly 70,000 botanical names used for Australian vascular plants. Distribution is given according to the regions used in the *Census of Australian Vascular Plants* (CAVP) (Hnatiuk, 1990). APNI is expanding rapidly in response to differing client needs in this new century. We are now incorporating cultivar and common names. From 2001, photos, images and line drawings are being integrated. Locality maps are also available, recording geographical data from all herbaria in Australia through Australia's Virtual Herbarium.

APNI provides comprehensive information on all published Australian plant names, whether currently in use or not. One of the first new products available through APNI is the What's its Name? [WIN] project, which was set up in 2000 to provide a concise list of current, accepted names of Australian plants. WIN also includes recent name changes and explanations of taxonomic decisions. WIN is compiled using the on-line Australian Plant Name Index, the Flora of Australia publication series and other recent taxonomic literature.

Both WIN and APNI can be found at:
www.anbg.gov.au/win

Two examples from APNI are given below.
For further information contact:

The Director, Centre for Plant Biodiversity Research, GPO Box 1600, Canberra, ACT 2601
Tel: (02) 6246 5108 Fax: (02) 6246 5249
Email: cpbr.director@csiro.au
Web site: http://www.anbg.gov.au/cpbr

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Chapman, A.D. (1991), *Australian Plant Name Index.* Australian Flora and Fauna Series 12-15. AGPS Press, Canberra.

Hnatiuk, R.J. (1990), *Census of Australian Vascular Plants.* Australian Flora and Fauna Series 11. AGPS Press, Canberra.

Goodeniaceae R.Br.

Brunonia australis Sm. ex R.Br.

Smith, J.E. ex Brown, R. (1810), *Prodromus Florae Novae Hollandiae*: 590
Type: "(D.M.) v.v." [given by J.E.Smith, *Trans. Linn. Soc. London* 10 (1811) 367 as "Abundant in Van Diemen's Land, and observed also on the opposite shore of New Holland at Port Phillip, flowering in Jan. 1804 (R. Br.)"].
Comment: The publication by R.Brown, *loc. cit.* predates that by Smith in *Trans. Linn. Soc. London* 10 (1811) 367, t. 28.

Peacock, W.J. & Smith-White, S. (1978), Cytogeography of *Brunonia australis* Sm. ex R.Br. *Brunonia* 1(1): 31-43

Brummitt, R.K. (1992), *Vascular Plant Families and Genera*: 72
Status: Now family Goodeniaceae.

Carolin, R.C. (1992), Brunoniaceae. *Flora of Australia* 35: 3
taxonomic:***Brunonia australis var. macrocephala Colozza***
taxonomic:***Brunonia australis var. sericea (R.Br.) Colozza***
taxonomic:***Brunonia australis var. simplex (Lindl.) Colozza***
taxonomic:***Brunonia sericea R.Br.***
taxonomic:***Brunonia simplex Lindl.***
Distribution: Widespread in Australia in all States south of the 17th parallel, from the arid regions to the higher rainfall areas on the mountains of the south-east; mostly on sandy soils. Flowers winter and spring.
Status: A species that inhabits a variety of different environments and is very variable, particularly in the degree of hairiness.
Common name: Pincushion
Vascular Plant Families and Genera: 72
under: **Goodeniaceae R.Br.**
Status: Now family Goodeniaceae (see Brummitt, 1972)
CANB collections, Map., /images/photo_cd/732131822162/098.html/images/photo_cd/732131822162/098.html, /images/photo_cd/732131822162/096.html/images/photo_cd/732131822162/096.html, /images/photo_cd/732131822162/095.html/images/photo_cd/732131822162/095.html, /images/photo_cd/732131822162/097.html/images/photo_cd/732131822162/097.html
CAVP: **ACT:** CAN; **NSW:** NCS, NNF, NNP, NCT, NSP, NST, NSS; **NT:** DBT, DCN, DCS, DVR; **QLD:** QGN, QLE, QMI, QPC, QWA, QDD, QMA; **SA:** SEB, SEP, SGT, SSE, SLN, SLS, SMB, SNW; **TAS:** TNE, TSQ; **VIC:** VC, VG, VH, VE, VD, VJ, VM, VZ, VX, VW, VV, VU, VT, VS, VR, VP, VN, VK; **WA:** WAU, WCG, WCO, WCV, WDM, WGI, WHE, WFO, WAV, WIR, WKE, WMU, WRO.

Fabaceae Lindl.

Desmodium tortuosum (Sw.) DC.

Candolle, A.L.P. de (1825), Leguminosae. *Prodromus* 2: 332
basionym: ***Hedysarum tortuosum Sw.***

Hartley, W. (1953), *Standardized Plant Names [C.S.I.R.O. Bull. No. 272]*: 26

Green, P.S. (1994), Norfolk Island & Lord Howe Island. *Flora of Australia* 49: 179

Pedley, L. (1999), *Desmodium* Desv. (Fabaceae) and related genera in Australia: a taxonomic revision. *Austrobaileya* 5(2): 253, map 42
nomenclatural:***Meibomia tortuosa (Sw.) Kuntze***
taxonomic:***Desmodium purpureum (Mill.) Fawc. & Rendle***
taxonomic:***Hedysarum purpureum Mill.***
CANB collections, Map.
CAVP: **NT:** DDG; **QLD:** QCO, QKN, QLE, QMO, QPC; **WA:** WGA.

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Acacia species as large-scale crop plants in the Western Australian wheatbelt

JOHN BARTLE[1], DON COOPER[1], GRAEME OLSEN[2] AND JEROME CARSLAKE[1]

[1] Department of Conservation and Land Management, Locked Bag 104, Bentley Delivery Centre, Western Australia 6983
[2] Olsen & Vickery, PO Box 357 Waroona, Western Australia 6215; email: golsen@iinet.net.au
Corresponding author: John Bartle, Manager, Farm Forestry Unit; phone 08 9334 0321; email: johnb@calm.wa.gov.au

SUMMARY

Revegetation with perennial plants is a well-accepted tool in salinity control across the agricultural regions of southern Australia but the scale on which revegetation must be undertaken in order to have significant impact on salinity has become clear only recently. This scale is so large that it must involve extensive change in the commercial plant base of agriculture. Hence, an array of profitable perennial plants must be developed to complement existing annual crops. Apart from their role in salinity control, new perennial plant crops can bring a range of other benefits to agricultural areas, including improved erosion control, protection of biodiversity (and in some cases its enhancement), diversification of farm incomes, and regional development resulting from local processing of perennial plant products.

This paper discusses some issues relevant to the development of new industries based on woody perennial crops. They include size of markets, using the whole plant to make multiple products, crop rotation length, temporal and spatial integration of perennial crops into agriculture, the financial consequences for farmers growing woody crops, and the desirability of deriving new crops from native species. These issues provide useful guidelines for the objective selection of potential new commercial crop species. From this foundation, a selection and development project called 'Search' has evolved, to systematically assess potential new large-scale tree crops and processing industries based on native species, select those with high potential for commercial development, and take the first steps towards their development.

The genus *Acacia* provides considerable potential for the development of new perennial crops. *Acacia* species appear to be especially suited for use as phase crops in rotation with conventional annual crops, or as low cost, direct-seeded coppice crops. A large number of *Acacia* species occur naturally in the Western Australian wheatbelt and several have attributes that may make them suitable for commercial development. Potential products include solid wood, panel board, paper, gum, tannin, fodder, edible seed, and large-scale generic products such as solid fuel for electricity production, liquid transport fuel and charcoal products.

BACKGROUND

During the 1990s the potential scale and impact of dryland salinity became apparent and emerged as the leading environmental issue in Australia. Major reviews focused national attention on the problem (National Land and Water Resources Audit 2000; Murray Darling Basin Ministerial Council 2000; State Salinity Council 2000; National Farm Forestry Roundtable 2000). This work shows that salinity-related damage has many impacts beyond the obvious land and water resource losses, including biodiversity loss (450 potential species extinctions in W.A. according to State Salinity Council 2000), infrastructure attrition and flood risk (Bowman and Ruprecht 2000), possible catchment-wide litigation (Turley 2000) and international sanction (Bartle 1999a). The consequences and costs of these less tangible impacts of salinity are still poorly defined.

Dryland salinity is inherently difficult to manage. In contrast to salinity arising from irrigated agriculture, dryland salinity involves only diffuse recharge from rainfall (i.e. no managed irrigated component), large areas, and long distances and time delays between recharge and discharge. Also, unlike intensive irrigated systems, broadscale dryland agricultural systems produce low returns per hectare, from which treatments for dryland salinity must ultimately be financed.

Two categories of treatment are available. Both are complex and costly:

- recharge control: a preventative strategy, using water at or near where it infiltrates the soil and enters groundwater systems. This can be achieved most effectively by increasing the proportion of deep-rooted perennial vegetation (both non-commercial and commercial) on agricultural land.
- discharge control: ameliorative measures to collect and safely dispose of groundwater that has accumulated in low landscape positions and is close enough to the surface to affect soils. Where this water is not too salty it can be used by salt-tolerant plants, some with grazing and timber value. However, groundwater in discharge areas is often too saline to be used by plants, and its control requires engineering works such as drains, pumps and discharge basins.

These two types of treatment are complementary because they apply sequentially along the same hydrologic flow path, and neither forms a complete, efficient management system on its own. If the amount of recharge can be diminished by increased use of perennial plants, then the amount of discharge will be reduced in the longer term and become more manageable. Similarly, regardless of the effectiveness of upslope recharge control, engineering treatments will be required to cope with highly saline groundwater emerging in discharge areas.

Recent hydrological research contends that perennial plants are able to control recharge on agricultural land only if they cover a substantial proportion of it, i.e. up to 80% (Hatton and Nulsen 1999; George *et al.* 1999). This would require a 'revolution' in agriculture (Bartle 1999a; Stirzaker *et al.* 2000). Not surprisingly, the requirement for such radical change, and the perceived difficulty of achieving it, give rise to the pessimistic view that we should learn to live with the problem rather than solve it! For example, the Western Australian State Salinity Council (2002) adopted the proposition that a substantial proportion of public funds available for salinity be invested in a few high-value areas to ensure their successful treatment, implying continued degradation of the balance.

What alternatives are there to this bleak outlook? Despite significant investments of public money in promoting it, large-scale revegetation with non-commercial species is unlikely to occur, because:

- farmers are unlikely to revegetate with non-commercial plants if their costs exceed the benefits,
- in most cases, the benefits to individual farmers from non-commercial revegetation are low;

Ethical imperatives, volunteer participation, peer pressure and integrated catchment management, the laudable tenets of landcare, will not be sufficient motivation if revegetation on the necessary scale would bankrupt farm businesses (Pannell 2000).

The solution is very simple in concept – expand and diversify the range of profitable perennial crops and pastures used in agriculture. So the question becomes: what are the prospects for increasing the extent and diversity of commercially viable perennial crops and pastures? There are opportunities in some areas to increase the use of existing perennial pastures and expand the area of farm forestry, but this alone will not be sufficient. A range of new herbaceous and woody perennial plants and associated industries is required.

A start has been made on woody crop development with the domestication of mallee eucalypts in Western Australia. Bartle (2001) reviewed the development of mallee and its influence on the Search Project (NHT 973849), a project funded by the Natural Heritage Trust, that aims to generalise the experience gained with mallee by applying it systematically to screen new woody crop and product prospects. More recently, this approach has been incorporated into the new Cooperative Research Centre for plant-based management of dryland salinity (www.crcsalinity.com).

This paper presents a conceptual framework for assessing attributes of tree crops that favour both their large-scale commercial success and salinity control. It then assesses the genus *Acacia* as a source of new woody crop germplasm for the Western Australian wheatbelt.

DEVELOPMENT OF NEW TREE CROPS

Four aspects to consider and integrate when developing new tree crops are the type of crop (layout, duration, type of material produced), type of site (recharge or discharge), type of product (market size, feedstock requirements) and species suitability (biological attributes). Each is described briefly below.

Woody crop types

There is currently no large-scale tree crop in use in the wheatbelt regions of southern Australia. However, three conceptual woody perennial crop types have potential for development:

1. Short-rotation coppice crops: where harvest occurs every 2 to 5 years from successive crops regenerated from rootstocks that re-sprout or coppice after each harvest. Interest in short-rotation coppice crops has been stimulated by the experience with mallee development in W.A. (Bartle 2001). Coppice crops are costly to establish (with seedlings) but are ready for harvest at an early age and can regrow many times from the same stump. They are well suited to planting in permanent belts oriented along the contour, or in other strategic locations, to intercept downslope water movement. In this concentrated form they are readily integrated into large-scale annual cropping systems in alley farming layouts.
2. Short-rotation phase crops: where the crop occupies a phase within the annual crop rotation and is harvested once and removed at age 3 to 6 years. The high cost of seedling propagation is a significant barrier to profitable production of large-volume, low-value products by phase crops (Harper *et al.* 2000). Hence, species that can be readily established by direct seeding, such as those with large seeds, are the most likely candidates to be developed. Phase cropping can be used to dewater cropland where soil characteristics limit the rate of lateral movement of subsurface water and therefore limit the potential for water consumption by permanent belts of perennial plants. The woody plant phase has the potential to improve soil structure and to utilise leguminous species to enhance subsequent annual crop production but this is offset to some extent by clean-up costs after harvest, and an increased risk that the dewatered soil profile will reduce yield in the following annual crop. Phase cropping has yet to attract much investment in research and development, despite being conceptually attractive.

3. Long-rotation crops: where the production cycle is greater than 10 years and may be as long as 100 years. Long rotation crops require intensive, long-term capital investment and very careful site selection. They are suited to planting in belts or small blocks and, in addition to timber products, they can provide shelter and aesthetic benefits. The long rotation period enables production of large logs that can be sold into existing timber industries. They have greatest potential in the wetter wheatbelt regions where growth rates are higher, rotation length will be shorter and where they will be comparatively close to current timber industries (Moore 2001).

Economic analysis of crop types

The relative economics of the three different crop types described above, and their profitability compared to current agricultural returns, will determine their attractiveness to farmers, and hence influence their priority for development.

To assess the economic performance of each crop type, discounted cash flows over 25 years were calculated. The results for each crop type were compared with each other, and with the discounted value of conventional agriculture based on annual plants.

Data were generated for four rainfall zones ranging from 300 to 600 mm mean annual rainfall. Results for the 400 mm rainfall zone are presented here. Production cost and yield were estimated for each crop type, and then used to calculate the 'stumpage', or selling price of the crop standing in the field, that would be necessary for each crop type to achieve a return equivalent to conventional agriculture (that is, averaging $65 per hectare annually over a 25-year period). These calculated 'break even' stumpages were then compared with estimates of stumpages that are likely to be paid by timber and biomass industries. Note that no allowance is made in this analysis for any positive or negative indirect effects of woody perennial crops such as erosion control, shelter, salinity control, and interactions with other crops.

Estimated values of production parameters used in the financial analysis are presented in Table 1, and results are presented in Table 2.

TABLE 1
Estimated parameters for input to financial analysis of crop types in a 400 mm/yr rainfall area in south-western WA.

	COPPICE	PHASE	LONG ROTATION
Establishment cost $/ha[1]	1500 / 380	1350 / 300	1200 / 300
Density (stems/ha)	2667	2000	500 planted100 harvested
Grazing revenue $/ha/yr	0	0	20
Annual costs $/ha	30	30	25
Prune and thin ($/ha)[1]			575 / 675
First harvest age (yrs)	5	4	25
First harvest (t/ha)[2]	60	70	90
Coppice interval (yrs)	3		
Coppice harvest (t/ha)[2]	60		

[1] *First value is for planted seedlings. Second value is for direct seeding.*

[2] *Coppice and phase crops harvest tonnages are for total biomass. Long-rotation harvest tonnage is for sawlogs only.*

Notes: Establishment by seedlings varies with planting density.

The cost of direct seeding is based on assumptions of the likely outcome of a modest investment in research.

Coppice crop establishment by direct seeding incurs a higher cost than direct seeding of phase crops or long-rotation crops, as smaller, more specialised machinery is required to seed narrow belts.

Phase crop costs include $200 per hectare for site clean-up after each harvest, to prepare the land for a resumption of annual cropping. Coppice and long-rotation crops do not include clean-up costs, as it is assumed that the land will be used for the same purpose again.

TABLE 2
Impact of establishment technique on the economics of woody crop types in the 400 mm annual rainfall zone.

CROP TYPE	SEEDLING ESTABLISHMENT			DIRECT SEEDING			
	Break even[1]	Average debt[2]	Calculated stumpage[3]	Break even[1]	Average debt[2]	Calculated stumpage[3]	Estimated stumpage[4]
Coppice	14	931	14	8	332	8	15
Phase	16	432	32	8	126	14	15
Long rotation	25	1417	130	25	696	87	60

[1] *years to break even.*

[2] *average debt ($ per hectare) over period to break-even.*

[3] *selling price necessary to make return equivalent to that of conventional agriculture (in $ per tonne of biomass for short rotation crops, and $ per cubic metre of wood for long rotation crops).*

[4] *estimate of stumpage likely to apply for each crop types (same price basis as [3]).*

The sensitivity of cash flow to establishment method is examined under two scenarios: current technology using containerised seedlings, and future technology using large-scale direct seeding. Seedling propagation is expensive, as indicated in Table 1, and greatly increases costs compared to direct seeding.

Graphs of discounted cash flows are shown in Fig. 1 (establishment using containerised seedlings) and Fig. 2 (establishment by direct seeding). Note that phase crops are shown to follow each other without break, to enable comparison of all three crop types over a 25-year period. Each successive phase crop is assumed to be located on a different piece of land.

The results of the financial analysis, shown in Table 2, indicate that coppice crops established by planting seedlings can produce biomass for a stumpage of $14 per tonne. This is slightly less than the $15 per tonne shown in Enecon's (2001) feasibility study to be a commercially viable purchase price for mallee biomass feedstocks. In contrast, phase crops established by seedlings would produce biomass at $32 per tonne, over twice the expected price. Phase crops would have to be established by direct seeding to achieve production at $15 per tonne. If coppice crops could be established by direct seeding, biomass could be produced for $8 per tonne, a price likely to stimulate large-scale demand by wood processing and bioenergy industries. The economics of long-rotation crops are far less favourable. Even using direct seeding, the selling price would have to be above the estimated stumpage of $60 per cubic metre used in this analysis.

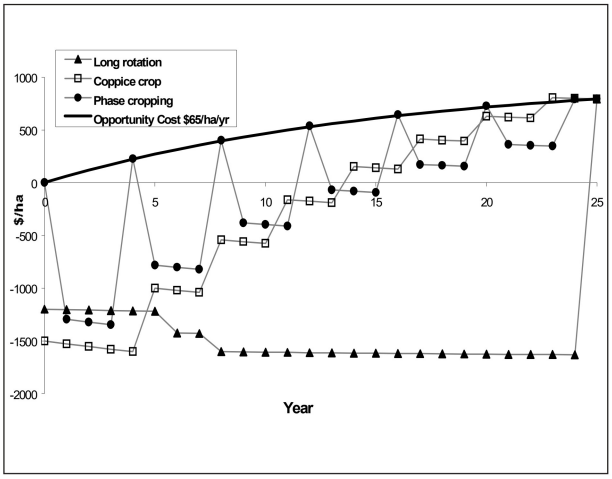


Figure 1: Discounted cash flow using conventional establishment.

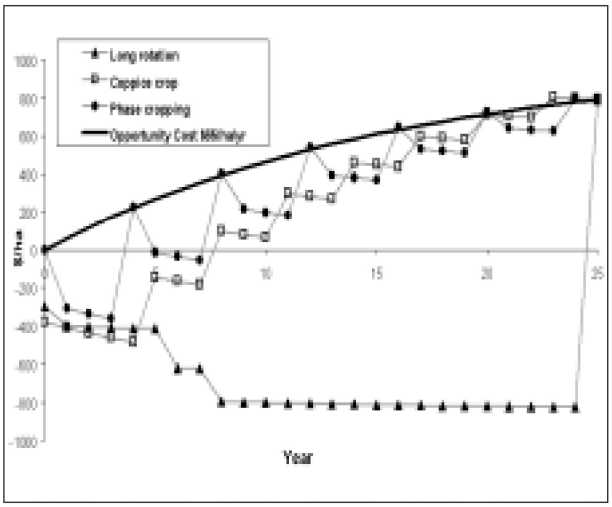


Figure 2: Discounted cash flow using direct seeding establishment.

For long-rotation crops the average debt load of $1417 per hectare over the 25-year period to harvest indicates a major financing constraint that is beyond the resources of most farm businesses. For this reason, long-rotation crops are unlikely to be planted on a large scale unless long-term arrangements involving external finance are developed. The debt level is much lower for coppice and phase crops and must be carried for a shorter period, because the time to break even for these crops is much shorter than for long-rotation crops. Coppice and phase crops are more likely to be within the financing ability of farm businesses.

This financial analysis indicates several important directions for the development of tree crops:

- Direct seeding provides a major economic advantage. Hence, large-seeded plants like *Acacia* that are relatively easy to establish by direct seeding have a significant advantage over small-seeded ones like eucalypts for which there is currently no adequate direct-seeding method.
- Direct-seeded *Acacia* phase crops could produce biomass at a cost similar to mallee coppice crops. The cost of re-establishing phase crops after each harvest is offset by the benefit of direct seeding.
- Very low cost biomass, produced from coppice crops, requires the development of direct-seeding techniques for fine seeded species like mallee eucalypts, or selection and development of *Acacia* species that establish easily by direct seeding and also coppice strongly and reliably after harvest.
- Long-rotation crops carry the burden of a large, long-term capital requirement that will limit their use. Their economics could be improved by developing species that produce high value 'appearance grade' wood rather than general construction timber.

Site types based on the hydrological setting

From the hydrological point of view sites fall into two major categories and several subcategories.

Recharge sites: where the water table is well below the soil surface and rainfall may infiltrate to some depth in the soil profile. Subcategories are:

high recharge sites: where light-textured soils permit rapid, deep infiltration; water use and productivity under annual plant agriculture are low; potential for lateral movement of water within the profile is high; and groundwater salinity is comparatively low. On these sites,

woody crops in belt configuration have the potential to intercept down-slope movement of perched or deep groundwater, as observed by White *et al.* (2002).

low recharge sites: where soils are heavier-textured; leakage past annual plant root systems is less; salt storage in the profile is greater; groundwater salinity is higher; and lateral transmission of groundwater is slower. On these sites phase crops could be used intermittently but extensively to reduce soil water storage and prevent net recharge (Harper *et al.* 2000).

Discharge sites: where infiltration is impeded by a shallow water table. Groundwater is usually brackish or saline and may be discharging from the surface. The soil is poorly drained and only species that can tolerate waterlogging and salinity are present. Barrett-Lennard (2001) has proposed three subcategories based on potential productivity:

high: where groundwater is sufficiently deep that salt accumulation in the upper soil profile is not great enough to affect productivity.

medium: where the soil is salt affected but still able to support saltland pastures.

low: where salt has accumulated to the extent that only halophytes can survive.

Large-scale woody crop development is likely to focus on species and crop types suited to recharge sites and high productivity discharge sites, because plant survival and growth rates are likely to be highest in these areas.

Product types

The scale of perennial plant cover necessary to arrest salinity is very large. Therefore it is essential to choose products and markets that have the capacity to absorb very large-volume production. This argument was presented more fully by Bartle (2001). Table 3 lists products that could be produced from wheatbelt woody crops. It includes estimates of market size, and the development period for potential markets. For example, alcohols made from woody biomass are still undergoing technological development as transport fuels, but within a generation they could compete in these very large markets, at a time when the dominance of petroleum could be declining (Foran and Mardon 2000).

The priority for selection and development of tree crops will be dominated by their commercial potential. In the case of grazing, sawn timber, food and flowers, the nature of the product will limit the number of suitable species from which selections can be made. For panel and paper products, bioenergy and derived chemicals, feedstock criteria may be less demanding, allowing selection from a greater diversity of species; they may also allow a range of species grown in different locations to contribute feedstocks to a single processing centre. Bioenergy and derived chemicals are likely to be the least discriminating uses for biomass, and are most likely to be profitable when made from low-cost residues, for example, from biomass remaining after the removal of a select woodchip product for panel board manufacture.

To be profitable, it is almost certain that new woody crops will have to provide feedstock to two or more different products, to fully utilise 100 per cent of the biomass produced, and to maximise the revenue they earn. Indeed, this complementarity between products has been a factor in achieving commercial feasibility in integrated mallee processing, where activated carbon, eucalyptus oil and electricity will be produced concurrently from mallee biomass feedstocks (Enecon 2001).

Local processing of most raw materials from new woody crops will be essential because of their low value per tonne and high sensitivity to transport costs. Although this may be a disadvantage for some product types, it provides significant regional economic benefits, including

TABLE 3
Potential large scale products from woody plant crops.

PRODUCT CATEGORY	PRODUCT TYPE	MARKET SIZE[1]	DEVELOPMENT PERIOD[2]
Grazing	Meat	Large	Current
	Wool	Large	Current
	Manufactured feeds	Medium	Current
Wood	Sawn wood (appearance, construction)	Large	Current
	Panels (particle board, medium density fibreboard (MDF), oriented strand board (OSB))	Large	2010-2020
	Processed wood (pulp/paper, charcoal)	Large	2005-2020
Bioenergy	Solid fuel (electricity, heat, desalination)	Very large	2002-2025
	Liquid fuel (alcohols, biodiesel)	Very large	2015-2030
Chemicals	Extracts (oils, gums, tannins, resins)	Medium	2002-2010
	Derived (pyrolytic liquids, commodity chemicals)	Large	2020-2040
Food and flowers	Staple food (bulk grain)	Large	2005-2010
	Bush tucker	Tiny	Current
	Ingredients (oils, edible gums etc.)	Small	2005-2010
	Flowers	Tiny	Current

[1] *Potential market volume in land area, very large > 5 million ha, large 1 to 5 million ha, medium 100,000 to 1 million ha, small 10,000 to 100,000 ha, tiny < 10,000 ha.*

[2] *Period during which significant industry development is likely to occur.*

local investment and employment, plus greater stability to farm budgets and rural economies due to year-round harvesting and processing (CSIRO Land and Water *et al.* 2001).

Biological attributes

A large number of biological attributes may be important in selecting species for development as crop plants. Major categories are:

- survival, growth rate and yield: any species being considered for use as a commercial crop must have good yield potential over the required rotation length.
- morphology: plant morphology determines the range of products for which any species might be suited. Each product type in Table 3 could require plants of different morphology. An overriding requirement is that plants be of a form amenable to low-cost harvest.
- breeding biology: influences issues such as collection of propagules, method and ease of genetic improvement, method of establishment in the field, and assessment of weed risk.
- conservation biology: including natural distribution, diversity within species, status and security of native populations, and relationships with other species.
- adaptability: how easy new crops are to establish and manage, and how tolerant they are of the farm environment (climate, soils, pests and diseases, grazing animals, herbicides).

Native species score highly on many of the biological attributes listed above and therefore deserve further investigation of their commercial potential. Native species are well adapted to their natural environment, are less likely to become weeds in native vegetation, and may contribute directly to the maintenance of biodiversity in rural areas. A key point in their favour is that their genetic resource is available locally (Bartle 2001).

ATTRIBUTES OF *ACACIA*

The preceding sections give a broad perspective on the role of tree crops in agricultural systems. This section surveys the potential of *Acacia* species to be developed as commercially viable woody crops for salinity control.

Diversity, geographical range and ecology

Acacia is a large genus with a wide diversity of plant form and function and a large geographical range. Many species have large variation between provenances. A large part of the diversity in the genus occurs in Australia, where many species are endemic. This localisation of *Acacia* diversity provides an opportunity for Australian researchers to sift through the local flora for potentially commercial species, and then to select or breed productive crop lines from the full range of genetic diversity within those species.

Acacia species occur in all the dryland farming regions of southern Australia, on a full suite of habitats and ranging from small shrubs to trees. There are major centres of diversity in both the central wheatbelt of W.A. and in the inland slopes of the south-east of the Murray-Darling basin. Species that occur naturally in the southern Australian wheatbelt would be expected to be well adapted to many of the conditions they would encounter if grown as commercial crops in that region. For species that occur naturally in several different environments, it may be possible to select from different populations to produce different commercial lines of the same species, to suit different types of farm environment. Or, closely related species with different environmental requirements could be grown in different farm situations as part of the same industry, as long as their wood (or other saleable plant parts) had sufficiently similar attributes that could be processed together.

Many species fill a 'pioneer' role (rapid re-colonisers after disturbance). Such species have attributes that are potentially valuable in crops (easy establishment, rapid early growth) but these same attributes may pre-dispose them to weediness. Weed risk can be offset by developing local or regional species in preference to introduced species. Alternatively, weed risk can be controlled by various weed reduction strategies such as developing sterile hybrids, non-flowering forms or lines with reduced hard-seeded dormancy, or by developing management practices that eliminate flowering.

Many faster-growing *Acacia* species are also short-lived. This attribute is unlikely to be a disadvantage for short-rotation phase crops but may make some species unsuitable for use as coppice crops.

Commercial potential

In keeping with their diversity of form, function and distribution, *Acacia* species have found a wide range of commercial uses. Some of the larger species are used for sawn timber, firewood, charcoal, panel board pulp manufacture, and are grown in large commercial plantations (El-Lakany 1987; Brown and Ho Chin Ko 1997). Other commercial uses include tannin production from bark (Barbour 2000), and edible gum exuded from wounds on the stem, most notably from *Acacia senegal*, the source of gum arabic (Anderson and Wang Weiping 1990). *Acacia saligna* is used as a fodder crop in North Africa (El-Lakany 1987; Dumancic and Le Houerou 1981), and is being planted in farming areas in southern Australia as a combined landcare and supplementary fodder species (Lefroy *et al.* 1992). Edible seed from over 40 species from the dry zone may have been included in the diet of Australian aborigines (Devitt 1992). A small industry now exists to supply niche 'bush food' markets in Australia (Maslin *et al.* 1998, Simpson and Chudleigh 2001), and some Australian species have been introduced into famine-prone semi-arid regions in sub-Saharan Africa (Harwood 1994).

Many *Acacia* species are likely to provide suitable feedstocks for large-scale generic products such as solid fuels for electricity production, liquid transport fuel, charcoal and other pyrolytic products, and various

commodity chemicals, as the feedstock specifications required for these products are very broad.

Most existing commercial uses of *Acacia* utilise species that are not commonly found in the wheatbelt of southern Australia and, in some cases, are not native to Australia. However, it is likely that some wheatbelt *Acacia* species also possess commercially desirable characteristics that, once identified, could lead to their development as commercial crop plants. Screening Western Australian wheatbelt species for desirable feedstock characteristics, growth rate and form is being carried out by the 'Search Project'.

Water use potential

While virtually any woody perennial species is likely to consume more water than annual crops, there is likely to be considerable variability in water use potential between species, especially within a large and diverse genus such as *Acacia*.

High water use is an important selection criterion for potential *Acacia* crop plants that are intended to play a role in salinity management in agricultural areas. Partial selection for high water use is likely to occur coincidentally during preliminary selection of *Acacia* species for commercial crops, since two key factors for commercial success, namely high survival rates in medium to low rainfall areas, and high biomass production rates, are most likely to coincide in plants that are effective at extracting water from soil. Although the relationship between water use and a plant's root size and distribution is complicated by many factors, including the availability of water and nutrients (Brouwer 1963, cited in van Noordwijk *et al.* 1996), and management of the plant's above ground parts (van Noordwijk *et al.* 1996), a useful first approximation is that 'the more extensive the root system is, the higher nutrient and water uptake efficiency may be' (van Noordwijk and de Willigen 1991).

Once several highly productive *Acacia* species have been identified for potential crop development, further testing will be needed to find particular forms with optimum root architecture and water use characteristics for the sites on which they are to be grown, and the functions they are expected to perform. Techniques suitable for low cost assessment of plant water use are available and could be used at this stage.

Various aspects of tree root architecture also need exploring, including the effect of pruning or removing the tops, as practised in short-rotation coppice crops. Some studies have found that increased severity of pruning results in an increased proportion of roots near the soil surface, due to new roots growing from the stem base (Hairiah *et al.* 1992, cited in van Noordwijk *et al.* 1996). The relevance of this finding for *Acacia* coppice crops should be tested, as it has implications for both water use and competition between *Acacia* belts and adjoining crops.

Some species have a propensity to develop deep root systems, others shallow ones, and the actual root pattern for a species on a particular site is determined by the interaction between genotype and environment (Kerfoot 1963, cited in van Noordwijk *et al.* 1996). It is likely that at least some *Acacia* species, especially those adapted to dry environments, are deep rooted, or would grow deep roots if grown as an agricultural crop, since deep rootedness is common in xerophytic species where there is access to groundwater (van Noordwijk *et al.* 1996). Knight *et al.* (2002) reported finding live tree roots at a depth of 16 metres under 4-year old belts of *Acacia saligna* and *Atriplex nummularia* (saltbush), while at a similar depth soils under adjacent annual plants had none, although it was not specified whether the deep roots were from *Acacia saligna* or saltbush. In Africa, roots of *Acacia senegal* have been reported at a depth of 32 metres (Deans 1984, cited in van Noordwijk *et al.* 1996).

Deep rootedness is likely to be a desirable attribute for *Acacia* species grown as phase crops on permeable soils, to maximise their productivity when grown at high densities, and to maximise their soil drying capacity. Deep rootedness would usually be preferred for *Acacia* species grown in alley layouts, to minimise competition for water with the adjoining crop. However, if the main aim of growing woody perennials in belts is to reduce waterlogging in the alley, or if the site on which they are grown has shallow soil, then *Acacia* species with a more spreading root architecture may be suitable.

Competition for water between annual crops and adjacent perennial woody crops will be strongly affected by the perennial crop's root architecture and water use. But other factors will also be important, including depth of soil, existing hydrological conditions, rainfall during the annual crop's growing season, and management strategies such as root ripping, or harvesting the perennial crop. In very wet areas or in very wet seasons, annual crop yields may be enhanced if adjacent perennial crops reduce waterlogging, whereas in dry years or on dry sites, they are likely to be suppressed by adjacent perennial crops unless the latter have been harvested recently or their roots are ripped.

Nitrogen fixation

Being a legume, *Acacia* can fix nitrogen and could play a significant role in nitrogen input to agricultural systems, especially when grown as a phase crop on soils poor in nitrogen.

Mele and Yunusa (2001) found significant increases in nitrogen and organic matter in soil at Rutherglen in Victoria following a six-year period under *Acacia*. This was not reflected in greater yield in a subsequent annual crop, partly because the *Acacia* phase had exhausted the soil water supply, and partly due to competition from weeds. However, modelled results from simulated wheat crops indicated that yields would be boosted for at least five years after removal of the *Acacia* crop, due to high soil nitrogen, once the soil water in the crop root zone had been replenished (by one wet year in this simulation).

Other researchers have investigated the effect of a leguminous crop on subsequent non-leguminous crops.

For example, using annual leguminous plants in rotation with maize on acid soils in the humid tropics, van Noordwijk *et al.* (1995) recorded an average increase in maize grain yield of 0.5-1 tonne per hectare following the legume rotation, compared to maize following a grass-weed fallow. The efficiency of using biomass N was found to be about 0.8 times that of applying urea in two split applications.

It appears likely that nitrogen fixed by an *Acacia* phase crop could provide a direct economic benefit by reducing the need to add N fertiliser to subsequent crops. However, to maximise this benefit, new farming systems should be developed based on optimised site selection, crop rotation sequences and integrated management.

Soil rejuvenation

In addition to producing salinity benefits by dewatering soil profiles, a range of other beneficial soil effects has been proposed for woody plants grown in rotation with annual crops. They include, 'nutrient pumping' to relocate plant nutrients from deep in the soil to the surface, 'hydraulic lift' in which dry topsoil is rehydrated with water drawn by plant roots from deep in the soil profile, thereby enabling nutrient uptake to continue in surface soils during dry seasons and droughts (van Noordwijk *et al.* 1996), and the provision of new root channels to improve soil porosity and facilitate root development in subsequent crops, a topic reviewed by Cresswell and Kirkegaard (1995). However, little information is available on these postulated influences of tree roots on soil physical properties (Ong 1996).

Acacias grown as phase crops could provide extensive soil rejuvenation that would benefit subsequent crops, through better soil aeration, reduced surface waterlogging, and easier access for roots. Working at the Rutherglen site described above, Yunusa *et al.* (2001) examined the soil under a wheat crop planted on land that had been occupied by *Acacia* for six years. In the second year after the *Acacia* harvest, the duplex soil (shallow sandy to clay loam surface over a fine sandy clay loam B horizon) contained a greater number of large pores and had a higher air-filled porosity than adjacent continuously cropped soil. Soil porosity increased between the first year after *Acacia* and the second year, as the *Acacia* roots decomposed. The wheat crop grown on the 'acacia soil' had higher root dry matter and higher root length compared to the adjacent wheat crop grown on 'annually cropped soil'. Further investigation of the effect of *Acacia* phase crops on soil physical structure and the productivity of subsequent crops is required.

Seed size and ease of harvest and establishment

Acacia carries its seed in pods, the seed size is large and, in southern Australian species, the seed is generally produced annually in a well-defined season. These attributes mean that the cost of seed collection should be relatively low and that plants can be established by direct sowing rather than by seedling production in a nursery.

The treatments required to break hard-seeded dormancy in many *Acacia* species are now well understood within the nursery trade and among companies and organisations involved in land rehabilitation and revegetation. Similar techniques are likely to be successful for new species developed as crops or, as mentioned above, it may be possible to breed forms with reduced hard-seededness, to lower long-term weed risk, while simultaneously improving ease of establishment.

Vegetative regeneration

Some *Acacia* species can regenerate vegetatively after the stem is cut and this could make them suitable for use in 'permanent' belts in alley farming systems. The ability to resprout from the cut stump (coppicing) appears to be restricted to certain species or, in some cases, provenances or variants within species. Further research is needed to understand the coppicing behaviour of potential commercial species, including variation within species, reliability of coppicing, conditions that favour successful coppicing, and the robustness of successive coppice regrowth from the same rootstock.

Root suckering, also a feature of some *Acacia* species, is likely to be a disadvantage in species that sucker indiscriminately but could be useful in those that sucker more strategically, after a trigger such as death or removal of the main stem. Again, more research is needed to determine the suckering propensity of different species and provenances within species, as well as the environmental conditions that might favour or discourage suckering, so that appropriate farming systems and management techniques can be developed.

Some preliminary information on the coppicing and suckering ability of various *Acacia* species is given in Table 4.

Assessment of individual species

Acacia species that occur naturally in the south-west of Western Australia were assessed in 2000 and 2001for their suitability to be developed as biomass crop plants. The boundaries of the study area were the regions defined in the Interim Biogeographic Regionalisation of Australia (Thackway and Cresswell 1995) as Geraldton Sandplains, Avon Wheatbelt, Mallee and Esperance Plains.

Species considered to be most suited to further investigation are listed in Table 4, along with attributes that may affect their commercial prospects. 'Plant form and growth rate' determine the amount of biomass produced and its ease of harvest, and have a strong effect on profitability, while 'other features' affect each species' potential suitability as a crop plant, the type of farming systems with which it would be compatible, its management requirements, and its potential primary uses (influenced by wood density) and secondary products (such as seed, fodder, tannin and gum).

This assessment was carried out by Bruce Maslin from the Western Australian Herbarium, in association with the Search Project.

TABLE 4
Preliminary assessment of some Western Australian *Acacia* with potential for crop development.

SPECIES AND DISTRIBUTION[1]	PLANT FORM[2] AND GROWTH RATE	OTHER FEATURES[3]
A. acuminata Widespread (wheatbelt)	Tall shrub or tree 2-7 (-10) m tall. Multi-stemmed from ground level, or with a fairly straight bole 0.3-1.5 (-2) m long and 10-30 (-45) cm dbh.Stems and main branches fairly straight. Pendulous forms occur occasionally in parts of the range. Growth rate: moderate	+ Low to moderate salt tolerance + Drought and frost tolerant - Susceptible to waterlogging, fire ± Unlikely to sucker, can coppice from rootstock + Genetically diverse- Seed yields unreliable ± Wood density: high (1 plant, 7 cm stem)
A. anthochaera Northern wheatbelt	Tall shrub 2-4 m tall, occasionally maturing to bushy tree to 8 m. Multi-stemmed from or near ground level. Each stem 6-10 cm in diameter at its base and 4-8 cm dbh. May be single-stemmed to about 1 m above ground level and reach 30 cm in diameter at the base (10-20 cm dbh). Slightly crooked trunks and main branches. Growth rate: moderate to fast	+ Moderately salt tolerant ± Not known to sucker (unlikely to coppice) + Edible seed (large reliable crops) ± Wood density: high (1 plant, 8 cm stem)
A. conniana South coast (geographically restricted)	Dense, bushy shrub or small tree 1.5–6 m tall. Sparingly divided at the base or up to 1 m above the ground Stems sub-straight and 5-8 cm dbh. Growth rate: low to moderate	± Unlikely to sucker, coppicing ability unknown ± Wood density: medium (3 plants, 5-7 cm stems)
A. cyclops ***Coastal***	Spreading shrub (1-4 m tall) or small tree (to 7 m tall). Single-stemmed to about 1 m or sparingly divided at ground level into a few sub-straight or rather crooked main stems (dbh often 10-15 cm, rarely over 20 cm). Growth rate: moderate	+ Salt tolerant + Some provenances grow in waterlogged clays ± Rarely coppices, but may sometimes sucker - Weed potential ± Wood density: medium (4 plants, 5-11 cm stems)
A. jennerae Arid zone	Shrub or small tree, often with 'mallee-like' form, 1.5-4 (-6) m tall.Sometimes single-stemmed but more commonly dividing at ground level into 2 or more, straight, rather slender stems. Often suckering to form clonal thickets. Growth rate: moderate	+ Tolerant of fire, frost, salt, drought ± Strong root suckering and coppicing + Edible seed
A. jibberdingensis Widespread (wheatbelt)	Shrub or small tree 2-4 m tall, occasionally 7 m tall. Single-stemmed to 1.5 m or sparingly dividing just above ground level. Stems up to 25 cm diameter at the base (to 15 cm dbh). Stems and main branches can be rather crooked. May be spindly when growing in dense scrub. Growth rate: moderate	+ Appears to be adaptable to a variety of habitats ± Unlikely to sucker, coppicing ability unknown, but probably poor- Variable seed set
A. lasiocalyx Widespread (wheatbelt)	Spreading shrub or tree commonly 2-5 m tall, dbh 13-15 cm. Often an erect tree around the base of granite rocks, reaching 10-15 m tall, dbh 30-50 cm, with fairly straight trunk. Usually single-stemmed or sparingly divided at the base. Growth rate: fast?	± Unlikely to sucker, coppicing ability unknown - Phyllodes contain relatively high concentrations of cyanogenic glucoside ± Wood density: medium (15 plants, 4-12 cm stems)
A. microbotrya Widespread (wheatbelt) except south-east	Bushy, tall shrub or small tree 2-4 m tall (Dandaragan variant is a tree to 7 m tall). Single trunk to about 1 m before branching (about 11 cm diameter at base), or dividing at ground level into 2-4 main trunks (6-9 cm dbh). Often forming dense clonal clumps by root suckers. Growth rate: fast	+ Slight to moderate salt tolerance? + Drought and frost tolerant± Suckers readily, and probably coppices- Taxonomically complex (under review) + Many related species that may also warrant investigation+ Edible seed, possibly gum, tannin, fodder± Wood density: medium (42 plants, 4-10 cm stems)
A. murrayana Arid zone	Large shrub or tree 2-6 (-8) m. Single- or multi-stemmed from the base. Stems straight or sometimes rather crooked, dbh to 15 cm. Commonly suckering to form clonal thickets. Growth rate: fast	- Salt sensitive + Tolerant of fire (coppices) and drought ± Suckers and coppices - Potential weed + Edible seed, possibly gum ± Wood density: low (3 plants, 8-9 cm stems)

TABLE 4 (continued)

SPECIES AND DISTRIBUTION[1]	PLANT FORM[2] AND GROWTH RATE	OTHER FEATURES[3]
A. prainii Widespread (wheatbelt)	Dense, spreading shrub 1.5-3 (-5) m tall. Branching at or just above ground level into a number of erect to ascending stems. Main stems and branches rather straight (4-6 cm dbh). Growth rate: moderately fast	+ Hardy ± Unlikely to sucker, coppicing ability unknown ± Wood density: high (1 plant, 5 cm stem)
A. aff. redolens Restricted distribution (Esperance)	Small tree 4-7 m tall, may reach 10 m on good sites. Dividing at 0.5-1.8 m above ground level into 2 or 3 main stems (9-20 cm dbh). Stems and main branches sub-straight. Growth rate: unknown	+ Moderately tolerant of salinity? + Grows in waterlogged clays ± Unlikely to sucker or coppice? + Thin bark± Wood density: medium (5 plants, 5-10 cm stems)
A. resinimarginea Northern wheatbelt	Tree 4-7 m tall. Single-stemmed or branched into 2-5 stems near base. Trunks fairly straight, generally erect, reaching 20 cm dbh. Growth rate: slow	- Low tolerance to salt? + Suited to Wodjil sands ± Unlikely to sucker, coppicing ability unknown ± Wood density: high (3 plants, 5-11 cm stems)
A. rostelliferaCoastal	Dense shrub or tree commonly 2-5 m tall. Branching near ground level, with main stems usually 5-10 cm dbh, although some specimens considerably larger. Usually clonal. Spindly when growing within dense clonal thickets, with stems about 2-3 cm dbh. Growth rate: fast	+ Suited to light soil + Root suckers, probably coppices + Many related species - Difficult to get seed ± Wood density: medium (13 plants, 4-12 cm stems)
A. saligna Widespread (wheatbelt)	Bushy shrub or tree 2-6 (-10) m tall. Either single- or multi-stemmed, mature trunks 20–40 cm dbh. Sometimes forming thickets due to root suckering. Variable growth form. The largest, tree form occurs on the Swan Coastal Plain. Growth rate: fast	- Susceptible to various insects and diseases ± Root suckers and coppices (all forms?) + Variable growth forms ± Genetically variable (currently under review) + Edible seed, gum, tannin, fodder, yellow dye- Weed potential? ± Wood density: low (34 plants, 3-15 cm stems)
A. victoriae Arid zone	Spreading, often straggly shrub or small tree 1.5-5 (-6) m tall. Main stems commonly about 6 cm dbh but reaching 12-14 (-18) cm. Readily root suckering and sometimes forming thickets. Growth rate: fast	+ Tolerant of salt, lime, fire (when young), frost and clay soils- Sensitive to severe drought + Coppices and suckers readily + Edible seed, charcoal, fodder- Quite prickly ± Wood density: medium (2 plants, 4-8 cm stems)

1. Distribution refers to the south-west of Western Australia.
2. Some heights and diameters are given for the normal range, with unusually large sizes in brackets. For example: height 2-7 (-10) m tall. 'dbh' refers to diameter at breast height (1.3 m above ground).
3. Wood density was calculated from wood cores taken from some species. Sampling was biased towards small trees. The number of plants sampled and their stem diameter at the sampling height (usually waist height or below) are included. Quoted densities are 'basic density' (oven-dry weight divided by green volume, expressed in kg per cubic metre). Density categories used in this table are: Low: less than 650, Medium: 650 to 850, High: over 850 kg per cubic metre.
4. Symbols in column 3: + advantageous attribute; - disadvantageous attribute; ± advantageous or disadvantageous attribute depending on circumstances.

Table adapted from Maslin (2001).

CONCLUSION

Large-scale revegetation for salinity management is likely to occur only if commercial perennial crops are developed. *Acacia* is a prospective genus for crop development in southern Australia due to the large number of species occurring naturally in Australia, their favourable breeding biology, and their diversity. Many have suitable growth rates and form, and the potential to produce commercially attractive products such as wood, fibre, gums, tannins and seeds.

Acacia species could be suited to each of the perennial woody crop types described in this paper. For example, species with good tree form and good wood quality may be suitable for long-rotation cropping, while species with the ability to sprout reliably from the stump after harvest could be used as short-rotation coppice crops. Obligate seeders might be particularly suitable for use as phase crops. Each crop type could fill a quite different role in agricultural systems.

The economic analysis discussed in this paper shows that *Acacia* species are most likely to be profitable if developed as short-rotation crops, producing low-cost woody biomass. These crop types are best able to utilise the biological potential of *Acacia* to improve water balance and sustainability in southern Australian wheatbelt agricultural systems. Large-seeded *Acacia* species are especially suitable for development, because low-cost establishment using direct seeding has a large, positive effect on profitability, net debt load, and time to break even.

Detailed evaluation will be required to identify taxa with the best commercial prospects. The extent to which *Acacia* crops may be developed will depend on the size of markets for low-cost biomass feedstocks, and criteria for commercial success such as:

- adequate feedstock quality for processing,
- ability to provide feedstock material for more than one product,
- low cost of production relative to competing feedstocks.

The potential of *Acacia* is being investigated in a current project in Western Australia sponsored by the Natural Heritage Trust. Known as the Search Project it is conducting systematic screening of the native flora of the Western Australian wheatbelt to identify species with the potential to be developed into large-scale crop plants.

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Economic potential from Western Australian *Acacia* species: secondary plant products

DAVID S. SEIGLER[1]

[1]Department of Plant Biology, University of Illinois, Urbana, Illinois 61801, USA
Email: seigler@life.uiuc.edu; www.life.uiuc.edu/seigler

SUMMARY

Widespread planting of native Western Australian trees may contribute to resolution of salinisation problems in parts of the wheatbelt and contribute to an overall increase in biodiversity. For these approaches to succeed, however, they must provide income for farmers in the area. Among the most common and most promising tree species in Western Australia are wattles, Australian species of *Acacia* subgenus *Phyllodineae*. Wattles produce a number of interesting classes of secondary compounds, some of which have potential as foods or food additives, whereas others have potential industrial applications. Water-soluble polysaccharides, known commonly as 'gums', are common constituents of these *Acacia* species. There is a significant demand for these products because of long-term shortages–a situation that appears unlikely to change in the near future. Gums are important components of food products and are often used to microencapsulate not only particles of food mixes and pharmaceuticals but also hazardous materials such as insecticides, herbicides, detergents and dyestuffs. Although gum substitutes are available, none of these gums has the desirable physical properties of gum arabic or gum acacia, now primarily derived from one African species of *Acacia*. Some Australian *Acacia* species also produce gum of excellent quality, but new methods of gum induction, harvest, extraction and purification must be perfected before they can compete in the world market. Tannins also are found in many Australian *Acacia* species. Mostly these compounds are used for production of leather but they have a range of other uses. In the past, Australia was a major leather producing and exporting country; the ready availability of good quality, inexpensive tannins might put this again within reach. Plants rich in tannins may not be as suitable for gum production, because the presence of tannins in gums decreases the value of the latter. However, new techniques make it possible to separate gums and tannins more efficiently.

Triglycerides and fatty acids are common components of the seeds of wattles and have a range of non- uses in food. Cultivation and harvest of the seeds can provide edible oils and protein-rich press cake for both human and domestic animal consumption. Other wattle compounds such as resins (diterpenes) probably have limited economic potential. The distribution and chemistry of saponins (triterpene or steroid glycosides) is incompletely known among wattles but some of these compounds appear to have profound biological activity. Although many compounds found in wattles are beneficial, some species contain potentially harmful substances such as cyanogenic glycosides, ß-phenylethylamine, fluoroacetate and non-protein amino acids. The presence of these compounds is not necessarily limiting, but species must be selected to avoid or at least them into account.

Why is cultivation and utilisation of wattles potentially important in the wheatbelt of W.A.? The direct value of products from cultivated wattles may produce new farm income, but large-scale cultivation of the plants may also contribute to amelioration of salinisation problems. This may be accomplished with elements of the native flora and contribute to an overall increase in biodiversity. Although products of intermediate value, such as gums and tannins, would not be expected to accomplish these goals alone, in combination with bulk products such as wood pulp and fibreboard, gums, tannins and possibly resins may improve the economic picture in W.A.

INTRODUCTION

The distinctiveness of the vegetation creates the strong impression of an exotic environment in visitors new to Western Australia, a feeling that is strengthened by the unique geology, the infertility of soils and the flatness of the terrain. Although this unusual perennial sclerophyllous or 'hard-leaved' vegetation is still abundant in much of south-western W.A., it has largely been converted to agriculture based on annual plants (cereals, pasture for sheep, known locally as the 'wheat and sheep' zone). With the discovery of methods to amend the severe nutrient deficiencies of the soils during the last century this region became a rich agricultural area. However, this change has not occurred without problems.

With the flatness of the landscape and the permeability of the soils the original deep-rooted native vegetation was able to capture virtually all of the rainfall because the winter surplus was efficiently stored in the deep soils and extracted during summer. This process also efficiently accumulated

the trace of salt that occurs in rainfall and, over many millennia, substantial stable storages of salt were built up. With conversion to winter-growing annual plant agriculture, the capacity for summer extraction of deeply infiltrated water was removed, groundwater accumulated and mobilised the stored salts. As rising groundwater tables intersect the surface, usually on the broad valley floors, saline water is discharged and extensive degradation of land and streams occurs. Some 10% of previously arable land has been degraded by salinity and it is projected that this will rise to more than 30% within several decades.

Many solutions to the salination problem have been proposed. One proactive approach is to replant trees and shrubs in an attempt to regenerate the original water balance. Placement of the trees in strategic locations, where surface and sub-surface down-slope water movement can be intercepted, is critical to the success of this kind of initiative. Because trees must be planted in great number to be beneficial, they must replace a significant proportion of land presently devoted to annual plant agriculture and this will reduce production. Further, the expense incurred in planting trees is significant. If such programs are to be widely adopted, these problems must be dealt with. One logical solution is for farmers to obtain financial return from the trees and shrubs themselves.

Many factors complicate the search for appropriate tree species for these planting schemes. Past experience with exotic species becoming weeds, even those from eastern Australia, suggests that widespread introduction of these plants should be avoided. Because they are adapted to local conditions, trees and shrubs native to W.A. might be expected to grow best. However, few plants native to the south-western wheat and sheep zone are productive forestry trees and, with a few exceptions such as quandong (*Santalum acuminatum*), they do not produce useful fruits, seeds, or other widely used or conventional consumer products. Obviously, the products derived must be of enough value to offset the cost of planting, maintenance, harvesting and transportation to sites where the plant materials can be processed. It seems likely that large-volume, low-cost production systems utilising all parts of tree and shrub crops and generating multiple products will be required. Because wattle species dominate in the vegetation of much of Australia (Orchard and Wilson 2001) and are especially numerous in south-western Australia, they constitute an obvious group of plants that should be considered. Although the wood of most wheatbelt wattle species is unsuitable for timber in the usual sense, it may be used to make quality panel board and paper products. In addition, these plants often contain substances of potential value, such as gums, tannins, oils (triglycerides), proteins and resins.

Gums

Of these phytochemical products, perhaps the most promising are gums. These water-soluble polysaccharides are common constituents of wattles but also are found in a number of other plants. The most important plant-derived gum exudate for its desirable properties and value is gum arabic (also commonly known as gum acacia), mostly obtained from a single African species, *Acacia senegal* (*Acacia* subgenus *Aculeiferum*). Gum arabic is produced in the Sudan by artificially wounding trees, collecting the tears of gum and transporting them to centres where they are cleaned manually to remove impurities and extraneous material, a very labour-intensive process. The gum is then dissolved, filtered, treated with charcoal, heat-treated (to reduce oxidative enzymatic activity associated with crude gum), and spray-dried (Glicksman and Sand 1973). Depending on quality, the price is between US$3.70 and US$4.30 per kilogram for spray-dried grades, and up to US$19.80 per kilogram for the best quality gums (1993 prices, Whistler and BeMiller 1993). The average yield is about 250 g/tree per year; the total annual production is approximately 60,000 tonnes (Whistler and BeMiller 1993). Substitute gums are produced by modification of starches, from bacterial cultures, from legume cultivars such as guar and carob, and from other plants, but for many applications none of these gums has the desirable physical properties of gum arabic (Whistler and BeMiller 1973, 1993).

Although the production of gums in plants is not well understood, these substances often accumulate in response to stress, injury, or bacterial, fungal or insect attack on the plant (Esau 1965). Degeneration of cells resulting in the formation of complex, variable gums occurs in a broad range of species. This process, called gummosis, results in the depletion of starch in cells and in many cases appears to involve breakdown of cell walls. Gums are usually associated with xylem cells and special structures called gum ducts (Esau 1965). Commonly they are exuded from the sites of injury into cracks and crevices in the bark or as irregular masses or 'tears' onto the surface of the trunk or branches. Gums have been collected by hand for millennia, but only in the last century have collectors purposefully injured the plants in order to collect greater amounts (Glicksman and Sand 1973).

Chemically, gums are water soluble or dispersible complex carbohydrates. Although the structures of naturally occurring plant gums vary widely, many (including the premier plant gum, gum arabic) have backbones of 1→3 linked D-galactopyranose units and most consist of four sugars: L-arabinose, L-rhamnose, D-galactose and D-glucuronic acid. Gum arabic contains the cations Mg^{++}, Ca^{++}, and K^{+} (Glicksman and Sand 1973). This substance is soluble in water to as much as 50% by weight, producing a clear, mucilaginous solution of relatively low viscosity.

Most useful properties of gums are associated with their ability to form hydrophobic or hydrophilic colloids or gels at low dry substance content (Whistler 1973). The particles in solution or suspension become hydrated and associate with each other and with other particulate matter in various products (coacervation) (Glicksman and Sand 1973). Coacervates are considered as immense interacting groups of molecules including the gums, water and other components consisting of colloids with opposite charge.

These interacting units 'thicken' mixtures and keep various components from settling out of suspension or from crystallising. When mixtures of this type are spray dried or prepared by other technologies, the gums bind to various oils, carbohydrates and proteins, stabilise and protect them from water. This 'microencapsulation' of mixture components can produce free-flowing powders of otherwise intractable and even hazardous ingredients, making them more stable, as well as easier and/or safer to utilise.

Gums are important components of many products and processes, although their presence is often not suspected by the general public. They are commonly used in prepared food products as thickeners and emulsifiers to modify physical properties of the foods and to make them conform to consumer preferences. Gums contribute to the desirable physical properties of candies, chewing gum and confections. In soft drinks they help to maintain flavourings in suspension. They are usual components of commercial ice cream where they prevent the formation of sugar and ice crystals. Gums are found in non-food applications such as cosmetics (face masks, hair cream, face powder), toothpaste and dentifrices, soap and laundry detergent, tobacco products, adhesives (paper products, postage stamps), sizes for paper and fabrics, coatings for paper products, paints (water-based paints, thixotrophic mixtures), inks (for lithography, for writing), ammunition and explosives, polishes, ceramics, oil well fracturing, water flow in fire hoses, and hot-quenched steel products. Gums are employed in a number of medical uses including emulsifiers and suspending agents for pharmaceuticals, as antiseptics, bulk laxatives, in pills and tablets, as a replacement for gelatin in capsules, for preparation of time-release capsules, and even as blood substitutes in some situations.

At present, however, the most important use of gums is for microencapsulating particles of water-sensitive, water-insoluble or hazardous materials; these include many kinds of free-flowing powders such as food mixes (puddings, cake mixes, drink mixes), flavour additives for foods, detergents, inks (for printers, 'inkless forms' and ball points), insecticides and insect repellents, herbicides and dyestuffs.

In Australia, many gums are eaten by Aborigines, including those of *A. acradenia*, *A. estrophiolata*, *A. georginae*, *A. jennerae*, *A. ligulata*, *A. murrayana*, *A. pruinocarpa*, *A. stipuligera* and *A. victoriae* (Latz, 1995). In general, however, humans are thought to be unable to digest the complex carbohydrates of gums (Whistler and BeMiller 1993).

Many wattles are capable of producing plentiful quantities of gum (Mantell 1947) and, in the past, gum from a few Australian species was collected and marketed. Among the species previously used as sources of commercial gums were *Acacia pycnantha*, *A. decurrens*, *A. dealbata*, *A. victoriae* (syn. *A. sentis*) and *A. homalophylla*, as well as the gum of an unidentified species (Glicksman and Sand 1973).

Gum from *A. rivalis* provided the basis of a small commercial industry in South Australia near Blinman in the early 1900s (Whibley and Symon 1992). However, most Australian gums were considered to be of poor quality; they dissolved poorly, were dark reddish brown, strong in taste and had a tendency to form gels rather than a mucilage with water. Aqueous solutions of wattle gums have low viscosity (Mantell 1947). Maiden (1906) noted that gums produced east of the Great Dividing Range are more or less insoluble, whereas those of the dry interior tend to be more water soluble, suggesting that gums of Western Australian wattle species may be of more interest than those examined in the past.

In more recent studies, both the physical and chemical properties of wattle gums of have been investigated by Anderson and his colleagues. The Australian species of subg. Phyllodineae examined in these studies include *A. acradenia*, *A. aestivalis*, *A. aneura*, *A. auriculiformis*, *A. bancroftiorum*, *A. calamifolia*, *A. coolgardiensis*, *A. cyclops*, *A. dealbata*, *A. dealbata* subsp. *subalpina*, *A. deanii*, *Acacia deanii* subsp. *paucijuga*, *A. decurrens*, *A. dictyophleba* (or possibly *A. melleodora*), *A. difficilis*, *A. difformis*, *A. elata*, *A. falcata*, *A. filicifolia*, *A. georginae*, *A. harpophylla*, *A. holosericea*, *A. implexa*, *A. irrorata* subsp. *irrorata*, *A. jennerae*, *A. kempeana*, *A. latescens*, *A. leptostachya*, *A. leucoclada*, *A. ligulata*, *A. longifolia*, *A. mabellae*, *A. maidenii*, *A. mearnsii*, *A. microbotrya*, *A. mangium*, *A. mollissima* (probably *A. mearnsii*), *A. montana*, *A. murrayana*, *A. parramattensis*, *A. parvipinnula*, *A. penninervis*, *A. podalyriaefolia*, *A. prainii*, *A. pruinocarpa*, *A. pubifolia*, *A. pycnantha*, *A. resinimarginea* (published as *A. microneura*), *A. retinodes*, *A. rostellifera*, *A. saliciformis*, *A. salicina*, *A. saligna* (syn. *A. cyanophylla*), *A. silvestris*, *A. stereophylla*, *A. tetragonophylla*, *A. torulosa*, *A. trachyphloia*, *A. uncinata*, *A. victoriae* and *A. xanthina* (Anderson 1972, 1978; Anderson and Dea 1969; Anderson and Gill 1975; Anderson *et al.* 1972, 1980, 1983, 1984a, b, 1985). Although initial studies indicated that gums of species of subgenus *Phyllodineae* were characterised by low rhamnose content, low acidity, low intrinsic viscosity and a high galactose/arabinose ratio, later studies revealed a much wider range of variation in many of these parameters than was initially observed (Anderson *et al.* 1984a).

Isolation of gums in the manner used in the Sudan is not economically feasible in Australia. Gum from Australian acacias will probably have to be isolated by cutting or grinding and extracting the tree material, and almost certainly will be linked to other on-going processes and products. There are many unknowns: will young plant material produce the gum or is older growth required? Is wounding required to get the plant to produce the gum? Can wounding be simulated? Can or must gum be removed in processing wood and wood fibre for making fibre or composition board? What steps are needed to clean up the gum in extracts? How much water is required? Is the gum of adequate quality when isolated in this manner?

Most likely, gum would be isolated from aqueous washes or extracts made in the manufacture of wood products. These processes require water, a commodity in limited supply in most of Australia. Although the water can be recovered, there is a significant energy cost linked to that process. Whether gum isolated in this manner will be of suitable quality is not known.

Past research suggests that the trees must be 'wounded' or 'stressed' in some way to get them to produce and accumulate sizable quantities of gum. This might be possible by selective application of herbicides. However, initial experiments with 2,4-dichlorophenol (2,4-D) (chemical defoliation) did not increase gum exudations with *A. murrayana* and a number of other species (Anderson *et al.* 1984a). Other forms of stress such as girdling trees, that would be less labor-intensive than the methods used in Africa, also may cause accumulation of gums. Extraction processes may mobilise tannins, which are found in many of the same tissues, and complicate cleaning up the gums. To determine the best methods for enhancing gum production, extraction and cleanup, studies must be carried out under Australian conditions.

The viscosity is low for gum arabic solutions compared to other commercial exudate gums, but viscosity alone doesn't determine the suitability of a gum. One must examine the physical properties and match them to particular applications. There are some properties that decrease the value of gums. Among them are insolubility, colour, strong taste and the presence of tannins. The single step of removal of tannins from wattle gums will yield gum products that then can be evaluated for various applications.

From time to time individuals or companies have advocated collection and development of Australian wattle gums as competitors for gum acacia. Most of these 'promoters' and 'entrepreneurs' have not considered either the technical aspects or the economics carefully. Gums do represent a resource that can complement other products and can offer additional income for farmers. If wattle species are cultivated, harvested and used for sources of wood products (fibre board, chip board, pulp etc.), it may be possible to isolate gums as a by-product of these processes. Most likely the trees would have to be grown under contract to companies with the financial resources to provide the processing needed and with a vital interest in obtaining gums of good quality. The developer would have to market the product for specific applications, establish that the gum really is superior for those applications and do so at competitive price.

In recent years, supplies of good quality gum arabic (from *A. senegal*) have decreased because of the long-term civil disturbance in the Sudan and because the financial rewards are insufficient for gum collectors. Consequently, many substitutes have been used and, according to Whistler and BeMiller (1993), because of irregular supply and cost, the market for plant-derived gum exudates would seem to have a limited future. Nonetheless, if these problems can be solved there is still a strong world demand for good quality gums and, if gums of the quality of gum arabic can be produced at reasonable cost from Australian wattles, this could be reversed.

Condensed tannins

The Australian species *A. mearnsii* is a major source of commercial tannins, although now production is based on plants cultivated in southern Africa and in Brazil. This species (formerly known as *A. mollissima* or *A. decurrens* var. *mollis*) was once the basis of a thriving industry that supplied colonial tanners in Victoria and N.S.W. (Searle 1991). In the late nineteenth century, wattle bark was collected widely from natural stands (Maiden 1906). By the early 1900s, plantations of *A. mearnsii* were established in Victoria (Searle 1991). This continued into the 1920s, when large quantities were extracted and leather was produced locally (Searle 1991), but then the manpower available to strip the bark from the trees decreased. Lines of *A. mearnsii* that consistently produced good quality tannins were not selected and developed. Although the bark often contained 20-40% tannin there was considerable variation in yield and quality of wild-harvested tannins. Contributing to the variability was the collection of samples from similar species such as *A. irrorata*, *A. parramatta*, and *A. decurrens*. Often the quality of the bark was low because of improper stripping and storage. Competing land uses removed a large proportion of the former tannin-producing area from consideration. There was a long wait (5-7 years) until the trees could be profitable, and the profit was often uncertain (Maiden 1906; Searle 1991). In a number of instances, plantations of wattles were attacked by insects and pathogenic rusts. Today, Australia imports tannins, mostly from China, that are produced from this Australian tree under a special joint program (Searle 1991). Although leather production in Australia has decreased in recent years, the need for tannins appears to be increasing.

Other species also have been utilised as tannin sources in the past. In South Australia *A. pycnantha*, and in Western Australia, *Eucalyptus astringens*, also were widely used as sources of condensed tannins. These species often contain 20-40% tannins in the bark (Maiden 1906).

Little is known about the identity of the proanthocyanidin molecules of condensed tannins of Australian wattle species. The only species that has been examined in any detail is *A. mearnsii*, because it represents one of the world's major tannin resources. The extract from the bark of this species contains about 70% proanthocyanidins (up to 3000 MW) (Young *et al.* 1986). The proanthocyanidins themselves consist largely of bi-, tri-, and tetrameric profisetinidins and prorobinetinidins (Roux 1972; Young *et al.* 1986; Coetzee *et al.* 1995).

Leather produced from black wattle (*A. mearnsii*) is pliable and has good colour. These tannins are used primarily for the manufacture of leather but also have applications as dyestuffs, corrosion inhibitors, to promote flow of liquids in pipes, and as pharmaceutical products. They formerly were used in the manufacture of inks. Another major demand is for production of tannin-based

wood adhesives (Anonymous 2000; Searle 1991). Particle board bonded with *Acacia mearnsii* tannin adhesives has improved water resistance properties compared with urea-formaldehyde bonded board that is commonly used (Searle, 1991). Yet other uses for tannins include flocculation of clay suspensions in municipal water supplies, surface coatings for wood and thinning agents for drilling muds (Roux 1972).

As is true for gums, much basic research work must be done on tannins to ensure a quality product and to resolve problems of harvest, isolation and preparation for market. A number of species of wattle suitable for tannin production have been identified but most are native to N.S.W., Victoria and S.A. Apart from *A. pycnantha*, which is an environmental weed, none is likely to grow well in the semi-arid wheatbelt of W.A. However, preliminary tests indicate that a number of Western Australian *Acacia* species are rich in tannins. To be economically successful, these plants also would have to be useful as sources of wood products. Plants rich in tannins may not be as suitable for gum production because the presence of tannins in gums decreases the value of the latter, but this assumption should be examined in view of new separation techniques that make it possible to separate gums from tannins and to purify the gums more efficiently.

In the past, Australia was a major leather producing and exporting country; the ready availability of good quality, inexpensive tannins might put this within reach again.

Seed oils and proteins

The seeds of a number of Australian wattle species were used by Aboriginal people as sources of protein and, to a lesser extent, oils (Anonymous 2000). Among those commonly eaten in eastern Australia were *Acacia dealbata*, *A. longifolia* subsp. *sophorae*, *A. pycnantha*, *A. stenophylla* and *A. verniciflua* (Anonymous 2000). In southern Australia 42 species were eaten, but at least 47 species appear to have promise for human consumption (Maslin *et al.* 1998).

The oil content of 20 *Acacia* species, 18 of them known to have been consumed by Aborigines, was given by Brown *et al.*, (1987). These comprise mostly triglycerides (3-22%) in which either linoleic or oleic acid predominated. The protein content of *A. alata* (23.6%), *A. dealbata* (20.9%), and *A. drummondii* (28.5%) is relatively high (Rivett *et al.* 1983). Polyunsaturated oils predominate in the seeds of each of these species. In *A. cyclops* the oil from seed and funicle differs in composition–in the seed (10% dry weight of the seeds) it is highly unsaturated, whereas in the funicle (40.6%) it consists mostly of saturated fatty acids (Black 1949).

In recent years there has been a resurgence in popularity of the 'bush tucker' industry and seed from several species of wattle has been used as a source of human food (Maslin *et al.* 1998). The most important are *Acacia victoriae* and *A. murrayana*. Seed of *A. murrayana* contains as much as 5% oil and 20% protein (Maslin *et al.* 1998). The oil consists mostly of polyunsaturated fatty acids (62% linoleic acid), with 20% monounsaturated fatty acids (18% oleic acid), and 18% saturated fatty acids (Brown *et al.* 1987). The seeds of *Acacia victoriae* contain 17% protein (Brand and Cherikoff 1985).

Many wattle seeds contain proteinase inhibitors and must be heated before being consumed in order to denature these potentially toxic compounds. Others contain non-protein amino acids which can be toxic to non-adapted animals (including man) but, as these seeds have previously been eaten by humans, in these particular species the compounds occur in quantities that do not appear to be harmful (Maslin *et al.* 1998).

Cultivation and harvest of wattle seeds can provide edible oils and protein-rich press cake for both human and domestic animal consumption. There is always a good market for seed triglycerides. Fatty acids derived from these triglycerides are used commercially to make soaps, as precursors for plastics, for manufacture of lubricants, waterproofing substances, and a variety of other products. Highly unsaturated oils are traditionally used for paint and varnish formulation and are also considered highly desirable in human diets.

Terpenes

A few Australian wattles produce resins, usually mixtures of diterpenes (Forster *et al.* 1985). These lipid-soluble materials are used in a number of minor applications, primarily as adhesives that might be useful in manufacture of wood products. Some diterpenes may serve as relatively versatile precursors for synthesis of other groups of useful compounds, but *Acacia* resins will probably be only by-products with little practical value. A series of labdane diterpenes was isolated from a Western Australian species that appears to be *Acacia rossei* (Forster *et al.* 1985).

In a report of Maiden (1907), saponins were from a number of species of plants including *Acacia pulchella*, *A. anthelmintica*, *A. concinna*, *A. delibrata* and *A.* '*cunninghamii*', the last not a currently accepted name. Pedley (1999) stated that '*Acacia concurrens* together with *A. crassa, A. leiocalyx* and *A. longispicata* constitute a group of closely interrelated and taxonomically 'difficult' species belonging to the often confused and poorly defined '*A. cunninghamii* group' (see also Pedley 1974, 1978). Further, *A. anthelmintica* and *A. concinna* are non-Australian species. Recently several saponic triterpene glycosides from *Acacia victoriae* have been examined for their ability to decrease tumor cell proliferation and to induce apoptosis (Haridas *et al.* 2001; Mujoo *et al.* 2001). The distribution and chemistry of this group of compounds in wattles should be investigated more fully.

Toxicity problems

Although most compounds found in wattles are of benefit to humans and domestic livestock, there are also some harmful substances. The presence of these compounds may not rule out using a particular species, but certainly any

utilisation plan must consider them. For example, many Australian plants contain fluoroacetate. This substance is apparently known from only one *Acacia* species, *A. georginae* (Georgina Gidgee), primarily of the Northern Territory (Cowan 2001). The foliage (Everist 1978) and the seeds (Latz 1995) are highly toxic to livestock and people.

Many species of Australian wattles contain cyanogenic glycosides. These substances can release hydrogen cyanide when the plants are damaged. For this to occur, both the glycosides and special enzymes, ß-glucosidases, must be present. Among Australian wattles, plants are known that lack both, that have the glycosides and not the enzymes, that have the enzymes and not the glycosides, and that have both. This last type is potentially toxic, especially to livestock. In a survey of approximately 96% of the Australian species of *Acacia*, 45 species were shown to be cyanogenic (Maslin *et al.* 1987, 1988). Forty-three of these were in subgenus *Phyllodineae* and two in subgenus *Acacia*. Cyanogenesis was limited to certain sections of the subgenus *Phyllodineae*; most cyanogenic species were in section *Juliflorae* (Maslin *et al.* 1988). The cyanogenic glycosides in subgenus *Phyllodineae* are prunasin and/or sambunigrin, derived from phenylalanine, whereas those from two species of subgenus *Acacia* are proacacipetalin, derived from leucine (Maslin *et al.* 1988). Everist (1981) noted that poisoning under field conditions was limited to *A. binervia*, *A. sparsiflora* and one species in the *A. cunninghamii* complex. As noted above, however, the *A. cunninghamii* complex is taxonomically vague and in subsequent testing the other two species were found to be non-cyanogenic (Maslin *et al.* 1987), suggesting that even these reports are dubious.

The seeds of many wattles contain non-protein amino acids. These compounds can be toxic to non-adapted animals, including man. Should the seeds be used to isolate fatty acids or triglycerides, the press cake (the residue remaining after expression of oils) of species with seeds especially rich in these compounds may have limited value for animal feed and could become a disposal problem. Of approximately 100 species of *Acacia* examined, most contained non-protein amino acids (Evans *et al.* 1977; Seneviratne and Fowden 1968). This included more than 60 species of the largely Australian subgenus *Phyllodineae* and several Australian members of subgenus *Acacia*.

Potentially toxic non-protein amino acids, such as djenkolic acid, are found in several tropical dry-zone Australian *Acacia* species, but at levels below those that normally would cause toxicity (Maslin *et al.* 1998). Because the seeds of many of these species were eaten by Aborigines, those species would appear not to contain excessive quantities of these compounds. The non-protein amino acids 2-amino-4-acetylaminobutyric acid, 2,4-diaminobutyric acid, and 2-amino-6-*N*-oxalylureidopropionic acid (oxalylalbizziine) are found in the seeds of the New World species *A. angustissima* (probably from materials sometimes considered to be a distinct species, *A. boliviana*), which was introduced into Queensland for forage in the 1980s (Evans *et al.* 1985).

N-Methyltyramine characterises a number of species of *Acacia* in subgenus *Aculeiferum* section *Monacanthea*. These include species from North and South America, Africa, and Asia (Evans *et al.* 1979). The amine is found in the seeds (Evans *et al.* 1979) and in vegetative material (Evans *et al.* 1977). *N*-Methyltyramine co-occurs with ß-phenethylamine and *N*-methyl-ß-phenethylamine in vegetative material of *A. berlandieri* (Camp and Norvell 1966; Evans *et al.* 1977; Forbes *et al.* 1995). However, amines also occur in Australian species. For example, *N*,*N*-dimethyltryptamine and other *N*-methylated tryptamines have been reported from the bark of two eastern temperate zone species of subgenus *Phyllodineae*, namely, *A. maidenii* and *A. phlebophylla* (Fitzgerald and Sioumis 1965; Rovelli and Vaughan 1967).

Whether any of the above types of compounds would be of concern depends on many factors, but with careful planning and proper selection of species, otherwise toxic compounds may not be a major constraining factor in the domestication of Australian wattles. However, the chemistry of any wattles being assessed for extensive planting should be carefully investigated.

Utilisation of wattles in Western Australia?

The problems of salinisation are sufficiently serious to require immediate remediation. Cultivation of trees on former wheat lands is one of the strategies being explored for accomplishing this effect, but many problems will be encountered. Not least of these is a possible reduction in income for farmers unless suitable economic value can be found for these newly cultivated tree crops. Use of native flora will help to overcome problems that have arisen from use of introduced plants that have become invasive and weedy. Careful planting can restore a measure of the former biodiversity as well. The trees selected must be easily grown and possess a reasonable base of variation. Only those generating products such as fuels, petroleum replacements, wood products, major industrial solvents, major chemical precursors, fibres or foods are likely to be effective. To be useful, these bulk products must be of sufficient value to offset the costs of harvesting and transportation to sites where they can be processed efficiently. Nonetheless, commodities of intermediate demand and value such as gums, tannins and resins may supplement or complement low-cost bulk products. Smaller amounts of products of high value could round out this picture.

Several examples suggest that marketing chemical products from Western Australian species can be successful. One native species, sandalwood (*S. spicatum*), is cultivated, despite some challenging problems, and Australia already exports sandalwood and sandalwood oil. Another potential product, the monoterpene cineole, is isolated from several *Eucalyptus* species, notably oil mallee (*E. kochii* with two subspecies) and *E. horistes*. There are widescale plantings of these species in several places in the wheatbelt and a facility for isolation of the essential oil has been constructed.

The scheme most likely to succeed will be a mosaic of some exotic and eastern Australian plants, Western Australian natives, plants cultivated for wood products and bio-energy, with by-products based on tannins, gums and resins, wood waste for fuel, and plants used for essential oil production, all grown in combinations to suit local soil, slope and drainage, nearness to processing plants, centres of usage and shipping points, and many other factors thrown together.

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Livestock potential of Australian species of *Acacia*

ROBYN A. DYNES[1] AND ANTHONY C. SCHLINK[1]
[1]CSIRO Livestock Industries, Private Mail Bag 5, Wembley, Western Australia 6913
Email: Robyn.Dynes@csiro.au

SUMMARY

Trees and shrubs have long been considered important for the nutrition of grazing and browsing animals in Australia, particularly where the quantity and quality of pastures is poor for long periods The economic or feeding value of *Acacia* species for animal production will depend on when the nutrients are available (i.e. does foliage/seed/pod production match feed gap or drought?) and the concentrations of essential nutrients and secondary compounds in foliage, seeds or pods.

The feeding value of any forage is a function of a number of characteristics of the species, including its availability, accessibility, nutrient availability, chemical composition and presence or absence of secondary compounds. The accessibility of foliage and/or seeds and pods on acacia trees and shrubs is likely to limit the performance of grazing ruminants, although the potential exists to select lines more suited to grazing species. Forage digestibility is an important component of nutritive value, but only limited data exist for Australian *Acacia* species. The digestibility of *Acacia anuera* is reported to be between 39% and 64%, suggesting that there are lines suitable for animal production. Mineral composition of Australian acacias varies considerably between species, ranging from toxic to inadequate for livestock production. Plants that grow in inhospitable environments commonly contain secondary compounds which play a role in plant survival. Acacias are reported to have a wide range of secondary compounds including tannins, oxalates, cyanides, saponin, amines, alkaloids, fluoroacetate and other unidentified toxins. The level and presence varies with both species and plant part. Options for reducing the impact of secondary compounds are discussed.

Utilisation of acacias in farming systems could be improved through selection of species to provide feed for livestock during feed gaps and droughts, as long as issues of fodder accessibility and secondary compounds are overcome. An effective selection process will require screening a very large number of samples to determine plant quality. Near-infrared reflectance spectroscopy (NIR) is a rapid, inexpensive and accurate method and requires only small samples of plant material.

INTRODUCTION

Trees and shrubs have long been considered important in the nutrition of grazing and browsing animals in Australia, particularly where the quantity and quality of pastures are poor for long periods (Lefroy *et al.* 1992). Foliage from trees and shrubs has the potential to provide both protein and energy supplements during the annual feed gap or during drought (McMeniman and Little 1974; Bhattachrya 1989; Reed *et al.* 1990). Several species of *Acacia* are recognised by graziers for their feeding value during drought (Chippendale and Jephcott 1963; Everist 1969). The economic value of these species to animal production will depend on when the nutrients are available (i.e. does foliage/seed/pod production match feed gap or drought?) and the concentrations of essential nutrients and secondary compounds.

Investigations of the potential of trees and shrubs (particularly acacias) as fodder sources for livestock in Australia has been limited to the more widespread, better-known fodder species such as Mulga (*Acacia aneura*). The accumulated data are now sufficient for *A. aneura* to become incorporated into pasture grazing systems models (Hall *et al.* 2000). For most acacia species there are limited or no data, making it impossible to select and exploit variation within and between species to maximise animal productivity.

This paper addresses the potential of Australian species of *Acacia* for selection for animal production, their nutritional value, and the opportunities for incorporating them into grazing systems. It also looks at intraspecific variation in feeding value, secondary compounds and how the secondary compound issues have been addressed for ruminant livestock.

FEEDING VALUE OF *ACACIA*

Feeding value of any forage is a combination of dry matter availability (and accessibility) and the value of the ingested dry matter for use by the grazing animal (nutritive value, NV). Variation in voluntary feed intake (VFI) accounts for 50% of the variation in feeding value of forages (Ulyatt 1973). As a consequence, any characteristics of the feed which affect intake and the ease of harvesting are critical to the value of the feed for animal production. A number of physical and chemical factors determine both actual intake and utilisation.

Accessibility

The growth architecture of acacia trees and shrubs is likely to limit access by grazing ruminants. Animals can increase intake rate to compensate partially for a reduction in bite size associated with browsing (for review see Ungar 1996), but usually small bite size cannot fully compensate for harvesting difficulties. However, litter fall from acacias (foliage plus fruit) can be as high as 7 tonne/ha/year, suggesting that the quality of litter should be assessed in any selection program. Management by seasonally controlling stocking rates, lopping, or cutting-and-carrying are options to increase fodder accessibility to the animal (Goodchild and McMeniman 1987).

Digestibility

Digestibility (dry matter digestibility, DMD) of forage is one of the measures used to describe the NV of forage. It is the proportion of the feed that is not excreted in the faeces and, although a simple method, large scale *in vivo* experiments are very expensive. Laboratory-based estimates of animal digestibility (*in vitro* dry matter digestibility IVD) are rapid and relatively inexpensive. Growth and production can be predicted by using digestibility, to calculate megajoules (MJ) of metabolisable energy (ME) per kg feed dry matter (M/D) (Standing Committee on Agriculture 1990).

The IVD of acacia foliage has been determined for only a small percentage of the Australian species but available data indicate that it is relatively low, ranging from 28.9% to 55.0%. The lower values have been recorded for the phyllodinous species (Gohl 1981; McDonald and Ternouth 1979; McLeod 1973; McMeniman *et al.* 1981; Skerman 1977; Vercoe 1986; Craig *et al.* 1991). This relatively low DMD is probably associated with the high lignin content of the cell wall; fibre digestibility is inversely related to lignin content of the fibre (Van Soest 1982). Craig *et al.* (1991) found that digestibility differed between shoots and phyllodes as well as with season and that these differences varied between species.

Where forages have low digestibility, low metabolisable energy and high fibre values, then theoretically a grazing animal can still grow by increasing intake. In reality, when IVD falls below 55%, physical limitations on the rate of eating, rate of digestion and passage through the gastrointestinal tract mean that intake is restricted and live weight loss is inevitable (calculated from Standing Committee on Agriculture, 1990).

Mulga is the only Australian acacia so far subjected to detailed *in vivo* digestibility studies in Australia, although *Acacia saligna* has been studied extensively overseas. Mulga has an *in vivo* digestibility of 39-64.5% (Gartner and Niven 1978; Goodchild and McMeniman 1987; Pritchard *et al.* 1992), suggesting scope for selection of lines suitable for animal production.

Digestibility can be improved by supplementation and ensiling. Digestibility of *A. aneura* was increased from 46.8 to 58.1% by the addition of phosphorus and molasses (McMeniman 1976). Prichard *et al.* (1992) showed a 3.4% increase in DMD but a change in nitrogen balance from -0.52 to 1.28 g/day with the use of polyethylene glycol and mineral supplement in the diet to reduce the influence of tannins on animal production. *Acacia saligna* is grown extensively overseas and animal studies have shown DMD ranging from 31.3% to 54.4% (Howard *et al.* 2001; Ben Salem *et al.* 1997; Abou El Nasr *et al.* 1996) with ensiling improving digestibility to 63.4% (Abou El Nasr *et al.* 1996). Australian studies by Howard *et al.* (2001), have reported the lowest digestibilities, 23.1% units lower than international studies, suggesting that there is a marked difference between the *A. saligna* accessions under study in animal experiments. Acacias grow in diverse environments, including salt affected areas so, when reviewing *in vivo* digestibility figures, consideration should be given to the soluble mineral content, the non-protein nitrogen and tannin content, as well as the traditional link between fibre content and digestibility. In areas where acacias will be utilised, however, supplementation and ensiling are unlikely to be cost effective and selection of suitable lines of acacias is required.

Studies of the Oxford *Gliricidia* collection showed large variation in both leaf *in vitro* DMD and nitrogen content in the 26 lines grown in the same environment (Schlink *et al.* 1991). Nitrogen content ranged from 3.00 to 4.15%, DMD from 67 to 80% and dry matter yield from 2.1 to 6.5 tonnes/ha with no relationship between dry matter yield and nutritional parameters. This poor correlation between plant yield and nutritional quality indicates that nutritional quality should be taken into account in the selection of species for animal usage.

Chemical composition

A selection of chemical compositions of Australian acacia species is presented in Table 1. Mineral concentrations also vary significantly between species, ranging from toxic to inadequate for livestock production. The ash in forage has no energy value but the apparent digestibility will be increased if the soluble ash content is high and not accounted for. Using DOMD (digestible organic matter in the feed dry matter) corrects for very high ash content; for example, hay with a 60% DMD has an DOMD of 55% whereas in a sample of *Atriplex* (salt bush: total ash 30%, soluble ash 24%) still with a digestibility of 60%, DOMD would now be 36% and ruminants would not be able to eat enough organic matter to prevent live weight loss (Masters *et al.* 2001).

Vercoe (1986) and Craig *et al.* (1991) reported phosphorus deficiencies in most acacias tested, leading to an imbalance in the calcium to phosphorus ratio in foliage (Table 2). Similarly, for most species the levels of potassium, sodium and sulphur were low (Vercoe 1986), but Craig *et al.* (1991) found that most acacias tested had adequate sodium levels. In the latter case, differences between species should be treated with caution, as the plant material was collected from the wild. Such differences may reflect differences in soil and growing conditions more than differences between species. In a study of the mineral composition of foliage of some species of *Acacia*, Vercoe

TABLE 1
Proximal composition of leaves of some commonly grazed species of *Acacia* (extracted from: Goodchild and McMeniman 1987; Craig *et al.* 1991; Howard *et al.* 2001; Abou El Nasr *et al.* 1996; Degen *et al.* 2000; Kaitho *et al.* 1997; Salem *et al.* 1999).

SPECIES	CRUDE PROTEIN g/kg	ETHER EXTRACT tg/kg	CRUDE FIBRE g/kg	ASH g/kg	OMD *In vivo* g/g	OMD *in vivo* g/100 g	DMD *in vivo* g/100 g
A. aneura	92-203	21-56	238-366	34-69	35-63	35-50	
A. cambagei	109-133	31-59	137-159	110-140		44	
A. pendula	132-164		255-296	56-89	43	43-50	
A. farnesiana	150-242	20-60	100-223	44-78		54-68	
A. albida	171-197	15-30	124-215	64-86	53		
A. seyal	111-293	12-68	84-228	10-84			
A. ampliceps	120-170			110-150			50-55
A. brumalis	100-140			30-40			36-48
A. cyclops	80-100			60-100			39-44
A. ligustrina	90-120			40-60			44-52
A. saligna	50-150			80-140	31-60		

TABLE 2
Mineral composition of leaves of some species of *Acacia* (source: Vercoe 1986)

SPECIES	Ca (%)	P (%)	Na (%)	Mg (%)	S (%)	Zn (ppm)	Mn (ppm)
A. bidwillii	2.43	0.09	0.06	0.24	0.21	37	49
A. salicina	3.52	0.11	0.02	0.29	1.13	55	30
A. leptocarpa	.97	0.06	0.25	0.37	0.18	75	622
A. aneura	1.39	0.07	0.01	0.26	0.17	76	863
A. melanoxylon	0.81	0.09	0.16	0.28	0.16	64	457
A. deanei	0.70	0.09	0.09	0.27	0.15	37	64
A. concurrens	0.97	0.05	0.25	0.26	0.18	47	917
A. stenophylla	2.08	0.10	0.16	0.35	0.58	123	42
A. glaucocarpa	1.01	0.05	0.08	0.23	0.14	45	53
A. fimbriata	0.30	0.06	0.13	0.25	0.12	33	83

(1986) found that copper was at levels that may be toxic to sheep, but copper contamination of samples could not be ruled out. Other minerals (Table 2) were at acceptable levels.

Protein levels provided by plant analysis are often a misleading indication of protein available to animals consuming the plants. This is partly due to the methods used to determine protein in the plant and partly to the processing and absorption of protein and other nitrogen compounds in the ruminant gastrointestinal tract. Most acacias examined have adequate crude protein contents for animal production. Again, there is considerable variation between species, ranging from 5.0% to 29.3% (Table 1).

An effective selection process will require screening a very large number of samples to determine plant quality. Near infrared reflectance spectroscopy (NIR) is a rapid, inexpensive and accurate method, requiring only small samples of plant material. NIR requires calibration with actual wet chemistry results from a subset of samples.

Pods and seeds

In general, pods have lower crude protein concentration and higher organic matter digestibility than foliage (Gohl 1981). In Australia and internationally there are few reports of the nutritional value of acacia pods and seeds for livestock despite the extensive knowledge of the use of acacias for human consumption and widespread consumption of ripe pods by animals in the dry season. In many areas, fruits are collected and brought to feed cattle or sheep or sold for fodder. In some regions animals are taken to the trees and fruit is consumed as it falls naturally or is knocked down by herders. In the semi-arid grazing regions of Australia *A. aneura* pods are much sought after by sheep, either on the trees or after they have ripened and fallen (Everist 1969). A number of other Australian acacias have been identified as being sought after by livestock (Maslin *et al.* 1998).

The fruits from *A. tortilis*, *A. albida*, *A. nilotica* and *A. sieberiana* have been evaluated in comparison with more traditional extracted protein meals (Tanner *et al.* 1990).

In general, *A. tortilis* and *A. albida* appear to have a nutritive value comparative to that of the extracted protein meal when offered as a supplement to maize stover. Lower growth rates and feed intakes occurred with *A. sieberiana* and *A. nilotica*, which the authors attributed to the phenolic compound and proanthocynidins in the fruit. The extent of digestion of the seed in the fruits ranged from 54% for *A. tortilis* to 96% for *A. sieberiana*. Ingestion and passage of seed through the digestive tract and subsequent appearance in the faeces permits seed distribution and improved seed germination (Gwynne 1969). Low apparent digestion of *A. tortilis* seeds would mean a significant loss of potentially available nitrogen and energy to the animal but effective spread of the seeds. Lowry *et al.* (1993) found that *A. nilotica* fruit used as a supplement on dry Mitchell Grass hay stimulated the intake of hay while the sheep remained in negative nitrogen balance. Improved nutritional status with fruit supplementation had positive effects on both live weight and wool growth.

Cleaned seed has been proposed for human consumption and extensive studies of the composition have been undertaken of a number of acacia species (Brand and Maggiore 1991; Rivett *et al.* 1983). A number of species have been identified for potential commercial production for human consumption (Simpson and Chudleigh 2001). Although the emphasis in these studies has been on the potential for human consumption, the possibility of livestock utilisation should not be overlooked. Simpson and Chudleigh (2001) determined that harvesting technology may pose an economic constraint on the human-food industry, particularly in the early phase of establishing the industry. Livestock can self-harvest seed that may be uneconomic to harvest in the early stages of plantation and technology development, thus providing an economic return beyond that obtained from the harvested product alone.

Secondary compounds

Plants growing in inhospitable environments frequently contain secondary compounds that play a role in plant survival. Secondary compounds may function to enable the plant to tolerate the soil, water and climatic stress or may act as deterrents to grazing herbivores (e.g. tannin, oxalate, nitrates). Acacias are reported as having a wide range of secondary compounds apart from tannins, summarised in Table 3.

Tannins

Tannins are polyphenolic compounds found in many plants and are by far the most common secondary compound found in acacias of Australia. Tannins can be beneficial or detrimental to the ruminant, depending on concentration. From 2-4 % tannins in the diet protects protein from rumen degradation and increases the absorption of essential amino acids whereas 4-10% depresses voluntary feed intake (VFI) (Terrill *et al.* 1992; Barry and McNabb 1999). Benefits reported include increases in wool production, milk protein secretion, ovulation rate and the development of more nutritionally based and ecologically sustainable systems for disease

TABLE 3
Toxic compounds in *Acacia* species for ruminants.

SPECIES	PART OF PLANT	TOXIN	REFERENCE
A. aneura	phyllode	oxalate	Gartner and Hurwood 1976
A. aneura	phyllode	tannin	
A. burrowii	flowers	hydrogen cyanide	Cunningham *et al.* 1981
A. cambagei	phyllode	hydrogen cyanide	
A. cambagei	timber, bark	oxalate	
A. cana	browse	selenium	
A. deanei	browse	hydrogen cyanide	
A. decora	browse	abortive agent	
A. doratoxylon	browse	cyanogenic glycoside	
A. georgina	browse	hyrolytic enzyme only	Hall 1972
A. georgina	seeds/pods	fluoroacetate	Everist 1969
A. giraffae	unripe pods	unknown toxin	Gohl 1981
A. implexa	unripe pods	unknown toxin	Cunningham *et al.* 1981
A. longifolia	browse	hydrogen cyanide	
A. murrayana	browse	unknown toxin	
A. paradoxa	browse	unknown toxin	
A. salicina	phyllode/bark	tannin	Hall 1972
A. salicina	pods	saponin	Hall 1972
A. saligna	browse/pods	tannins	Degen *et al.* 1998
A. berlandieri	browse	amines and alkaloids	Clements *et al.* 1997
46 *Acacia* spp.	foliage	hydrogen cyanide	Maslin *et al.* 1986

control in grazing animals. Tannins may also appear to have some protective effects against the establishment of, and tissue damage caused by, gastrointestinal nematodes (Kahn and Diaz-Hernandez 2000). Tannins levels in excess of 50 g/kg dry matter, on the other hand, can lead to low palatability, reduce digestibility, lower intake, inhibit digestive enzymes and be toxic to rumen micro-organisms (Kumar and Vaithiyanathan 1990). The availability of sulphur and iron also becomes limiting to animals consuming tannin-rich foliage. Sheep ingesting 0.9g hydrolysable tannins per kg body weight can show signs of toxicity in 15 days. Animals such as mule deer, rats and mice have been shown to secrete proline-rich proteins in saliva and these constitute the first line of defence against ingested tannin. Unfortunately, the proline-rich protein defence is not present in domestic ruminant species to enable domestic livestock to consume plants high in tannins.

Oxalates

Oxalates cause precipitation of insoluble calcium oxalate in the rumen and kidneys, resulting in kidney damage, rumen stasis, gastroenteritis, calcium deficiency and possible death. Poisoning in sheep and cattle has been reported when pasture contains 7-8% oxalate (Hungerford 1990). Voluntary feed intake is significantly depressed by 3% oxalates (Burritt and Provenza 2000) and may contribute to the observed low intakes of acacia.

Nitrate

Nitrates are converted to nitrites in the rumen and, following absorption, result in the conversion of haemoglobin to methaemoglobin. Methaemoglobin is unable to bind oxygen and causes anoxia accompanied by increased pulse and respiration rates. As with oxalates, high nitrates also result in depressed feed intake. Toxic levels of nitrogen as nitrate are above 5000 mg N/kg DM in the diet (National Research Council 1974), 8000 mg N/kg DM reduces feed intake in the sheep by over 60% (Burritt and Provenza 2000).

Oxalate, fluoroacetate and hydrogen cyanide are well-recognised toxins to livestock (Barry and Blaney 1987). These compounds should be identified early in the evaluation of plants for animal production and only species or provenances with low levels should be considered for further evaluation for nutritional potential. A similar situation applies for amines and alkaloids in plant material. Where these compounds exist in plants within current grazing systems then animal management strategies must be put into place to minimise the impact of secondary compounds on animal production.

Reducing the impact of secondary compounds

There has been a heavy dependence on *A. aneura* as a drought feed in the semi-arid grazing areas of Australia. *A. aneura* contains both tannins and oxalates that result in a feed source with poor animal production despite its favourable concentrations of crude protein. Attempts have been made over a number of years to develop strategies to improve the value of this feed source because in some situations, for example drought, it is the only feed available.

Pritchard *et al.* (1992) showed that dosing sheep with polyethylene glycol (PEG) increased both intake and wool production in sheep fed with *A. aneura*. The sheep both retained and digested more nitrogen and sulphur than sheep supplemented with non-PEG. Economically, supplementation with PEG may not be viable.

Alternative but less efficient methods of improving digestion of *A. aneura* have also been developed for grazing ruminants. Supplementation of sheep with molasses increased intake and dry matter digestibility of *A. aneura* (Entwistle and Baird 1976; McMeniman 1976). Hoey *et al.* (1976) showed that the molasses response was due mainly to the sulphur content of molasses. Molasses is overcoming a likely tannin-induced sulphur deficiency in the rumen, leading to improved microbial activity in the rumen and thence to improved rumen fermentation and feed intake. Increases in intake and live weight gain can also be achieved by using 50 g/day.head of cottonseed meal to provide additional protein and sulphur (McMeniman *et al.* 1981). These responses have been confirmed in grazing experiments where *A. aneura* supplemented with molasses (or sulphur), phosphorus and protein meal has improved live weight responses, wool growth and reproductive performance compared to non-supplemented sheep (McMeniman and Little 1974; Niven and McMeniman 1983).

Overseas, extensive studies have also been carried out with *A.saligna* to improve its utilisation by ruminant livestock. Utilisation of PEG to improve the nutritional value of *A. saligna* by increasing intake, nitrogen retention, microbial nitrogen yield and daily gain has been achieved compared with the performance of non-supplemented sheep consuming *A. saligna* (Ben Salem *et al.* 2000). This study used PEG in supplementation blocks to improve the effective utilisation of tannin-rich acacias, in contrast to other studies that used more intensive means to apply the PEG.

The most economically viable strategy for using acacias may be to select for lower levels of secondary compounds and to include other plants in a mixed grazing system. Natural variation within a species has been exploited extensively in agriculture to produce desirable outcomes. To improve the forage value of *Lotus corniculatus* (another forage legume), accessions have been selected with medium and low condensed tannin concentrations (Waghorn *et al.* 1987). As well as variation in secondary compounds within species there is also environmental variation. Tangendjaja *et al.* (1986) showed significant changes in minosine and flavonol glycosides with leaf age, whereas tannin concentration changes with soil fertility (Barry and Manley 1986), and season affects concentrations of both tannins and cyanogenic glucosides (Dement and Mooney 1974).

GRAZING SYSTEMS BASED ON *ACACIA*

Acacias can contribute to ruminant diets in several ways. Historically in Australia acacias have been browsed *in situ*, in the natural vegetation, usually as drought feed when the native pastures disappeared. Acacias may be utilised by browsing plants or litter and/or in a cut-and-carry system. One such species where a combination of the preceding options maybe applied is *A. aneura*. When conditions are severe enough and forage no longer available from standing trees, branches are lopped to provide *in situ* supplement for livestock, but *A. aneura* provides only a maintenance diet despite extensive efforts to reduce the nutritional impact of tannins (Goodchild and McMeniman 1987). A selection program to identify and exploit *A. aneura* trees which have naturally lower tannin levels may be the most cost-effective solution, with huge potential for animal production in semi-arid regions.

Predicting animal performance

Once plant quality characteristics of selected acacias have been estimated, the nutritional management program for ruminants GrazFeed (Freer *et al.* 1997) may be used to estimate potential animal performance. For example, weaner wethers grazing acacia foliage and pods with an estimated digestibility of 47% and protein content of 9% are predicted to lose 80 g of live weight per day. Weaners offered this combination with dead pasture (51% digestibility) were estimated to have a modest weight gain (13 g/day), due to increased capacity to select higher quality components in the diet. However if acacia species/composition resulted in a digestibility of 55% and protein content of 11% then weaners could maintain live weight with an intake of 900 g/day of acacias alone. These predictions would require validation by animal feeding before recommendations could be made since no account of secondary compounds or limitations to forage acquisition is included in these estimates.

CONCLUSIONS

Utilisation of acacia in farming systems could be improved through selection, which will establish and provide feed for livestock during feed gaps and droughts, provided that issues of fodder accessibility and secondary compounds are overcome. Successful selection will require simultaneous determination of the critical levels of nutritional and anti-nutritional factors for ruminants and validation in feeding studies. The results would then be used for the selection of potentially useful plants, which is likely to be more cost-effective than nutritional interventions to overcome the effects of secondary compounds. Australia has a large proportion of the world's acacia species. To date, their potential for animal production has not been studied in any systematic fashion, despite their extensive use in periods of nutritional stress.

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Review of the influence of *Acacia* species on establishment of Sandalwood (*Santalum spicatum*) in Western Australia

JONATHAN E. BRAND
Science Division, Department of Conservation and Land Management,
Locked Bag 104, Bentley Delivery Centre, Western Australia 6983
Email: jonb@calm.wa.gov.au

SUMMARY

Sandalwood (*Santalum spicatum*) is a root hemi-parasitic tree that produces valuable fragrant oils. Harvesting of *S. spicatum* timber occurs mainly from natural stands in the semi-arid pastoral regions of the Goldfields and Midwest, Western Australia. These natural stands consist mainly of mature trees, with very little successful recruitment. Recruitment failure is most likely due to grazing and poor seed dispersal. Trials show that the most dramatic way to improve recruitment in natural stands is by removing grazing and planting *S. spicatum* seeds near suitable host plants, especially *Acacia* species.

Sandalwood tree farm systems are also being established in the 400-600 mm mean annual rainfall areas of the Wheatbelt and Midwest. A successful establishment technique involves planting *S. spicatum* seeds near 1-2 year old *Acacia acuminata* seedlings. *S. spicatum* growth rates have been relatively fast, with mean stem diameters (at 150 mm) increasing up to 7-9 mm yr^{1}. Current research is determining methods to further improve *S. spicatum* performance by studying the influence of host species, parasite-to-host ratio and provenance.

In a host trial near Katanning, *S. spicatum* stem diameter was higher near *A. acuminata* (47 mm) than near *Allocasuarina huegeliana* (21 mm), at age five years. All *S. spicatum* seedlings died near *Eucalyptus loxophleba* subsp. *loxophleba* within two years. Foliar concentrations of N and K, and the K:Ca ratio were significantly greater in *S. spicatum* growing near *A. acuminata* than near *A. huegeliana*. Mean stem water potentials (Ψ_{stem}) of *S. spicatum* were significantly lower near *A. acuminata* than *A. huegeliana* in February-March 1999.

The performance of *S. spicatum* near four separate *Acacia* species is being examined at two sites, near Narrogin and Dandaragan. At age two years, *S. spicatum* mean stem diameter near *A. saligna* (28-33 mm) was 2-4 times greater than near *A. microbotrya* and *A. hemiteles*.

Recently, the *A. acuminata* group was divided into seven taxa. Seedlings from these different taxa have been planted together at two locations as hosts for *S. spicatum*. These trials will examine the influence of *A. acuminata* provenance on *S. spicatum* performance.

INTRODUCTION

Oils of sandalwood (*Santalum spicatum* (R.Br.) A.DC.) are a valuable ingredient in many products, such as incense sticks, perfumes, cosmetics and body-care lotions. Sesquiterpene oils accumulate within the heartwood of mature trees and give the timber its distinctive fragrance (Adams *et al.* 1975). *S. spicatum* occurs over the southern half of Western Australia and into South Australia (Loneragan 1990). Since 1845, export of its timber has provided a valuable industry for Western Australia (Talbot 1983). Today, the annual harvest is approximately 2000 tonnes (Jones 2001), with a value of up to $10 per kilogram. Harvesting occurs from natural stands, mainly on pastoral leases and vacant Crown land in central areas of Western Australia (Sawyer and Jones 2001).

Santalum spicatum is a root hemi-parasitic tree (Hewson and George 1984) that commonly grows with *Acacia* species (Loneragan 1990). Most natural stands occur in pastoral areas (Kealley 1991), where the annual average rainfall is below 250 mm. Natural recruitment in these stands is generally low, partly due to grazing by domestic and feral herbivores and poor seed dispersal (Loneragan 1990; Brand 1999; Brand 2000). There are concerns for the conservation of *S. spicatum* in these regions (Havel 1993). Current research is examining the effects of grazing, seed dispersal and host species on *S. spicatum* recruitment (Brand, 2000). In trials, seeds have been planted near a range of *Acacia* and other plant species to determine suitable hosts for these regions. *Santalum* species generally perform well when attached to N_2-fixing host plants, especially from the genus *Acacia* (Barrett *et al.* 1996; Radomiljac *et al.* 1999; Brand *et al.* 2000).

In Western Australia, sandalwood farm systems are being established in the Wheatbelt and Midwest, where the mean annual rainfall is 400-600 mm (Shea *et al.* 1998). A practical method of establishing *S. spicatum* is to plant seedlings of *Acacia acuminata* in rows and then sow *S.*

spicatum seeds near the hosts when the latter are 1-2 years old (Fox and Wijesuriya 1985; Brand *et al.* 1999). Using this technique, *S. spicatum* growth has been relatively fast, with mean stem diameters (at 150 mm) increasing up to 7-9 mm per year in the first five years (Brand *et al.* 1999; Brand *et al.* 2000). The predicted returns are 2-3 tonnes of commercial wood per hectare, at age 20 years (Brand and Jones 1999). Although this establishment technique is successful, current research is examining methods to improve *S. spicatum* performance through host selection, parasite-to-host ratios, and provenance trials of both host and *S. spicatum*.

This paper reviews the influence of *Acacia* species on *S. spicatum* establishment in conservation trials in semi-arid areas and in tree farm systems in the Wheatbelt and Midwest.

CONSERVATION

Ninghan Station

In 1996, a *S. spicatum* recruitment trial was established in natural vegetation on an alluvial plain at Ninghan station, near Paynes Find (Brand 2000). Sheep graze on this station and the mean annual rainfall is 293 mm. Recruitment of *S. spicatum* in the Paynes Find region is currently low (Brand 1999), and occurs mainly beneath parent trees, where survival is also low. Seeds tend to remain near the parent due to their large diameter, sometimes over 2 cm. Moving *S. spicatum* seeds away from parent trees and planting them near host species protected from grazing had a significant effect on seedling survival at Ninghan. *S. spicatum* seeds were planted near *Acacia burkittii*, *A. ramulosa*, *A. tetragonophylla* and *Hakea recurva*. A total of 6400 *S. spicatum* seeds were planted near 640 host trees.

At age three years, mean survival of seedlings raised near host trees was significantly greater (25%) than natural recruitment (0%). Seedling survival was also greater when fenced (30%) than unfenced (20%). Within the fenced treatment, *S. spicatum* survival was significantly higher near *A. burkittii* (41%) than *A. tetragonophylla* (23%, Fig. 1).

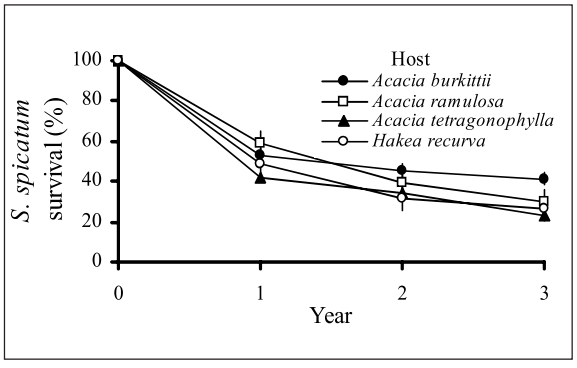


Figure 1. Mean seedling survival of S. spicatum *(± standard error) near four separate host species within the fenced treatment at Ninghan station (source: Brand 2000).*

Mean height increased only 10-20 cm per year and was similar between host treatments. At age three years, mean stem diameter (at 150 mm above the ground) was only 3-4 mm.

Goongarrie station

In the north-eastern Goldfields, a host trial for *S. spicatum* was established in natural vegetation on Goongarrie pastoral station, near Menzies. Goongarrie has been de-stocked of sheep since 1994 and has a mean annual rainfall of 252 mm. In March 1997, *S. spicatum* seeds were planted near seven host species: *Acacia aneura*, *A. burkittii*, *A. coolgardiensis* subsp. *coolgardiensis*, *A. hemiteles*, *A. ramulosa*, *A. tetragonophylla* and *Senna artemisioides* subsp. *filifolia*. A total of 3840 seeds were planted near 480 host plants, on four landforms: hills and ridges, granite, calcareous red earths and red sand plains.

At age three years, mean survival of *S. spicatum* seedlings was highest near *A. burkittii* (56%), and lowest near *A. ramulosa* (10%) and *A. tetragonophylla* (10%). Mean survival in the other treatments was 24-44%. At the same age, mean seedling heights were 70-110 cm, and seedling diameters (at 150 mm) were only 5-10 mm.

TREE FARM SYSTEMS

Northampton trial

Sowing *S. spicatum* seeds near young *A. acuminata* seedlings is a successful establishment technique. In 1988 and 1989, seeds were planted near one- and two-year-old *A. acuminata* seedlings in a plantation near Northampton, Western Australia (Brand *et al.* 1999). In both years, 3-6 *S. spicatum* seeds were planted near each host tree, with an aim to have a parasite-to-host ratio of 1 : 1. In 1997, mean survival of *S. spicatum* was 87% from 1988 plantings (age 9 years) and 50% from 1989 plantings (age 8 years). Initial growth was encouraging, with mean stem diameters (at 150 mm) increasing 6-7 mm per year between age 4.5 and 7 years. Growth then decreased to 4-5 mm per year between age 7 and 9 years. This decrease in growth may be related to the low host survival, especially when *S. spicatum* was introduced when the host was only one year old. In 1997 (host age 10 years), mean survival of *A. acuminata* with *S. spicatum* introduced at year one (37%), was significantly lower than when introduced at year two (84%). Therefore, the extra year without a parasite may have increased survival of *A. acuminata*.

Besides the stress of a root hemi-parasite, the *A. acuminata* seedlings planted at Northampton showed signs of wind-burn from the southerly sea breeze, whereas the natural stands of *A. acuminata* near the site were less affected. The *A. acuminata* seedlings were from a provenance south-east of Perth and may not have been suited to the local conditions. It may be possible to select superior types or provenances of *A. acuminata* that improve *S. spicatum* growth. The effects of host age, host-

to-parasite ratio and provenance on *S. spicatum* performance requires further investigation. To address these research needs, a series of trials have been established on farmland in south-western Australia.

Kwobrup host trial

The influence of two N_2-fixing woody hosts (*A. acuminata* and *Allocasuarina huegeliana*) and a non N_2-fixing woody host (*Eucalyptus loxophleba* subsp. *loxophleba*) on *S. spicatum* establishment and growth was investigated at Kwobrup, near Katanning (Brand *et al.* 2000). In June 1991, the host seedlings, age six months, were planted in separate species blocks. Within each block, the seedlings were planted at 4 m intervals along 21-25 rows, spaced 4 m apart. At host age five years (June 1996), four *S. spicatum* seeds were buried 2-3 cm below the surface near each host stem.

Germination of *S. spicatum* was relatively good, with 60-86 % of sowing spots having at least one germinant near each host. At age five years, mean survival of *S. spicatum* near *A. acuminata* was 85%, significantly greater than near *A. huegeliana* (28%, Fig. 2). All *S. spicatum* seedlings near *E. loxophleba* subsp. *loxophleba* died within two years. At age five years, the *S. spicatum* had a mean height of 205 cm near *A. acuminata* and 177 cm near *A. huegeliana*. At the same age, mean stem diameter (at 150 mm) of *S. spicatum* was 47 mm near *A. acuminata*, far greater than near *A. huegeliana* (21 mm, Fig. 3). Growth of *S. spicatum* near *A. acuminata* at Kwobrup was relatively good compared to that at Northampton where the mean stem diameter was 40-44 mm at age 5.5 years (Brand *et al.* 1999).

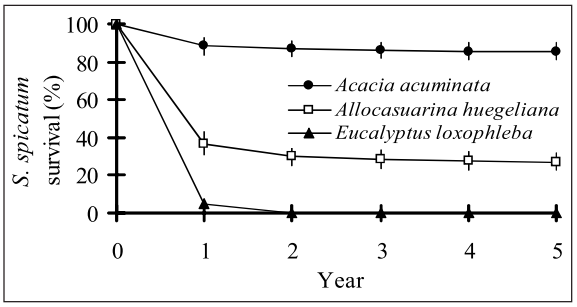


Figure 2. Mean survival (± standard error) of S. spicatum *near three host species, planted at Kwobrup.*

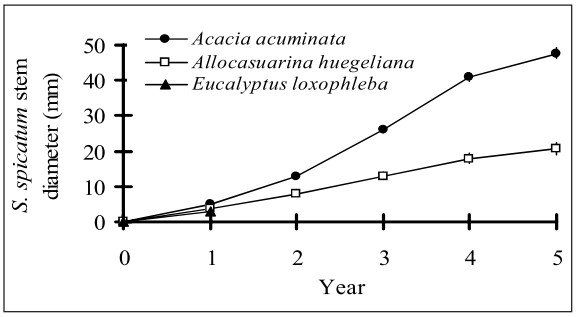


Figure 3. Mean stem diameter (± standard error) of S. spicatum *near three host species, at Kwobrup.*

Possible reasons why *S. spicatum* performed better near *A. acuminata* than *A. huegeliana* may be due to nutrition or water movement. At age three years, the foliar N and K concentrations, and the K:Ca ratio were significantly higher in *S. spicatum* near *A. acuminata* than those near *A. huegeliana*. *S. spicatum* growing near *A. acuminata* had a mean K:Ca ratio of 4.9, almost five times greater than those near *A. huegeliana* (1.0). Parasitic angiosperms typically have a high K:Ca ratio when attached to suitable host plants, which aids in nutrient movement from host to parasite (Tsivion 1978).

During the dry months of February and March 1999, stem water potentials (Ψ_{stem}) of *S. spicatum* (age 3 years) were also compared between host species treatments (Table 1). Mean stem water potential of *S. spicatum* at pre-dawn was -4.0 MPa near *A. acuminata*, significantly lower than *S. spicatum* (-2.8 MPa) near *A. huegeliana*. A lower water potential implies that there is less water available to the plant (Turner 1981). This indicates that water was more readily available to the *S. spicatum* parasitising *A. huegeliana* than those on *A. acuminata*. It appears that improved *S. spicatum* performance near *A. acuminata* was not related to greater water availability but more likely due to the host plant's ability to provide high concentrations of key elements such as N and K.

TABLE 1

Pre-dawn and midday mean leaf and stem water potentials (± std. errors) of *S. spicatum* and host (control & parasitised) trees (n = 6-8). Measurements were recorded in February-March 1999 (source: Brand *et al.*, 2000)

Species	Ψ_{leaf} and Ψ_{stem} (MPa), Pre-dawn (18/3/1999)	Feb-March 99 Midday (24/2/1999)
(a) Jam/sandal.		
A. acuminata (control)*	- 3.5 ±0.2 b	-
A. acuminata (parasitised)*	- 3.7 ±0.2 ab	- 4.4 ±0.4 ab
S. spicatum #	- 4.0 ±0.3 a	- 5.1 ±0.4 a
(b) Sheoak/sandal.		
A. huegeliana (control)*	- 2.4 ±0.2 c	-
A. huegeliana (parasitised)*	- 2.6 ±0.2 c	- 2.2 ±0.1 d
S. spicatum #	- 2.8 ±0.1 c	- 3.8 ±0.1 bc
(c) York gum		
E. loxophleba (control)*	- 2.8 ±0.2 c	- 3.4 ±0.1 c
p-value	< 0.001	< 0.001

Values with the same letter are not significantly different, using Fisher's LSD test (p > 0.05).
*Ψ_{leaf}; #Ψ_{stem}

Acacia host trials

In June-July 1998, seedlings of *A. acuminata*, *A. microbotrya*, *A. saligna* and *A. hemiteles* were planted as initial hosts for *S. spicatum* at two sites, Dandaragan and Narrogin. *A. microbotrya* and *A. saligna* were selected as initial hosts because they are fast growing, though they may live for only 10 years. *A. acuminata* was also planted as the secondary or long-term host. Before planting, each site was ripped to a depth of 0.5 m, in rows spaced 4 m apart. Initial host seedlings were planted at 3 m intervals

along alternate rows, with the long-term hosts planted at 3 m intervals on every other row. Initial hosts were planted in separate species plots, and each plot contained 24 initial hosts and 24 long-term hosts. Each treatment was replicated four times, at both sites.

In April 1999, six *S. spicatum* seeds were sown near each initial host plant, at both sites. Germination was relatively high, with 76-98% near each host. At age two years, mean survival of *S. spicatum* was highest near *A. saligna* (91-92%) and lowest near *A. hemiteles* (48-58%), for both sites. Survival for the other two hosts was 62-84%. At the same age, *S. spicatum* planted near *A. saligna* were 144-170 cm in height and had stem diameters of 29-33 mm (Fig. 4). In contrast, *S. spicatum* growing near *A. hemiteles* and *A. microbotrya* were only 66-76 cm tall and had stem diameters of only 6-10 mm.

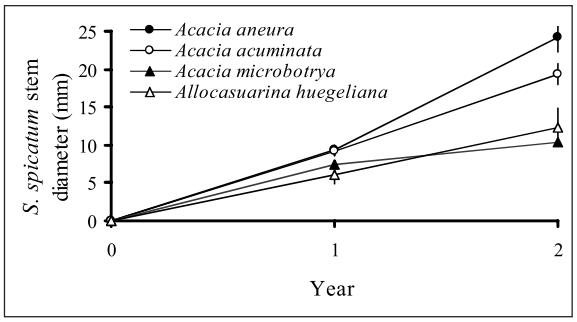


Figure 4. Mean stem diameter of S. spicatum *(at 150 mm) at age two years, planted near four different Acacia species at Dandaragan and Narrogin.*

Parasite-to-host ratio

The effects of different ratios of *S. spicatum* to host species is being trialed on farmland near Narrogin, Western Australia. In July 1997, six hectares were planted with four potential host species: *Acacia aneura*, *A. acuminata*, *A. microbotrya* and *Allocasuarina huegeliana*. The seedlings were planted at 4 m intervals along rip-lines spaced 4 m apart (625 stems per hectare), in separate species plots.

At host age two years (April 1999), *S. spicatum* seeds from a plantation near Narrogin were sown near the host plants at three parasite-to-host ratios: 0 : 1, 1 : 1, and 1 : 2. At the time of sowing, the mean height of *A. aneura* (0.7 m) was much smaller than the other three species (1.8-2.7 m). Six *S. spicatum* seeds were buried 1-2 cm below the surface, approximately 1 m from the stem of each host. In 1999, *S. spicatum* germination was 92-96% per spot.

After two years (June 2001), mean survival of *S. spicatum* was 90-99% within each host species treatment. Mean stem diameter of *S. spicatum* was 24 mm near *A. aneura* and 19 mm near *A. acuminata*, far greater than near *A. microbotrya* (10 mm) and *Allocasuarina huegeliana* (10 mm, Fig. 5). Mean height of *S. spicatum* near *A. aneura* and *A. acuminata* was 113-123 cm, again, greater than near *A. microbotrya* (90 cm) and *A. huegeliana* (94 cm). At this stage, there was no difference in *S. spicatum* performance between parasite-to-host ratio treatments.

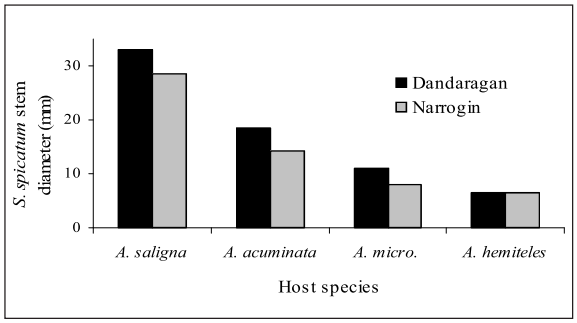


Figure 5. Mean stem diameter (± standard error) of S. spicatum *near four host species, at Narrogin.*

Provenance trials

Acacia acuminata is widely accepted as a suitable host for *S. spicatum* (Loneragan 1990; Barrett and Fox 1996; Brand *et al.* 1999). However, there is little information on the source of *A. acuminata* used in *S. spicatum* trials. *A. acuminata* and its close relatives are highly variable, and a recent taxonomic study of the group revealed seven taxa (Maslin *et al.* 1999): *A. acuminata* (typical); *A. acuminata* (narrow phyllode); *A. acuminata* (small seed); *A. acuminata / burkittii* (variant 1); *A. acuminata / burkittii* (variant 2), *A. burkittii*; and *A. oldfieldii*. Planting *S. spicatum* near these taxa may have a varying effect on *S. spicatum* performance.

In November-December 1998, seeds from these seven *A. acuminata* taxa were collected from 147 parent trees growing in 24 different provenances (Maslin *et al.* 1999). In July 2000, seedlings from 84 of these parent trees were planted at two sites: Morawa and Dowerin. At each site, the seedlings were planted at 3 m intervals along rip-lines spaced 4 m apart (833 stems per hectare), over an area of 5 ha.

At age six months (January 2001), seedling survival was 70-81% at Morawa and Dowerin. At both sites, the phyllode widths of the *Acacia* seedling types were already similar to their parent trees. More than 99% of *A. burkittii* seedlings had phyllode widths less than 2 mm, similar to their parent phyllode width of 0.7-2 mm. In contrast, over 99% of *A. acuminata* (typical variant) had phyllode widths greater than 2 mm, similar to their parent phyllode width of 3-10 mm. *S. spicatum* seeds will be direct-seeded near these host seedlings in May 2002 (host age two years) to examine the influence of *A. acuminata* type on *S. spicatum* performance.

CONCLUSIONS

Establishment of *S. spicatum* near *Acacia* species in tree farm systems has been successful in the Wheatbelt and Midwest, Western Australia. In a trial at Kwobrup, *S. spicatum* seedling survival and growth at age five years were significantly greater near *Acacia acuminata* than near *Allocasuarina huegeliana*. All *S. spicatum* seedlings died near *E. loxophleba* subsp. *loxophleba* within two years. Foliar analysis indicated that *A. acuminata* was providing more

N and K to the parasite. *S. spicatum* near *A. acuminata* also had high K:Ca ratios. These findings indicate that *A. acuminata* is a suitable host for *S. spicatum*. The *A. acuminata* group is variable and current research is examining whether certain provenances of *A. acuminata* improve *S. spicatum* performance.

In another trial, mean stem diameters of *S. spicatum* are increasing 14-16 mm per year near *A. saligna*, at Narrogin and Dandaragan. These are the fastest growth rates recorded for *S. spicatum* in a non-irrigated plantation. *A. saligna* may be short lived but it has the potential to be an excellent host for *S. spicatum* when planted in combination with a long lived host such as *A. acuminata*.

In natural stands at Ninghan and Goongarrie stations, planting *S. spicatum* seeds near established *Acacia* species has improved recruitment. At age three years, mean survival of *S. spicatum* was greater when planted near *A. burkittii* (a close relative of *A. acuminata*). In these semi-arid areas, *S. spicatum* seedlings are also growing well near some other *Acacia* species: *A. aneura*, *A. coolgardiensis* subsp. *coolgardiensis*, *A. hemiteles*, *A. ramulosa* and *A. tetragonophylla*. *S. spicatum* seedling growth is relatively slow in these regions with mean stem diameters increasing only 1-3 mm per year. This establishment method, combined with de-stocking, may help to improve *S. spicatum* recruitment in natural populations.

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Direct seeding Acacias of different form and function as hosts for Sandalwood (*Santalum spicatum*)

GEOFF S.WOODALL AND CHRIS J.ROBINSON

Department of Agriculture, 444 Albany Highway, Albany, Western Australia 6330 Email: gwoodall@agric.wa.gov.au

SUMMARY

It has long been recognised that *Acacia* species are the premier hosts upon which to establish the parasitic Sandalwood (*Santalum spicatum*). Most plantations established to date in the wheatbelt have Jam wattle (*Acacia acuminata*) at 830 per hectare as the main or sole host species of *Acacia*. Whilst it is apparent that *A. acuminata* is one of the ideal principal hosts and should form a significant part of the host mix, the inclusion of other species should also be considered as they can complement the role played by Jam. Inclusion of multiple host species can benefit Sandalwood plantations by: reducing the parasitic load on individual hosts and host groups, thus maximising the potential for long-term survival; providing additional seasonal sources of water and nutrition; providing shade to Sandalwood seedlings and full sun to mature trees; protecting seedlings against pests and diseases; reducing the weed burden; sustaining host vigour; and increasing nature conservation value. By direct seeding a biodiverse host mix it is possible to establish a large number and range of *Acacia* species (and other genera) as potential hosts. The use of direct seeding for host establishment is discussed.

INTRODUCTION

The sale of Western Australian Sandalwood (*Santalum spicatum*) harvested from remnant vegetation generates revenue of $12 million for the State of Western Australia (Anon. 2000). Sandalwood once grew throughout the wheatbelt of Western Australia but this resource has been exhausted due to over-exploitation and clearing for agriculture (Loneragan 1990). There has been increasing interest from the farming community and other investors in the development of a plantation *Santalum spicatum* industry in the wheatbelt.

Extensive trials have shown that parasitic *Santalum* species show improved growth and vigour when cultivated with leguminous hosts (Radomiljac and McComb 1998; Brand *et al.* 2000; Loveys *et al.* 2001). It has long been recognised that *Acacia* species are the premier hosts upon which to establish Sandalwood. Most host plantations established to date in the wheatbelt have concentrated on planting seedlings of Jam wattle (*Acacia acuminata*) at 830 per hectare as the sole species of *Acacia* (Brand *et al.* 1999, 2000; Brand and Jones 2001). This paper investigates why species other than Jam should be included in Sandalwood plantations. Direct seeding of acacias is discussed, as are the benefits of using direct seeding for host establishment.

A DIVERSITY OF HOST SPECIES BENEFIT SANDALWOOD

A large research effort has been spent on determining which species, grown as a sole host for Sandalwood, gives best growth (e.g. Brand *et al.* 2000). Such research has improved our understanding, but basing plantations on one host species planted at low densities ignores the research that has shown that Australian woody root hemiparasites of the Santalaceae, Olacaceae and Loranthaceae all naturally parasitise numerous species from a range of genera and families (Herbert 1925; Fineran and Hocking 1983; Pate *et al.* 1990). Both Herbert (1925) and Loneragan (1990) reported *Acacia*, *Allocasuarina*, *Templetonia*, *Dodonaea*, *Eremophila* and *Eucalyptus* as hosts of *S. spicatum*. Whilst it is apparent that *A. acuminata* is one of the ideal principal hosts of wheatbelt Sandalwood and should form a significant part of the host mix, the inclusion of other species should also be considered as they can complement the role played by Jam.

Justification for the inclusion of other species into the host mix is provided through the following factors:

Reduced stress

In most plantations established to date the parasitic load is imposed on one or two individual hosts of the same species. In some cases, five to ten years after establishment the parasitic load on hosts has caused host decline or death, resulting in a decline or death of Sandalwood (Brand *et al.* 1999). When sown among numerous host plants of diverse species, Sandalwood parasitises a number of individual hosts, even at one or two years of age (Table 1). This reduces the parasitic load applied to individual hosts and host groups, maximising the potential for long-term survival of sandalwood plantations.

TABLE 1
Maximum extent of host root parasitism of along a rip line (north and south) of four Sandalwood seedlings 17 months old. Sandalwood diameter was measured at the soil surface. The presence or absence of functional haustoria on excavated host roots at various distances from the sandalwood was used to determine the extent of parasitism.

	DIAMETER OF STEM (MM)	HEIGHT (M)	EXTENT OF PARASITISM FROM PLANT (M) NORTH	SOUTH	NUMBER OF ADDITIONAL HOSTS ACCESSIBLE TO PLANT
			NORTH	SOUTH	
Sandalwood 1	19	0.9	0.9	1.5	21
Sandalwood 2	5.3	0.4	0.4	1	9
Sandalwood 3	11.8	0.2	0.8	0.9	6
Sandalwood 4	13.9	1.3	1.2	1.2	7

Additional seasonal sources of water and nutrition

Although shallow-rooted annual and perennial hosts may not be good sole hosts and are unable to supply water to and support Sandalwood during the dry summer period (see study on the root hemiparasite *Olax phyllanthi* by Pate *et al.* 1990), they are parasitised during autumn, winter and spring and would be important nutrient and water sources during this period. The authors have observed that shallow-rooted perennial acacias such as *A. pulchella* and *A. lasiocarpa* and even annual weeds such as *Erodium* sp. *Brassica* spp., *Arctotheca calendula* and *Trifolium* spp. are extensively parasitised by Sandalwood grown in host plantations. These hosts provide Sandalwood with additional seasonal sources of water and nutrition. Acacias and other hosts with deep root systems (e.g. some *Hakea* and *Eucalyptus* species) are able to access moisture stored at depth and thus can be important sources of water for attached Sandalwood. Non-leguminous deep-rooted host may not be ideal sole hosts for Sandalwood but in a mixed species host plantation would provide attached Sandalwood with a much-needed additional water source.

Plants differ in their ability to extract and utilise nutrients from their surroundings. For example, proteoid roots of *Hakea* and other Proteaceae assist with phosphorous uptake from soils that have low phosphorous content (Bowen 1981). The authors have often observed functional *S. spicatum* haustoria on roots of *Hakea* and *Dryandra*, yet these species are not often included in host plantings. These species could provide the parasite with an important additional source of phosphorous. A similar nutritional benefit argument would exist for the inclusion of species which form mycorrhizal associations.

Access to sunlight

Santalum seedlings can benefit from partial shading (Barrett and Fox 1994), whereas wild mature trees are not often shaded. The use of low thorny or laterally spreading *Acacia* species in plantations initially shades Sandalwood seedlings but allows access by the hemiparasite to full sunlight when it grows beyond canopy (Fig. 1).



Figure 1. Complementary growth form: Acacia redolens *and an emergent* Santalum spicatum.

Protection from pests and diseases

Pests and diseases (i.e. galls, mistletoes, and viruses in or on *Acacia*) can kill host trees and, when a sole host species is grown, the consequences of a pest or disease outbreak can be severe. An outbreak of a pest or disease will have less impact in a mixed host plantation because a single ailment is unlikely to affect all host species.

Plants accumulate a range of chemical compounds that protect them from herbivores. Loveys *et al.* (2001) demonstrated that a defence compound was transferred from host plants to parasitic plants in the Santalaceae, where it offered protection from herbivores. It is possible that such transfers also occur between principal or other hosts and Sandalwood. Thus, establishing Sandalwood

with a diverse mix of host plant may increase the chance of such transfers occurring.

Sandalwood shoots are palatable to most herbivores. Host plants that have spines (e.g. *A. pulchella*, *A. lasiocarpa*) or form dense, low, laterally spreading bushes (e.g. *A. redolens* and *A. consobrina*) provide protection to young Sandalwood trees until they are above grazing height.

Reduced weed burden

Annual and perennial grass weeds compete with hosts for resources and can pose a fire hazard. Sandalwood is killed by fire (Loneragan 1990) and the industry requires that all harvested wood to be free of charcoal. The authors have observed that the inclusion of low, laterally spreading *Acacia* bushes (e.g. *A. redolens* and *A. consobrina*) significantly reduces weed growth (Fig. 2).



Figure 2. Suppression of grasses by Acacia consobrina.

Sustained host vigour

It is also important to include long- and short-lived acacias in the host mix. Fast-growing hosts (e.g. *Acacia saligna* and *A. pulchella*) offer protection to young Sandalwood seedlings, initial vigour and an immediate host resource, but longer-lived, slower-growing hosts such as *Acacia acuminata* and *A. redolens* are required to sustain Sandalwood growth in the long term.

Enhanced nature conservation

From field excavations the authors have found that *Santalum spicatum* naturally parasitises a wide range of native plants, from small perennial herbs to large deep-rooted trees. It makes good commercial and biological sense to attempt to simulate at least some of this diversity in host plantations. Direct seeding with a wide range of species can be designed to confer great structural and species diversity in the plantation (Fig. 3). The randomness, density and diversity resulting from direct seeding will provide a natural vigour and resilience



Figure 3. Direct seeded hedgerows such as this (composed of 6 Acacia *species and a selection of other species) can protect and camouflage Sandalwood seedlings. The system also provides suitable habitat for a number of animals. Inset: a burrow of the Bush Rat* (Rattus fuscipes) *and discarded Sandalwood nuts.*

potentially lacking in a more traditional forestry layout. Dense, species-rich host plantations will not necessarily look like plantations and may be strategically placed to form viable habitat corridors, or to buffer existing remnants. If the species mix is diverse enough, after natural competition has occurred, each soil type will be adequately vegetated. Usefulness to native animals is increased with density of planting which can provide protective cover (especially thorny species) for foraging and nesting (habitat) for smaller animals, which will not be favoured by widely spaced host monocultures. Many leguminous genera such as *Gastrolobium*, *Acacia* and *Daviesia* provide seed that is consumed by a variety of birds and insects.

The commercial aspect of Sandalwood plantations means that some establishment will be on good agricultural land that would not normally be available for nature conservation. It is the authors' experience that landholders are more likely to consider creation of habitat or corridors if there is the long-term prospect of some commercial gain through production of Sandalwood.

DIRECT SEEDING ACACIAS AS HOSTS FOR SANDALWOOD

Acacias are relatively large-seeded, and direct seeding is cheap and usually very successful if adequate site preparation is carried out. Seedling densities of over 5,000 per hectare are readily achieved from seeding rates of 0.5 kg per hectare. As seed costs about $300 per kg, direct seeding carried out by landowners can be a very cheap way of establishing hosts. Other costs apart from seed may be hire of machinery (e.g. Chatsfield tree planter with seed box) and weed control. Sandalwood will eventually kill some hosts and in plantations with a low host to Sandalwood ratio, host death will adversely influence Sandalwood growth and survival (Brand *et al.* 1999). High host densities achieved with direct seeding (*Acacia* and

other genera) result in a high host-to-Sandalwood ratio and thus the death of some hosts would have little influence on Sandalwood survival and vigour. Indeed the higher number of hosts per hectare will maximise host resource available to Sandalwood.

Direct-seeded hosts may form dense hedgerows of many vertical stems. In this formation, sandalwood is also forced to grow taller and the authors have observed reduced herbivore damage to young sandalwood seedlings growing amongst the host stems. This was particularly evident at a site adjacent to Stirling Range National Park where there was intense grazing pressure from kangaroos, rabbits and also sheep, which breached outer fencing several occasions. The hedgerows of *Acacia acuminata* at this site appeared to offer physical protection and/or camouflage to the sandalwood saplings that were growing up as part of the hedgerows.

Hedgerows of hosts and emergent sandalwood established at Narrogin suffered damage from parrots but the damage to the sandalwood was observed to be minimal. At this site many hosts were damaged but because there were very high numbers of hosts (>1500 host/ha) the impact on the plantation as a whole was minimal. Furthermore, host species with thorns (*Davesia* sp. and *Acacia lasiocapa*) were not damaged.

The proportions of species in direct seeding mixes must be selected carefully. High concentrations of cheap seed of fast-growing species such as *A. saligna* can swamp other slower growing, long-lived hosts, dry the soil out too much for Sandalwood seed germination, and shade young Sandalwood. In the south west, it is recommended that about half the seed mix by weight comprise *A. acuminata*, and that *A saligna* be no more than 30 gm per hectare.

TABLE 2
Species and genera suitable for inclusion in host mixes

SOME OF MANY SUITABLE ACACIA HOST SPECIES	OTHER NITROGEN -FIXING HOST GENERA	OTHER USEFUL GENERA
Acacia acuminata	*Allocasuarina* (sheoak)	*Hakea*
Acacia saligna	*Bossiaea*	*Dryandra*
Acacia pulchella	*Brachysema*	*Dodonaea*
Acacia cyclops	*Chorizema*	*Eremophila*
Acacia redolens	*Daviesia*	*Myoporum*
Acacia glaucoptera	*Jacksonia*	
Acacia rostellifera	*Kennedia*	
Acacia microbotrya	*Nemcia*	
Acacia dictyoneura	*Senna*	
Acacia consobrina	*Mirbelia*	
Acacia lasiocalyx	*Gastrolobium*	
Acacia lasiocarpa	*Templetonia*	

SANDALWOOD GROWTH IN DIRECT-SEEDED BIODIVERSE HOST PLANTATIONS

From a purely commercial viewpoint, growth (wood biomass), oil quantity and quality determine the financial returns from plantation Sandalwood. At Kwobrup, Brand *et al.* (2000) reported a mean annual growth rate (i.e. stem diameter increase at 150 mm above soil surface) of 8.6 mm per annum for sandalwood grown on *Acacia acuminata* as the sole host (625 hosts/ha). The mean was calculated from measurements made on the tallest Sandalwood sapling at each planting spot and there were up to four saplings per spot. At Narrogin, where plantation sandalwood is grown among many direct seeded hosts of diverse species, the authors have measured a mean annual increase in stem diameter (at 150 mm above the soil surface) of 6.5 mm (± S.E. 0.3, 50 randomly selected two-year-old Sandalwood saplings were measured). This result suggests that plantations composed of numerous hosts of diverse species can support Sandalwood growth rates that are similar to plantations consisting of a single host species planted at a low density.

CONCLUSION

Commercial plantations of Sandalwood (*Santalum spicatum*) may be achieved through direct seeding biodiverse host mixes. This technique is not only cheaper than conventional forestry techniques but provides many other benefits to the young Sandalwood, ensures long term growth and can make a beneficial contribution to nature conservation.

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The value of *Acacia saligna* as a source of feed for sheep

DELWYN HOWARD[1], GAYE L.KREBS[1] AND MAARTEN VAN HOUTERT[2]

[1]Muresk Institute of Agriculture, Curtin University of Technology, Northam, Western Australia 6401
[2]Department of Agriculture, Bunbury, Western Australia 6230

SUMMARY

Two pen trials were undertaken to evaluate the usefulness of ***Acacia saligna*** as a source of feed for sheep. In Trial 1, ***A. saligna*** was inadequate as the sole source of nutrients for sheep, weight loss being visually evident. Further, the level of detannification achieved in Trial 1, with the addition of polyethylene glycol (PEG), failed to improve the diet sufficiently.

Trial 2 investigated ***A. saligna*** as the basal source of nutrients together with straw, with or without a supplement of nitrogen in the form of urea or PEG. Sheep supplemented with PEG consumed more ***A. saligna*** than either the control group or those supplemented with urea ($P<0.05$). All sheep readily consumed the ***A. saligna*** in preference to straw. The consumption of straw did not differ ($P>0.05$) among treatment groups, all animals consuming less than 25% of the straw offered. Both the dry matter digestibility and organic matter digestibility were higher ($P<0.05$) where PEG was included in the diet compared to the other two treatments. For all treatments, the animals maintained body weight.

INTRODUCTION

As part of the battle against land degradation and desertification there is an urgent need to develop sustainable grazing systems. ***Acacia saligna***, a native of Western Australia, has been widely acknowledged as a useful species for land conservation. More recently, there has been a focus on the species as a potential source of fodder for ruminants (Degen ***et al***. 1998; Degen ***et al***. 1997; Abou El Nasr ***et al***. 1996; Degen ***et al***. 1995). A common conclusion of researchers is that the presence of condensed tannins is the primary factor inhibiting its use as a feed source (Chriyaa ***et al***. 1997; Degen ***et al***. 1995, 1997, 1998; Abou El Nasr ***et al.*** 1996).

Condensed tannins (CT) can be categorised as soluble, protein bound or fibre bound (Terrill ***et al***. 1992). Tannins bound to proteins or fibre in the leaves may render these indigestible, while soluble tannins can form complexes with dietary proteins following mastication (Vaithiyanathan and Kumar 1993) as well as endogenous proteins including enzymes (Kumar and D'Mello 1995).

The ability of tannins to form strong complexes with proteins is the most important aspect of their anti-nutritional effects. Tannins bind with at least four groups of proteins in the ruminant: dietary proteins, salivary proteins, endogenous enzymes and gut microbes including microbial enzymes (Hagerman and Butler 1981). The effects of CT, such as inhibition of feed intake and digestion by ruminants, are usually ascribed to their ability to bind proteins (D'Mello 1992). The strength of the tannin-protein complexes depends on characteristics of both the tannin and protein (Haslam 1989).

Most research on ***A. saligna*** tends to involve plant material grown in arid and semi-arid regions. However, it is also known to grow prolifically in areas of higher rainfall, e.g. south-west Western Australia where annual rainfall can exceed 1000 mm, as well as in climates ranging from cool to tropical. If the limitations to ***A. saligna*** being a worthwhile source of fodder for ruminants could be overcome then it could serve a dual role of conservation and animal feed.

TRIAL 1

Aims:

The aims of Trial 1 were to:

1. evaluate the usefulness of ***A. saligna*** as a sole source of nutrients for sheep

2. evaluate the effect that partial detannification of ***A. saligna*** might have on its value as a source of nutrients for sheep.

Materials and methods

A feeding trial was conducted during April-June 1999 and involved four Merino wether sheep, each fitted with a permanent rumen cannulae. The experiment was based on a cross-over design, each sheep undergoing each dietary treatment.

Acacia saligna was lopped from a three-year-old plantation at Gidgegannup, Western Australia (sown in 1996 directly from seed). Only foliage less than 12 months old was used. After harvest, material was stored at –18°C

pending feeding. The two feeding regimes used were: (1) control: basal diet of ad libitum access to ***A. saligna***; and (2) basal diet plus 25 g/d polyethylene glycol (PEG). PEG is a detannification agent, tannins binding to PEG in preference to protein (Pritchard ***et al***. 1988; Jones and Mangan 1977). For this trial PEG was first dissolved in water (1:1 w/v) and then administered as an oral dose immediately prior to feeding.

During the trial, animals were fed every morning, followed by collection of faeces and urine. Dry matter intake (DMI) was determined by subtracting the dry matter (DM) weight of daily feed refusal from the amount of feed offered (DM weight). The weight of faeces excreted from each animal was measured and a subsample of each animal's daily faecal output taken (and later pooled) for determination of organic matter content. Dry matter digestibility (DMD) and organic matter digestibility (OMD) were determined on the basis of the amount of DM or OM ingested and the amounts voided.

Results

The intake and digestibility of ***A. saligna*** offered to sheep with or without a supplement of PEG 4000 are shown in Table 1. The DMI of ***A. saligna*** was greater ($P<0.05$) in sheep supplemented with PEG compared to the control diet. This was associated with improved ($P<0.01$) DMD and OMD. The animals were not weighed throughout the trial, but a loss in body condition was obvious in all animals, particularly the control group.

TABLE 1
Intake and digestibility of *A. saligna* offered to sheep with or without a supplement of PEG 4000.

	TREATMENT		SIGNIFICANCE
	CONTROL	PEG 4000	
DMI (g/d)	187[a](57)	499[b](101)	*
DMD (%)	31.3[a](7.9)	36.8[b](9.1)	**
OMD (%)	30.4[a](7.8)	32.1[b](9.1)	**

**P <0.05, **P < 0.01. Values within rows with different superscripts are significantly different. Values within brackets indicate standard deviations.*

Protozoa were present in abundance in ruminal fluid only until the animals had undergone the control treatment, after which there were virtually none present.

Discussion

The DMI of ***A. saligna*** by the sheep that were not supplemented with PEG were lower than those reported by Abou El Nasr ***et al.*** (1996). Where fresh ***A. saligna*** was the sole feed, the DMI of ***A. saligna*** exceeded 800 g/d. Their higher DMI corresponded to a higher DMD of 54.2% compared to 31.1% in the current trial. Neither CT concentration nor its activity was reported for the former trial but such factors are expected to largely explain the differences in DMI between that trial and the present one.

In the trials of Degen ***et al.*** (1995) and Degen ***et al.*** (1997) the DMI of air-dried foliage from mature ***A. saligna*** trees was approximately 200-250 g/d. Both the DMD and OMD in these trials were 31-35%. These figures are comparable to those in the current trial but the experimental animals in the current trial were likely to be significantly heavier than the animals used by Degen ***et al***. However, in Degen ***et al.*** (1997), where foliage was harvested from young trees (8 months old), DMI was less than 150 g/d, despite both DMD (38.3%) and OMD (39.8%) being higher than those harvested from mature trees (32.3% and 33.8% for DMD and OMD, respectively). This was attributed mainly to the much higher CT content of the foliage from the younger trees compared to those obtained from the mature trees, the age of the tree being just one of many factors that may affect its CT content.

The results of this trial indicate that, in this instance, ***A. saligna*** could not be used as a sole diet to maintain the weight of sheep even with partial detannification as a result of inclusion of PEG. A higher dose of PEG or an alternative form of rumen degradable nitrogen might have yielded more positive responses.

TRIAL 2

It was shown in Trial 1 that ***A. saligna*** was inadequate as the sole source of nutrients for sheep. It was also shown that the level of detannification achieved in Trial 1, with the addition of PEG 4000, failed to improve the diet sufficiently to have any real impact on animal performance. of green feed to grazing animals.

Trial 2 was designed to investigate the use of ***A. saligna*** as a basal source of nutrients, with or without a supplement of rumen degradable nitrogen (urea) or PEG (at a dose rate higher than that used in Trial 1). Wheat straw was included in the basal diet to simulate a paddock situation in which plantations of ***A. saligna*** are interspersed with dry pasture during the summer/autumn period in W.A.

Materials and methods

The feeding trial was conducted during April-June 2000. The ***A. saligna*** was sourced from Bakers Hill, W.A. Branches were cut from mature trees (5-6 years old, grown from bare-rooted seedlings) and then manually fed through a mechanical leaf stripper. The ***A. saligna*** offered to the sheep consisted of phyllodes (mostly whole) and small twigs. After harvesting, material was stored at -18°C pending feeding.

The feeding trial was based on a Latin square design. Each of the six Merino wethers were randomly allocated to one of three dietary treatments. The three treatments used were:

1. control: ad libitum ***A. saligna*** + 400 g / d wheat straw (95% DM) (basal diet);
2. basal diet + 50 g / d PEG 4000
3. basal diet + 1% (DM basis) urea sprayed onto the straw and ***A. saligna*** 30 minutes prior to feeding.

Measurements and sampling were the same as those described for Trial 1.

Results

The intake and digestibility of ***A. saligna*** and straw offered to sheep with or without a supplement of 1% urea or PEG is shown in Table 2. Sheep supplemented with PEG consumed more ***A. saligna*** than either the control group or those supplemented with urea ($P<0.05$). All sheep readily consumed the ***A. saligna*** in preference to straw. The consumption of straw did not differ ($P>0.05$) amongst treatment groups, with all animals consuming less than 25% of the straw offered. Both the DMD and OMD were higher ($P<0.05$) where PEG was included in the diet compared to the other two treatments.

No defaunation was evident, suggesting a much lower concentration of CT and / or lower protein precipitation capacity of the CT present in the ***A. saligna*** foliage, compared to the foliage used in Trial 1. For all treatments, the animals maintained body weight.

Discussion

The results of Trial 2 are in stark contrast with Trial 1. The average daily DMI of ***A. saligna*** in the control group was almost seven times the intake of the control animals from Trial 1, and with PEG supplementation DMI was greater than 2.5 times higher in Trial 2 than it was in Trial 1. The DMD and OMD were also considerably higher in Trial 2 compared to Trial 1 and would help explain the higher DMI for Trial 2. Whereas Trial 1 demonstrated clearly that ***A. saligna*** was inadequate as a source of nutrients for sheep, Trial 2 indicated that ***A. saligna*** could in fact play a useful role as a major component of a sheep's diet.

Variations in the CT concentration of the ***A. saligna*** used in the respective trials may explain the differences observed in DMI, DMD and OMD. (Analyses of CT in the ***A. saligna*** of the respective trials has not yet been completed). There are several factors that may influence the CT contained within the foliage of browse species including genotype (Baldwin ***et al***. 1987), season (Hagerman 1988), soil (Barry and Duncan 1984; Kelman and Tanner 1990) and age of the tree (Degen ***et al.*** 1997; Makkar ***et al.*** 1991). The foliage used in the two trials was harvested from different sites in different years, from differently aged trees. Further research is needed to determine how CT may vary in ***A. saligna*** in relation to the many factors that may influence it. Greater understanding of such factors might enable its potential source of fodder to be realised.

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TABLE 2
Intake and digestibility of *A. saligna* and straw offered to sheep with or without a supplement of 1% urea or PEG 4000.

	TREATMENT			SIGNIFICANCE
	CONTROL	+ PEG 4000	+ 1% UREA	
DMI (G/D)				
- Straw	75	72	82	NS
- *A. saligna*	(44)	(28)	(52)	
- Total	1287[a]	1389[b]	1295[a]	*
	(200)	(126)	(238)	
	1362[a]	1461[b]	1377[a]	*
	(175)	(107)	(205)	
DMD (%)	48.2[a]	55.2[b]	49.0[a]	*
	(2.6)	(4.7)	(2.8)	
OMD (%)	49.7[a]	56.6[b]	50.9[a]	*
	(2.4)	(4.6)	(2.5)	

**P <0.05; NS, not significant. Values within rows within different superscripts are significantly different. Values within brackets indicate standard deviations.*

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A search for novel biologically active compounds in the phyllodes of *Acacia* species

KRISTEN WICKENS AND MARCELLO PENNACCHIO

Department of Environmental Biology, Curtin University of Technology,
GPO Box U1987, Perth, Western Australia 6845
Email: krissiwick_78@hotmail.com

SUMMARY

For thousands of years, indigenous Australians have relied on native plants as a source of medicinal agents. With a wide distribution and abundance, *Acacia* species were used routinely for this purpose. Preparations from at least 30 species of *Acacia* were either applied externally for skin sores, cuts, scabies and burns or taken internally for colds, coughs, sore throats and headaches. Some were used in smoke treatments for mothers and their babies. We briefly review the traditional medicinal uses of *Acacia* species and report on some findings obtained through preliminary screening of extracts from more promising species such as *Acacia pruinocarpa* and *A. dictophleba*.

INTRODUCTION

Acacias (Mimosaceae) are well known to Australians as wattles. More than 950 recognised species occur in Australia (Maslin 2001). Many species have adapted to the harsh conditions of the semi-arid and arid zones but they are also common in tropical and subtropical regions. Being widely distributed and often attractive, they have become icons to the Australian people. Many species have appeared on stamps, coins, military insignia and even the national coat of arms (Pearn 1993). The Golden Wattle, *Acacia pycnantha*, is the national floral emblem.

Indigenous Australians would have tested many species for their medicinal potential. Preparations from those species considered useful were mostly applied externally to treat sores, cuts, burns and scabies (Table 1). Among the more favoured species were *Acacia ancistrocarpa*, *Acacia pruinocarpa* and *Acacia holosericia*. Others were taken internally to treat colds, sore throats and as cough suppressants (Table 1). Routinely prescribed for coughs, for example, were preparations of *A. bivenosa* subsp. *wayi* (Cribb and Cribb 1981), *A. dictophleba* (Bindon 1996), *A. ligulata*, *A. monticola* (Reid and Betts 1977) and *A. tetragonophylla* (Webb 1959). Interestingly, one of the better-known uses for *A. tetragonophylla* was in the removal of warts (Barr 1993). The needle-like phyllodes were used to puncture unwanted growths causing them to shrivel up and dry out. An infusion of the phyllodes of *A. tetragonophylla* was used as an antiseptic to treat dysentery (Reid and Betts 1977).

Similar illnesses were treated with the smoke from burning wattles. For example, *Acacia ancistrocarpa* was considered useful in treating diarrhoea in babies (Reid and Betts, 1977). Most smoke treatments, however, were used to strengthen the mother and her child following birth. As part of the sacred rituals that followed childbirth, mothers would lay with their babies near trenches in which *Acacia* and other plant species were being burnt. In some cases this was believed to also inhibit post-partum bleeding.

Despite their widespread distribution and broad spectrum of uses, it is somewhat surprising that there is little or no known use for wattles in some areas of Australia. Scarlett *et al.* (1982), for example, reported that they were not used for medicinal purposes in Arnhem Land, one of Australia's largest Aboriginal reserves. It seems unlikely that indigenous Australians would have ignored the wattles that occur in such areas, and it is possible that knowledge on the medicinal potential was lost before it could be recorded. Aboriginal people kept no written account of their knowledge, much of which was lost when European colonists and their western medicines and practices began arriving (Scarlett *et al.* 1982).

The traditional medicinal uses of Australian plants did not go unnoticed by the European colonists. Impressed with the 'healing' powers of wattles, colonial doctors soon added many to their own practices. Prescriptions for the treatment of dysentery, diarrhoea and sore eyes were common. Many of these were still being used as recently as 1940 and were later named in honour of those doctors who adopted them (Pearn 1993).

As part of a larger study aimed at identifying novel biologically active compounds from Australian native plants and animals, we collected plant material from a number of the more promising *Acacia* species (Table 1) and screened them on routine bioassays. Previous studies into the medicinal uses of other native plants have already yielded a number of interesting pharmacologically active compounds (Pennacchio *et al.* 1995, 1996a, 1996b, 1997). We hope that our work will substantiate further some medical claims made for Australian plants by indigenous Australians. The preliminary results of our study are presented here.

TABLE 1
Acacia species which are known to be used for medicinal purposes by Indigenous Australians. Those species marked with an asterisk (*) were screened for biologically-active compounds.

SPECIES	PART USED	PREPARATION	TREATMENT	REFERENCES
A. adsurgens (*)	Leaves and twigs	Smoke treatment	To treat babies for diarrhoea	Low (1990)
A. ancitrocarpa	Leaves and twigs Leaves and twigs	Bashed and soaked Heated Smoke treatment	Skin sores & headaches Swellings and pain To treat babies for diarrhoea	Reid and Betts (1977) Bindon (1996) Low (1990)
A. aneura (*)	Leaves and twigs	Smoke treatment	Strengthens mothers and newborn babies	Barr (1993)
A. auriculoformis (*)	Leaves Leaves and pods. Leaves and pods.	Decoction Lather Lather	Antiseptic cleanser Pruritis & allergy rash Pain in legs and body	Barr (1993) Levitt (1981)
A. bivenosa subsp *wayi* (*)	Bark and roots	Infusion	Cough and cold medicine	Cribb and Cribb (1981)
A. coriacea (*)	Trunk and lateral roots	Ash	Chewed with pituri	Cleland and Tindale (1958)
A. cuthbertsonii	Bark Bark Bark	Unknown Stripped Moistened	Toothache, pain and rheumatism Splint and bandages Headache	Reid and Betts (1977) Barr (1988)
A. dictophleba (*)	Leaves Leaves and branches	Infusion Smoke treatment	Cold, coughs and headaches Strengthens mothers and newborn babies	Bindon (1996) Meggitt (1962) Low (1990)
A. difficilis	Bark	Stripped	Bandages and splints	Barr (1998)
A. estrophiolata	Bark from branches Bark Root bark	Decoction Moistened Infusion	Antiseptic for boils, scabies and sore eyes Bandage for sores and burn wounds Headache, sore throat, colds and alimentary discomfort	Barr (1993)
A. holosericea	Roots Leaves Roots Pods and seeds Pliable bark	Infusion Decoction Infusion Lather Moistened	Laryngitis Cleanser, deodorant and mild antiseptic for skin sores Sore throats Relieves itchiness Headaches	Reid and Betts (1977) Barr (1993)
A. inaequilatera (*)	Bast under cork bark	Infusion	For skin sores, cuts, chicken pox rashes.	Reid and Betts (1977)
A. kempeana	Leaves Leaves and twigs	Decoction Smoke treatment	Wash for severe colds Strengthens mother and newborn babies and help s stop post partum bleeding.	Barr (1993)
A. leptocarpa	Green leaves	Infusion	Sore eyes	Reid and Betts (1977)
A. ligulata	Leaves and branches Bark	Smoke treatment Decoction	Diaphoretic for several complaints including those of the nervous system and after childbirth Cough medicine	Barr (1993)
A. lysophloia	Leaves and twigs Leaves and branchlets Young leaves and twigs Phyllodes	Infusion Scorched on hot embers Decoction Smoke treatment	Body wash for colds and flu Relieves pain and aches when applied externally Anodyne of post-natal therapy Stregthens mothers and newborn babies	Barr (1993)

TABLE 1 (continued)

SPECIES	PART USED	PREPARATION	TREATMENT	REFERENCES
A. melanoxylon	Bark	Infusion	Skin wash	Low (1990)
A. monticola	Branches Roots	Decoction Infusion	Coughs and colds Cures coughing	Webb (1969) Reid and Betts (1977)
A. multisiliqua	Leaves	Boiled or crushed	Vapour inhaled for nasal congestion	Barr (1993)
A. oncinocarpa	Leaves	Decoction	Respiratory illnesses	Barr (1993)
A. pellita	Pods	Lather	Pruritic skin	Barr (1993)
A. pruinocarpa (*)	Leaves and branches	Smoke treatment	Strengthens mothers and newborn babies	Low (1990)
A. pyrifolia	Bark	Decoction	Skin sores (applied around the sore)	Webb (1969)
A. salicina	Leaves	Unknown	Considered to have medicinal properties	Latz (1995)
A. spondylophylla	Unknown	Unknown	Skin wash	O'Connell et al. (1983)
A. tetragonophylla	Inner bark Wood Leaves	Infusion Burnt to ashes Chewed	Cough medicine Antiseptic Dysentery	Webb (1969) Reid and Betts (1977)

MATERIALS AND METHODS

The phyllodes and stems of eight species of *Acacia* (asterisked in Table 1) were collected in early 2001 from the Ophthalama Dam area of Newman, Western Australia, by researchers working for the Mulga Research Centre (Curtin University of Technology). Additional material was collected from the Department of Environmental Biology's field trial area at the Bentley campus, Curtin University of Technology. All specimens were identified by Bruce Maslin. Voucher specimens (KW 1-8) were deposited at the Department of Environmental Biology's Herbarium.

All material was dried in an oven at 50°C for 48 hours and then ground to a fine powder using a vegetative grinder (Dietz-Motoren KG, Eleckromotorenfragnik, West Germany, 220V, type WRB 80C12QSIL). The powdered material was then put through a series of chemical extractions using hexane, dichloromethane, methanol and deionised water. Only the aqueous extracts were screened for biological activity. The other extracts were set aside for future testing.

Brine Shrimp Lethality Test

The aqueous extracts of the leaves of the eight species were screened for chronic toxicity (24-hour exposure) with the Brine Shrimp Lethality Test (BSLT). The median lethal concentrations were derived graphically after the data were treated according to the Reed-Muench procedure.

Dried eggs of brine shrimp (*Artemia salina*) were placed into 20% seawater, which was constantly aerated at 25°C, for one hour. They were then immersed in 40% bleach for seven minutes and rinsed in water until the smell of bleach had disappeared. The eggs were then returned to the 20% seawater and left for 48 hours, during which time most of them had hatched. One-day-old larvae were used in the tests.

Four concentrations of the aqueous extracts were prepared with 20% seawater and then transferred to vials (5 ml), with six replicates. Ten brine shrimp were transferred to each vial and left at a constant temperature for 24 hours. A fifth group, the control, comprised brine shrimp placed in vials containing 20% seawater only. After 24 hours the dead brine shrimp were counted to establish the median lethal concentration (LC_{50}).

Allelopathy

Allelopathy is the inhibition of germination and growth in plants caused by the secondary metabolites of other plants (Mueller-Dombois and Ellenberg 1974). These substances are usually phenolics, but tannins have also been shown to inhibit germination and growth in plants. Lettuce seeds were used in germination trials aimed at identifying allelopathic substances from *Acacia* species. As with the previous test, four different concentrations of the aqueous extracts were used in each trial. The control group was treated with deionised water only. Lettuce seeds were germinated in petri dishes (25 in each) lined with filter paper, with four replicates. The petri dishes were kept in the dark in an incubator set at 25°C and were checked every 24 hours for 72 hours.

Antimicrobial bioassays

The aqueous extracts were also tested in a concentration-dependent manner for antimicrobial activity. The test

organisms were comprised of two species of bacteria (*Staphylococcus aureus* and *Streptococcus pyogenes*) and one fungus (*Candida albicans*). Each extract was tested via small, sterilised paper disks saturated with a known concentration of the extracts. The disks were similar in size and shape to the commercial Oxoid Susceptibility Disks used in the controls (see below).

All three test organisms were grown on Mueller-Hinton blood agar plates obtained commercially from Royal Perth Hospital. All tests were performed in sterile conditions. Known antibiotics were used as controls. Penicillin G (Oxoid Susceptibility Disks) was used in all tests involving *S. aureus*. Erythromycin (Oxoid Susceptibility Disks) was used as a control for *Streptococcus pyogenes* and Nystatin was used in tests with *C. albicans* (Oxoid Susceptibility Disks).

RESULTS

Brine Shrimp Lethality Test

Following 24 hours of exposure to the extracts (chronic toxicity), the aqueous extract of the leaves of *A. pruinocarpa* resulted in an LC_{50} of 100 ppm when tested on the nauplii larvae of brine shrimp (Table 3). This was the most toxic extract. The second most toxic was *A. dictophleba*, which produced an LC_{50} of 158 ppm. These values were compared to those reported for potassium dichromate ($K_2Cr_2O_7$) by Sam (1993) to establish a relative toxicity for the extracts (Table 2). The least toxic extract was from the phyllodes of *A. inaequilatera*. Interestingly, the powdered foliage of this species gave one of the authors a skin rash.

TABLE 2
Chronic median lethal concentration for *Acacia* species using the BSLT. Relative toxicities are compared to $K_2Cr_2O_7$ (from Sam 1993).

PLANT SPECIES	LC_{50} (24 H) PPM	RELATIVE TOXICITY
A. pruinocarpa	100	0.37
A. dictyophleba	158	0.21
A. adsurgens	251	0.15
A. aneura	562	0.06
A. auriculiformis	1259	0.03
A. bivenosa	1778	0.02
A. coriacea	2113	0.01
A. inaequilatera	8912	3.8×10^{-3}

Allelopathy

Like the BSLT, the aqueous extract of phyllodes of *A. pruinocarpa* was the most potent of the species tested. A concentration of 0.19 g/L (Table 3) was sufficient to inhibit germination in all lettuce seeds. In contrast, all 25 control seeds in each petri dish germinated within 72 hours. The aqueous extract of *A. coriacea* phyllodes had no effect on the seeds at the concentrations tested, the highest of which was 20 g/L.

TABLE 3
Results of the Seed Germination Inhibition Assay on *Acacia* species. The lowest concentration, which completely inhibited germination in the lettuce seeds, is given.

PLANT SPECIES	CONC. (G/L)
A. pruinocarpa	0.19
A. dictyophleba	2.50
A. bivenosa	5.00
A. inaequilatera	7.00
A. aneura	10.00
A. auriculiformis	50.00
A. adsurgens	80.50
A. coriacea	No inhibition

Anti-Microbial bioassays

None of the aqueous extracts screened for antimicrobial activity inhibited the growth of the three test pathogens (Table 4). All three pathogens were, however, inhibited by known antibiotics. The average inhibition induced by Penicillin G on *S. aureus* was 42.60 ± 1.37 mm, and on *Streptococcus pyogenes* it was 38.63 ± 1.32 mm. Erythromycin was less potent. Nystatin is effective only on fungi. The inhibition mediated on *C. albicans* was 21.42 ± 1.19 mm. The average inhibition induced by these three controls was greater than that required before a pathogen could be considered susceptible to them.

TABLE 4
Results of the tests for antibiosis. Inhibition is reported in mm (mean ± SEM) for all extracts and for the controls. NA = not applicable.

SPECIES	*Staphylococcus aureus* (mm)	*Streptococcus pyogenes*(mm)	*Candida albicans* (mm)
A. adsurgens	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
A. aneura	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
A. auriculiformis	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
A. bivenosa	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
A. coriacea	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
A. dictyophleba	*0.00 ± 0.00*	*0.00 ± 0.00*	*0.00 ± 0.00*
A. inaequilatera	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
A. pruinocarpa	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Penicillin G	42.60 ± 1.37	38.63 ± 1.32	NA
Erythromycin	27.00 ± 0.89	25.31 ± 1.75	NA
Nystatin	NA	NA	21.42 ± 1.19

Discussion

Few studies have attempted to substantiate the medical claims made by Aboriginal people for *Acacia* and other plants. Previous work by our research team has shown that some of the plants routinely used for medicinal purposes by indigenous Australians do, in fact, produce

beneficial natural products (Pennacchio *et al.* 1995, 1996a; Pennacchio and Ghisalberti 2000). The results of our study with *Acacia*, despite being preliminary, add to the growing evidence that native plants may be a source of biologically active compounds.

One likely source for such compounds is the phyllodes of *Acacia pruinocarpa*. An aqueous extract of phyllodes grown at the field trial area at the Curtin University of Technology campus resulted in a significantly toxic effect on brine shrimp nauplii larvae and inhibited seed germination in a standard test for allelopathy. Equally promising are *A. dictyophleba* and *A. adsurgens*. Whether these three species are worth further investigation depends largely on the type of activity sought and the concentrations required to mediate the desired effect. The BSLT, for example, is a rapid, relatively simple toxicity test (Sam 1993). This preliminary bioassay, which may serve as a test for antitumour and pesticidal activity, does, however, have its limitations. There is currently no accepted standard for determining whether or not the level of toxicity exhibited by a compound or an extract is useful.

In our laboratory, we have adopted a practice similar to that of Sam (1993), comparing the median lethal concentration to that of potassium dichromate ($K_2Cr_2O_7$). Extracts that produce a similar toxicity to $K_2Cr_2O_7$ (in the 24-hour test) are considered worth additional testing. Work on extracts from *A. pruinocarpa*, *A. dictyophleba* and *A. adsurgens* will therefore continue. Before any bioassay-guided fractionations are attempted, however, the tannins will be removed from the extracts using a polyamide column.

Acacia pruinocarpa and *A. dictyophleba* also featured prominently in tests for allelopathy (the inhibition of germination and growth of plants caused by secondary metabolites of other plants), but the tannin content of these species is not known and it is therefore not clear whether those present in the phyllodes are likely to be responsible for inhibiting germination of lettuce seed. Both species will be rescreened once the tannins have been removed from the extracts.

To indigenous Australians, species such as *A. auriculiformis* were considered useful as antiseptics and for treating topical infections (Table 1). These were often prepared by crushing phyllodes and then mixing them with water to create a lather. Others were prepared as decoctions. This prompted our team to test for antimicrobial agents using similar aqueous extracts.

Surprisingly, none of the species we screened inhibited the growth of the two test bacteria, *Staphylococcus aureus* and *Streptococcus pyogenes*, or that of the thrush-inducing fungus, *Candida albicans* (Table 5). Barr (1993) performed similar tests with using *Klebsiella pneumoniae*, *Salmonella typhimurium* and *Escherichia coli*, none of which was inhibited by the extracts tested. The pods of *A. auriculiformis* did, however, inhibit *S. aureus* (Barr 1993). This was not considered a useful antimicrobial agent since it only inhibited that bacterium. A preliminary study we conducted earlier revealed that the hexane, dichloromethane and methanol extracts of our *Acacia* species were also ineffective in inhibiting the test pathogens. It is unlikely that the eight species screened produce substances with antimicrobial activity.

Our work, which is still at a preliminary stage, will soon focus on isolating and identifying the active constituents responsible for some of the activity we have observed. Previous phytochemical surveys have resulted in several simple compounds, but the number is disappointing (Collins *et al.* 1990). Thirteen of the 30 species listed in Table 1 were screened for alkaloids with only nine testing positive in standard tests. *A. aneura*, *A. estrophiolata*, *A. holosericea* and *A. tetragonophylla* all tested positive in the Mayers alkaloid test (Collins *et al.* 1990; Barr 1993). Along with *A. lysiphloia*, *A. multisiliqua* and *A. pellita*, these also tested positive for the Silicotungstic acid test and Dragendorff's test.

A number of *Acacia* species were also screened for the presence of saponins and tannins. *A. aneura* (phyllodes and twigs), *A. holosericea* (phyllodes, bark and pods), *A. ligulata* (phyllodes and twigs), *A. lysiphloia* (phyllodes and twigs), *A. multisiliqua* (phyllodes) and *A. pellita* (pods) have all been shown to produce saponins and tannins . None of these has any known pharmacological activity but some have been implicated in the death of fish in Aboriginal fishing practices. Bark from these species was pounded and dispersed in small waterholes, where it was left overnight (Barr, 1988). Dead and stunned fishes were collected the following day, most of them victims of asphyxiation.

In conclusion, there is some evidence to suggest that *Acacia* species do produce interesting and useful biologically active compounds that are worth investigating further.

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Horticultural potential of *Acacia*

GRADY BRAND[1] AND LUKE SWEEDMAN[2]

[1]Curator, Botanic Gardens and Display, Kings Park and Botanic Garden, West Perth, Western Australia 6005
[2]Curator, Western Australian Seed Technology Centre, Kings Park and Botanic Garden, West Perth, Western Australia 6005

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SUMMARY

The wattle is an acknowledged plant icon of Australia, with Western Australia the hot spot for diversity: Western Australia has 500 of the 960 Australia species. With familiarity comes complacency, and possibly this genus has become a victim of this in the horticultural world. Its potential is vast, with the ability to influence all communities in the State. Strategic marketing of Western Australian species that have undergone horticultural development trials would ensure that the most attractive wattles would be utilised. Kings Park and Botanic Garden has devoted 0.7 hectare to the cultivation of c. 70 of the most decorative acacias. This is combined with public artwork to inspire and focus attention on the more attractive species. There are distinctive localised acacias in each major region of Western Australia which could be adopted by each community, giving them their own identity and sense of place. Cultivation with seed of local provenance will create ecologically sound initiatives and will help develop green corridors, linking natural remnant bushland throughout the region. Table 1 indicates the species considered suitable to create this effect.

HORTICULTURAL OPPORTUNITIES FOR *ACACIA*

1. Ornamental species for home gardens

- ✔ Compact habit for small gardens and pot cultivation
- ✔ Unusual habit giving good architectural form for design purposes
- ✔ Dark green, soft foliage
- ✔ Grey, soft foliage
- ✔ Flowering regime, i.e. season, length of flowering, flowers complementing foliage
- ✔ Cut flowers and / or foliage
- ✔ Hardiness and ease of cultivation
- ✔ Suitability for a broad range of growing conditions
- ✔ Reliable performance under cultivation
- ✔ Attractive in a nursery container
- ✔ Potential for development to enhance the above features

2. Street scape potential (amenity horticulture)

- ✔ Creating a focused sense of place
- ✔ Reflect significant features of the local ecosystems
- ✔ Flowering to coincide with major events of the town, i.e. a flowering calendar
- ✔ Hardy and suitable for the site
- ✔ Longevity with minimal maintenance requirements
- ✔ Appropriate form / habit for situation

3. Road verge enhancement (sense of place)

- ✔ Creating a green approach to towns, especially to create a sense of place in denuded agricultural landscapes
- ✔ Mix local species to provide a long flowering display
- ✔ Reflecting biodiversity of the shire
- ✔ Conservation corridors
- ✔ Adapted species chosen to reflect soil type and produce a hardy, reliable performance
- ✔ Seed of local provenance to reflect biodiversity and their proven suitability for the region and soil type
- ✔ Formal recognition, e.g. Dalwallinu Shire Council adopting ***Acacia anthochaera*** as its floral emblem
- ✔ Strong, bold form for maximum impact, or mass planting to achieve similar effect

TABLE 1
Recommended species according to region in Western Australia

Region	Species	Flowering time	Size	Soil type
Kimberley				
	A. colei	May-Sept	1.5-9 m	rocky, clay, loam, sandplains, stony ridges, drainage lines
	A. delibrata	Mar-Aug	2-8 m	rocky soils, sandstone, basalt or quartzite
	A. dunnii	Jan-Jun	1.5-6 m	rocky soils, either sandstone, basalt or quartzite
	A. gardneri	May-Aug	1.5-5 m	sandy soils and rocky sandstone soils
	A. hippuroides	Mar-Oct	0.3-1.6 m	sandy soils and rocky sandstone soils
	A. kelleri	Mar-Oct	1.5-7 m	sandstone, rocky hills, creek beds
	A. lamprocarpa	Apr-Jun	4-15 m	sandy soil
	A. lycopodiifolia	Jan-Sept	0.2-1 m	sandy and rocky soil
	A. lysiphloia	May-Sept	1-4 m	sand loam and clay, wet areas
Pilbara				
	A. adoxa	Apr-Oct	1 m	sand dunes, stony ridges
	A. bivenosa	Apr-Nov	0.5-3 m	adapts to many soils, particularly sandy soils
	A. coriacea	Mar-Aug	1-10 m	sandy soils, limestone and coastal
	A. cyperophylla var. *omearana*	Mar-Apr	4-10 m	alluvial stony soils
	A. orthocarpa	Mar-Jul	1-3 m	sandy soils
	A. paraneura	Jun-Sept	3-8 m	sandy, clay and rocky soils
	A. pyrifolia	Apr-Oct	0.5-4 m	rocky soils
	A. spondylophylla	May-Aug	<1 m	sandy, rocky soils
	A. trachycarpa	May-Oct	1-4 m	sandy, rocky soils
	A. tumida	Apr-Oct	2-9 m	variety of soils
	A. validinervia	Jul-Aug	1-4 m	variety of soils
Gascoyne/ Goldfields				
	A. aneura (many forms)	Feb-July	1-10 m	variety of soils
	A. craspedocarpa	Mar-Sept	1-4 m	clay/loam soils
	A. cyperophylla var. *cyperophylla*	Jul-Aug	3-10 m	sandy and rocky along creeks/rivers
	A. demissa	April-Aug	1-4 m	clay/loam soils
	A. grasbyi	May-Oct	2-4.5 m	variety of soils
	A. hemiteles	May-Oct	0.5-2 m	variety of soils
	A. palustris		2-4 m	alluvial soils
	A. sibilans		3-7 m	sand/loam
	A. wanyu	Mar-Jul	1.5-5 m	clay/loam, sand
Arid interior				
	A. dictyophleba	Mar-Sep	0.5-4 m	sand/stony
	A. murrayana	Aug-Nov	2-5 m	sand
	A. papyrocarpa	Aug-Nov	2-8 m	sandy/loam, calcareous soils
	A. rhodophloia	May/Oct	1-4 m	sand/gravel
Northern Wheatbelt				
	A. ancistrophylla	Aug-Oct	0.5-2.5 m	sand
	A. anthochaera	Aug-Dec	1-5 m	sand/loam
	A. guinetii	Jun-Sep	0.3-2 m	gravelly
	A. multispicata	Mar-Oct	0.2-2 m	sand
Central Wheatbelt				
	A. acuminata	Jul-Oct	1-7 m	variety of soils
	A. anfractuosa	Jul-Dec	1-4 m	sand
	A. denticulosa	Sep-Oct	1-4 m	sand/loam/granite
	A. merinthophora	May-Sep	1-4 m	sand
	A. microbotrya	Mar-Jul	1-7 m	variety of soils
	A. rossei	Aug-Jan	1-3 m	sand
Southern Wheatbelt				
	A. glaucoptera	Aug-Dec	0.4-1.2 m	gravel
	A. lanuginophylla	Jul-Oct	0.5-1.2 m	variety of soils
	A. redolens	Aug-Oct	0.5-3 m	variety of soils, often saline
South coast				
	A. heterochroa	Apr-Dec	0.3-2 m	gravelly
	A. myrtifolia	May-Jan	0.5-3 m	sand/gravel
	A. rhamphophylla	Aug-Sep	0.2-0.5 m	rocky sand/clay
	A. subcaerulea	Mar-Sep	1-3 m	sand
Forest				
	A. browniana	May-Nov	0.2-2 m	sand/gravel
	A. drummondii	Jun-Oct	0.3-1 m	sand/gravel
	A. veronica	Mar-Sep	1.5-10 m	sandy/loam

Reproductive potential of *Acacia* species in the central wheatbelt: variation between years

MANGADAS LUMBAN GAOL[1, 2] AND J.E.D. FOX[1]

[1]Department of Environmental Biology, Curtin University of Technology, GPO Box U1987, Perth, Western Australia 6845; email: J.E.Fox@curtin.edu.au
[2]Department of Biology, Nusa Cendana University, Kampus baru, Penfui Kupang, West Timor, Indonesia; email: mangadas@hotmail.com

SUMMARY

In a study at Sandford Rocks Nature Reserve aimed at discovering how rainfall variation between years affects reproductive potential in *Acacia* species, the effect of phyllode number and branch position in the crown and seed quality were investigated. High rainfall in 1999 allowed heavier fruiting. More inflorescences set pods and more pods were produced. In 2000, pod yields were reduced by drought. The extent of flowering depends on good winter rainfall and fruit production depends on moisture availability in spring. Although all species suffered from drought in 2000, there were differences in their degree of susceptibility: *A. fauntleroyi*, *A. neurophylla*, *A. acuminata* and *A. steedmanii* were the least affected whereas *A. stereophylla* failed to develop pods; *A. hemiteles* did not flower, and less than 1% of inflorescences developed a pod in both *A. saligna* and *A. lasiocalyx*.

Late spring frost in 1998 limited seed development. All species produced few seed; many pods were empty; many immature and infected seed were found; and there was poor germination. Of 13 species, only three had more than 40% germination. In six species there was no germination, while all others had less than 30% germination.

Plants bearing more phyllodes had more flowers and fruits, and fewer inflorescences dried off. Generally, branches in the upper part of the crown initiated more inflorescences. In some species there were more pods in central parts of the crown. The difference in the form or architecture of branches among species presumably affected resource partitioning and consequently reproductive potential.

INTRODUCTION

The genus *Acacia*, with some 1165 taxa, is represented in most habitats of Australia (Maslin 2001). It dominates the woody vegetation of the arid and semi-arid regions and is well represented in more mesic environments. In Western Australia, Sandford Rocks Nature Reserve (SRNR; 31°18'S, 118°42'E), contains a complex mosaic of exposed granite rock, with surrounding shrublands and woodlands. The reserve has an area of 805.9 ha, consisting of granite outcrops, thickets and woodlands. Westonia experiences a Mediterranean climate with summer maximum temperatures ranging from 35-40°C and winter temperatures of 15–20°C (Beard 1979). The mean annual rainfall is 324 mm, most falling between May and August. Important floristic components of the vegetation are eucalypts, wattles, *Melaleuca* and grasses. Wattles are locally abundant, generally grow in mixed-species assemblages and clearly play important ecological roles. In three years of observations (1998-2000), most wattles flowered in July to September and produced seed in December. An exception was *Acacia jennerae* which flowered in March 1999 and 2000.

Reproductive potential or capacity of a plant is of practical concern in plant conservation as it often has an impact on management and recovery strategies. An upper limit to the number of pods that can be produced by *Acacia* during a reproductive episode is set by the number of inflorescences and the number of flowers per inflorescence. Similarly, an upper limit to the number of seeds is set by the number of ovules within the flowers. Reproduction is dependent on the number of inflorescences, the number of pollinated flowers, the number of fertilised ovules, the extent of pod and seed predation, weather conditions and the ability of the maternal parent to provide resources for development.

Factors that may reduce reproduction include a short growing season, low or high temperature, low nutrient and moisture availability, herbivory, humidity, wind at the time of pollination, competition, disease and scarcity of pollinators. Reproduction may vary within a reproductive episode due to weather conditions. Late spring frost, winter cold and drought have been proposed as causing fluctuations in reproduction. These factors may reduce the possibility of flowering and seed set.

Plants are usually depicted as accumulating resources and allocating them to growth, maintenance and reproduction (Willson 1972). The resources needed for reproduction come from several sources. Inorganic nutrients and water move into fruits *via* the xylem while

carbohydrates and recycled nutrients from vegetative organs enter fruits from the phloem (Kozlowski 1971). Leaves donate carbohydrates and nutrients to fruits (Hocking and Pate 1977). Fruits can potentially attract resources from leaves a metre or more away but the tendency is for resources to flow into fruits from the nearest leaves (Mooney 1972). Consequently, in terms of assimilates provided by leaves each inflorescence and its adjacent leaves can be considered as an independent unit (Harper and White 1974).

The resources available to a given flower or fruit depend on the total resources of the individual or branches and the number of reproductive structures drawing upon those resources. Plants match reproductive output to resources available by flower and juvenile fruit abscission (Stephenson 1981). Many species commonly produce mature fruits from only a small portion of the flowers (Stephenson 1979). These species regularly abort flowers and immature fruits. *Acacia* species seem to be included in this category.

A 3-year study was conducted to investigate the potential for natural regeneration of *Acacia* species present at SRNR. In spring 1998, frost occurred while most *Acacia* species were in the reproductive phase. Understanding its effect on *Acacia* reproduction is of particular interest. The following questions were addressed: What proportion of inflorescences initiated result in formation of pods? Does any temporal variation in pod production occur from year to year? Does late spring frost affect seeds produced? Do the number of phyllodes per branch and the position of branches affect reproduction?

METHODS

The study was conducted between December 1998 and December 2000. In 1999-2000, eight *Acacia* species were examined: *A. acuminata*, *A. fauntleroyi*, *A. hemiteles*, *A. lasiocalyx*, *A. neurophylla*, *A. saligna*, *A. steedmanii* and *A. stereophylla*. For each species one to three representative plants in reproductive mode were selected for study. The plants were mature but of unknown age. Most were 2-3 m tall, size varying from 1-1.5 m for *A. hemiteles* to 3-4 m for *A. lasiocalyx*. Sets of 15-35 branches per plant were labelled. Plants were selected depending on the availability of flowering individuals in the area and time in the field. Position of branches was divided subjectively as top (distal), middle (central) or lower (basal) part of the plant crown. Parameters recorded were number of phyllodes and inflorescences per branch. After all pods had matured (or nearly so), plants were re-measured. Calculations were made of the number of inflorescences that set pods and number of pods per inflorescence.

In December 1998, pods were harvested to investigate the production capacity of 13 species (six of the eight listed above, plus a further seven: see legend to Fig. 4 for names). Number of seeds and aborted or diseased seeds per pod and dimensions of pods (weight and/or length) were recorded. Seeds were then germinated to obtain percentage germination. Number of aborted seeds was determined by counting both empty locules and locules containing aborted seeds. Aborted seeds were seeds that started to develop but died before full maturation. Aborted seed were easily discriminated from the other categories by their size and texture. In this study an empty locule was considered as an aborted seed.

Analysis of variance was conducted to test whether reproductive characteristics differ between branch position. Tukey's family error rate was used to detect any significant difference between means for different positions. The relationships between the number of inflorescences initiated, pods set, pods matured and number of pods per inflorescence and the number of phyllodes were assessed using linear regression with number of phyllodes as predictor variables ($P < 0.05$). The relationships between the number of seeds and aborted seeds per pod; and the dimensions of pods were also analysed with regression in the same manner.

RESULTS

Comparison of reproductive characteristics in different years

All species sampled were flowering together in the period July-December. However, species differed slightly in the optimum time of flowering. They may share common pollinators and partition time to optimise pollinator availability. The flowering sequence among the eight species, based on percentage of open inflorescences and sizes of initial pods, was *A. fauntleroyi*, *A. acuminata*, *A. steedmanii*, *A. hemiteles*, *A. neurophylla*, *A. lasiocalyx*, *A. stereophylla* and *A. saligna*.

Reproductive success of each species was calculated based on the relative number of pods produced, number of pods per inflorescence and number of inflorescences initiated that produced a mature pod (b, c, d respectively in Fig. 1). This procedure gave these three characters sets of values totalling 100 and in sum the reproduction success criterion (RSC) had a maximum value of 300. Based on the percentage of inflorescences that set pods (d), the numbers of pods produced (b) and the number of pods per inflorescence (c), reproduction varied considerably among species and between years. Reproduction was better in 1999 than in 2000 (Fig. 1). More inflorescences set pods (d), more pods were produced (b) and there were more pods per inflorescence in 1999 (c).

Of the 8 species studied in 1999, the best reproduction (RSC) was attained by *A. neurophylla*, followed by *A. stereophylla* and *A. fauntleroyi* (Table 1). The poorest reproducers were *A. steedmanii*, followed by *A. lasiocalyx* and *A. saligna*. In the year 2000, the best reproduction was in *A. fauntleroyi*, followed by *A. neurophylla* and *A. acuminata*. The poorest reproduction was in *A. stereophylla*, followed by *A. lasiocalyx* and *A. saligna*, and *A. hemiteles* failed to flower.

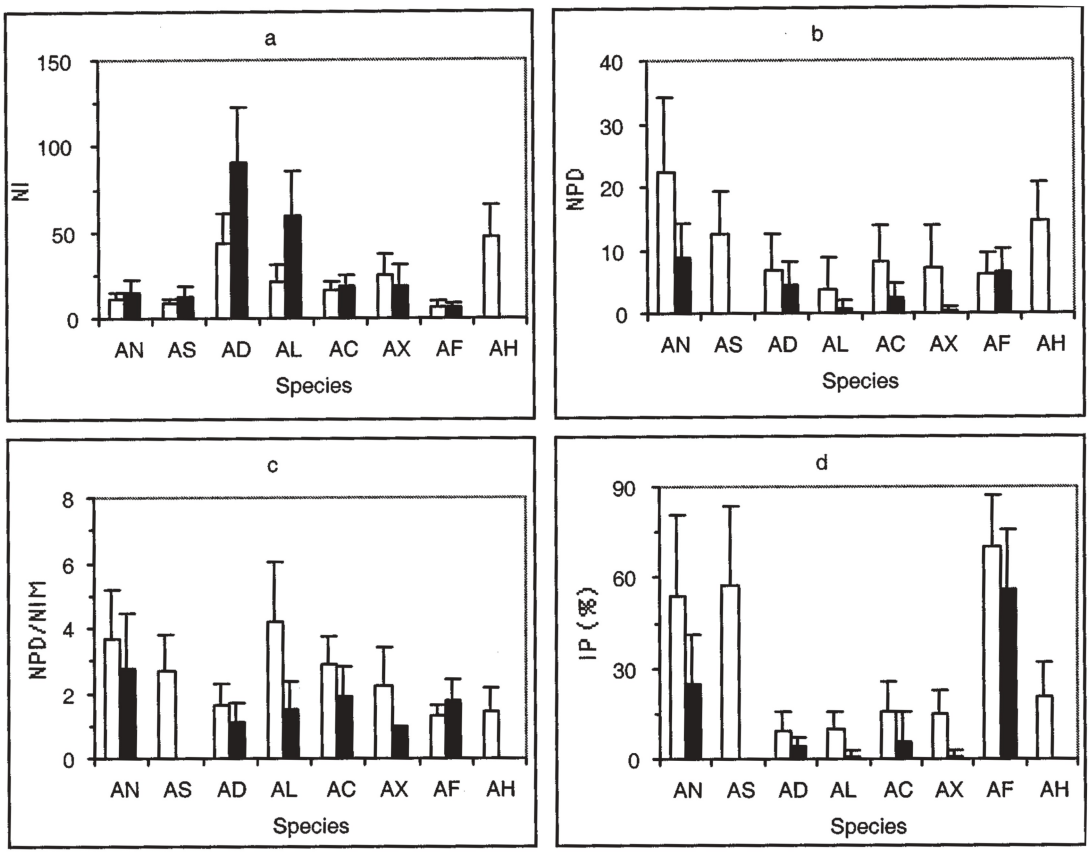


Figure 1. Comparison of Acacia reproductive characteristics in 1999 (white columns) and 2000 (black columns); error bars are shown. ***a****, number of inflorescences initiated (NI);* ***b****, number of pods produced (NPD);* ***c****, number of mature pods per inflorescence (NPD/NIM);* ***d****, percentage of inflorescences that set pods (IP%). Species: AN* = A. neurophylla; *AS* = A. stereophylla; *AD* = A. steedmanii; *AL* = A. saligna; *AC* = A. acuminata; *AX* = A. lasiocalyx; *AF* = A. fauntleroyi; *AH* = A. hemiteles.

TABLE 1
Reproduction success criterion (RSC) and its components for each of eight *Acacia* species (1999, 2000).

SPECIES	1999				2000			
	NPD	NPD/NI	IP	RSC	NPD	NPD/NI	IP	RSC
A. neurophylla	27.45	18.84	21.31	67.58	38.64	27.18	27.05	92.87
A. stereophylla	15.41	13.73	22.73	51.87	0.00	0.00	0.00	0.00
A. steedmanii	8.48	5.67	3.57	17.72	19.43	11.01	4.49	34.93
A. saligna	4.39	21.49	4.02	29.91	2.27	14.98	0.71	17.96
A. acuminata	9.82	14.75	6.26	30.83	10.47	19.15	6.51	36.13
A. lasiocalyx	8.85	11.28	5.92	26.06	0.85	9.92	0.62	11.39
A. fauntleroyi	7.54	6.74	27.96	42.24	28.34	17.76	60.62	106.72
A. hemiteles	18.07	7.50	8.22	33.79	*	*	*	*
SUM	100	100	100	300	100	100	100	300

NPD = Mean number of pods produced per branch; NI = number of inflorescences; IP = total of inflorescences that set pods; RSC = reproduction success criterion; * = no flowers in 2000.

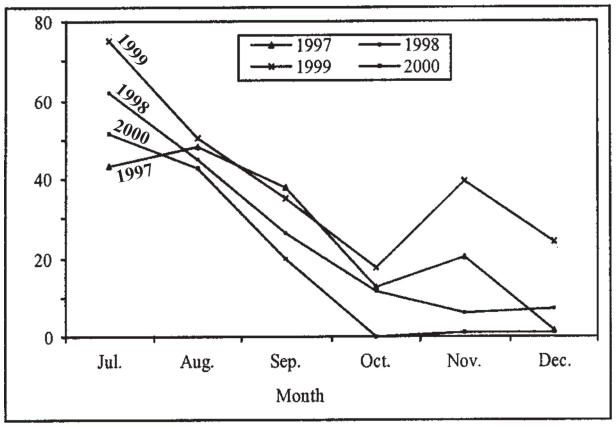


Figure 2. Monthly rainfall at Westonia during the reproduction season (July-December) 1997–2000.

Reproductive success is presumed to have been affected by lack of rain in 2000 from September onwards (Fig. 2). Between July and November 1999, approximately the period of inflorescence initiation to pod development and seed set, 335.3 mm of rainfall fell over 50 days compared with only 117.1 mm over 39 days in 2000. There was no rain in October 2000 at the time of pod development. It is of interest that the rainfall in 1999 was the heaviest recorded at Westonia (total: 597.3 mm).

Although all species suffered from drought in 2000, there were differences in the degree of susceptibility. Of the species studied, *A. fauntleroyi*, *A. neurophylla*, *A. acuminata* and *A. steedmanii* were the least affected by lack of rain in 2000. *Acacia stereophylla* was severely affected and failed to develop pods; *A. hemiteles* did not flower and less than 1% of inflorescences developed a pod in *A. saligna* and *A. lasiocalyx*.

Of all species studied in 1999, *A. neurophylla* attained the best reproduction. This species produced most pods and most pods per inflorescence. Some 39% of inflorescences initiated developed a pod; there were 15.5 pods per branch and 3.2 pods per inflorescence. Although growing in a well-drained sandy soil, the plants were not severely affected by the lack of rain in 2000. Only a small population of this species was observed. As seedlings were present, it may be assumed that there were no barriers to recruitment of new seedlings.

The second greatest number of pods produced was in *A. fauntleroyi*. A mean of 63% of those inflorescences initiated developed a pod, with 6.3 pods per branch and 1.6 pods per inflorescence. Reproduction in *A. fauntleroyi* was not severely affected by the lack of rain in 2000, presumably because the species is early flowering and plants had developed pods before severe drought had set in by October-November 2000. This species grows at the apron around the edges of granite rocks. Although it produced many pods and seeds, seedlings were rarely found in the field.

At SRNR, two varieties of *A. acuminata* occur: terete and broad phyllode types. The taxon studied was that with terete phyllodes. Of all inflorescences initiated, 11% developed a pod with 5.2 pods per branch and 2.4 pods per inflorescence. Of the *Acacia* species at SRNR, *A. acuminata* has the largest population and the widest distribution. It is generally found in moister sites, which may explain why it was less severely affected by drought. The species has good recruitment; many seedlings were observed.

In *A. lasiocalyx*, of all inflorescences initiated, 8% developed a pod with 3.7 pods per branch and 1.6 pods per inflorescence. This species was also drought-affected in 2000 with only 0.6% of inflorescences initiated developing a pod, compared to 15% in 1999. This species grows in clefts among granite rocks and no seedlings were found. However, some saplings were found, suggesting that seedling establishment does occur regularly.

Acacia steedmanii initiated 67 inflorescences per branch (more than all other species), but from all inflorescences initiated only 6.6% developed a pod, with 5.6 pods per branch and 1.1 pods per inflorescence. This species was less severely affected by drought in 2000, perhaps because it flowers earlier. Plants developed pods during the severe drought in October-November 2000, thus it can be said that drought only slightly affected pod development. This species occurs in small numbers and, over 3 years of observations, seedlings or small plants (< 1 m) were never encountered in the field.

In *A. saligna*, of inflorescences initiated, 5.4% developed a pod with 2.1 pods per branch and 2.9 pods per inflorescence. This was lower compared to *A. saligna* at the Field Trial Area, Curtin University of Technology (MLG, pers. obs.) where 12.5% of inflorescences initiated developed a pod and there were 12 pods per inflorescence. This species also suffered from drought in 2000 as 10% of inflorescences initiated developed a pod in 1999 but only 0.7% did so in 2000. Although only a few pods were produced by *A. saligna*, the plants have quite good recruitment and many seedlings were found in the field.

For *A. hemiteles*, reproduction in 1999 saw 48 inflorescences initiated per branch and 21% developed a pod; there were 14.7 pods per branch and 1.5 pods per inflorescence. Low rainfall in May-June 2000 may have inhibited flowering, or more rainfall may be needed to induce flowering. Only 22.5 mm of rain over 9 days occurred in May and June 2000 compared with 152 mm over 22 days in May and June 1999. *A. hemiteles* has a large population and wide distribution. It occurs as an understorey species in *Eucalyptus* woodland. Despite the large population, seedlings were very rarely found.

Acacia stereophylla initiated many inflorescences each year but very few pods and seeds were produced. Only in 1999 did plants produce many pods: 12.6 pods per branch and 57% of inflorescences initiated developed. However, most pods were empty or failed to develop seeds. This species has a localised distribution, occurring in bands at the edges of *Eucalyptus* woodland. Seedlings of this species were not observed in the field.

Effect of phyllode numbers and branch positions on reproductivity

Generally, higher numbers of phyllodes were associated with more inflorescences initiated and more inflorescences that set a pod ($P<0.05$). Numbers of pods per inflorescence were generally not related to the number of phyllodes per branch (Table 2). The result suggest that inflorescence initiation and subsequent pod development are related to the number of phyllodes as donor of resources or affected by resource availability, while number of pods per inflorescence may be determined by hereditary factors. High numbers of inflorescences affected by phyllode numbers may be a reflection of inflorescence initiation in axils (angle between phyllode and stem).

Number of phyllodes per branch was much greater in *A. fauntleroyi* compared to other species (Fig. 3). All others had about the same number of phyllodes per branch, except for *A. stereophylla* and *A. steedmanii*. Branches in the distal position generally had slightly more phyllodes than those in the basal position, whereas differences between the basal and central positions were not markedly different.

In *A. neurophylla*, the number of inflorescences initiated was greater in the distal than in the basal parts of the crowns (Table 3). However, more inflorescences set pods and produced pods in the basal position than in the distal position of the crown. In *A. stereophylla*, the number of inflorescences initiated and pods produced were greater in the central position of crowns. It would appear that more pods and more pods per inflorescence may result when fewer inflorescences initiated result in pods, allowing more resources to be available for pod development.

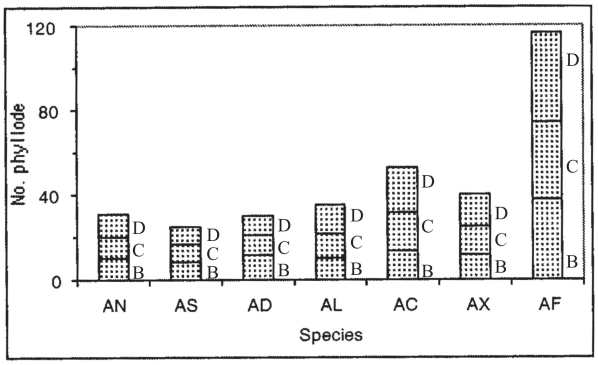


Figure 3. Mean number of phyllodes per branch of 7 Acacia species in basal (B), central (C) and distal (D) position of branches (combined 1999 and 2000). Species legend as in Figure 1.

In *A. steedmanii*, more inflorescences were initiated in the basal position, but pods produced did not differ among the branch positions. In *A. saligna*, more inflorescences and pods were produced in the distal position than in the basal position. In *A. acuminata*, slightly more inflorescences were initiated in the distal position than in the basal position but more inflorescences were produced and more pods set in the central position.

In *A. lasiocalyx*, the number of inflorescences initiated was greater in the distal position than in the basal position while the number of inflorescences that set a pod and the number of pods produced were greater in the central position of the plant. In *A. fauntleroyi*, the number of inflorescences initiated and pods produced were greater in the distal position than in the basal position. In general, the number of pods per inflorescences was not affected by position of branches.

Effect of frost and spring rain on reproductive characteristics

Seed and pod characteristics from pods collected in December 1998 suggest that late spring frost plus little rain in October-November 1998 (17.6 mm over 8 days) probably affected seed development. Most species produced low seed weight, many immature and infected seed, and germination was poor (Fig. 4). Many pods contained empty locules or locules that contained seeds that had started to develop but had died before maturation.

In *A. neurophylla* there was a mean of 1.4% diseased seeds and 8% immature seeds per pod. Mean seed weight was 4.33 ± 1.14 mg and 71% of these seeds germinated. *A. neurophylla* had 9.8 seeds per pod. The pods were 5 cm in length and weighed 54.4 mg. Larger numbers of seeds per pod were associated with longer, heavier pods and more immature seeds were found in these pods (Table 4), suggesting that competition for resources between seeds occurs.

Number of seeds per pod was not related to the number of seeds found to be infected. More immature seed was associated with lower pod weight, suggesting that some pods may have been unable to acquire sufficient resources.

Acacia steedmanii had 9.1 seeds per pod. The pods were 5.8 cm in length and weighed 120.7 mg. Mean seed weight was 3.64 ±2.93 mg, which was considerably less

TABLE 2
Significance values of linear regression between reproductive characters in 8 *Acacia* species (combined 1999 and 2000, except *A. stereophylla* and *A. hemiteles* 1999 only).

CHARACTERS/ SPECIES	AN	AS	AD	AL	AC	AX	AF	AH
NI Vs NP	<0.001	0.007	0.813	<0.001	0.008	<0.001	0.001	<0.001
NIM Vs NP	0.183	<0.001	0.042	0.070	0.754	0.245	0.089	0.092
NPD Vs NP	0.573	0.783	0.050	0.198	0.709	0.719	0.002	<0.001
NPD/NIM Vs NP	0.366	0.736	0.115	<0.001	0.238	0.204	0.011	0.310

NI = number of inflorescences initiated; NIM = number of inflorescences that set pods; NPD = number of pods produced; NPD/NIM = number of mature pods per inflorescence; NP = number of phyllodes. Species legend as in Figure 1.

TABLE 3
Mean reproductive characters in basal (B), central (C) and distal (D) branch positions, for 7 *Acacia* species (combined 1999 and 2000). Entries with different letters in a column indicate a significant difference between the means using Tukey's family error rate; significance (*P*), * *P* = < 0.05, ns = not significant. PS = position (B: basal; C: central; D: distal); NI = mean number of inflorescences initiated; NPD = number of pods produced; I = inflorescences that set a pod. Species (SP) legend as in Figure 1.

SP	PS	NI	NPD	NPD /NIM	I (%)
AN	B	11.90b	20.25a	3.79	33.20a
	C	11.91b	18.67a	3.95	18.51b
	D	14.85a	15.45b	2.69	17.82b
	P	*	*	ns	*
AS	B	9.36	14.90b	2.79b	23.41b
	C	11.48	41.03a	9.32a	11.43c
	D	10.74	13.00b	2.57b	34.55a
	P	ns	*	*	*
AD	B	94.50a	4.5	0.97	2.6
	C	70.40b	4.82	1.18	2.7
	D	78.27b	5.56	1.46	2.7
	P	*	ns	ns	ns
AL	B	34.04b	0.23b	0.29b	0.4b
	C	44.13a	2.24a	1.05a	3.0a
	D	48.05a	2.97a	2.69a	2.4a
	P	*	*	*	*
AC	B	16.36	4.14b	1.12	6.7b
	C	16.67	10.50a	1.66	20.7a
	D	17.42	0.73c	0.83	4.6b
	P	ns	*	ns	*
AX	B	12.50b	2.43	1.17	4.8b
	C	18.90 a	4.19	1.06	8.2a
	D	25.33a	3.35	0.83	4.2b
	P	*	ns	ns	*
AF	B	9.94b	7.67c	2.53	18.4b
	C	8.51b	10.20b	2.62	20.8b
	D	14.75a	14.40a	3.08	38.3a
	P	*	*	Ns	*

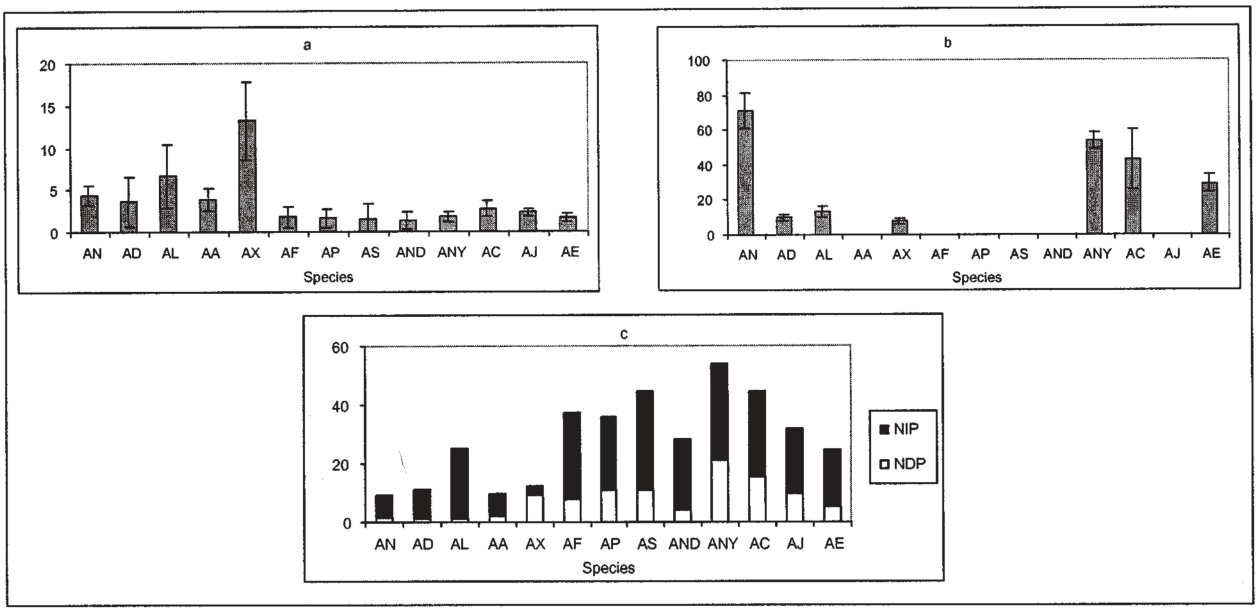


Figure 4. Seed characteristics of 13 species, from pods collected December 1998. ***a****, mean seed weight (n = 100);* ***b****, germination percentage (n = 4-8, for replicates, 50 seeds per replicate);* ***c****, percentage of immature (NIP) and diseased seed (NDP). Species: AN* = A. neurophylla; *AD* = A. steedmanii; *AL* = A. saligna; *AA* = A. acuminata; *AX* = A. lasiocalyx; *AF* = A. fauntleroyi; *AP* = *A.* prainii; *AS* = A. sessilispica; *AND* = A. densiflora; *ANY* = A. nyssophylla; *AC* = A. coolgardiensis; *AJ* = A. jibberdingensis; *AE* = A. eremophila.

than the mean weight of seed collected in 1994 (12.01 ± 1.24 mg). Only 10% of the 1998 seeds germinated; this is much lower than the 83% germination obtained from seeds collected in 1994. There were 1.2% diseased seeds and 10% immature seeds per pod, giving 11.2% of seed aborted. Larger numbers of seeds per pod were associated with longer, heavier pods; immature seeds occurred in pods with larger numbers of seeds per pod.

Acacia saligna had 6.2 seeds per pod. The pods weighed 76.8 mg. There were some 1.2% diseased and 24.1% immature seeds per pod. Mean seed weight was 6.64 ± 3.79 mg. Some 13.3% of seeds germinated. Larger numbers of seeds per pod were associated with heavier pods. At SRNR many mature plants of *A. saligna* were infected by the rust fungus, *Uromycladium tepperianum*.

TABLE 4
Significance values of linear regression between reproductive characters in 13 *Acacia* species (from pods collected in December 1998).

CHARACTER/SPECIES	AN	AD	AL	AA	AX	AF	AP
Length of pod vs no. seed/pod	+ < 0.001 *	+ < 0.001	NA	+ < 0.001	+ < 0.001	*	
Weight of pod vs no. seed/pod	+ <0.001	+ <0.001	+ <0.001	+ <0.001	+ 0.005	+ < 0.001	+ <0.001
No. seeds immature/pod vs no. seed/pod	+ 0.047	+ 0.047	0 0.775	+ 0.022	+ 0.040	0 0.246	+ 0.002
Weight of pod vs no. seed immature/pod	- < 0.001	0 0.718	0 0.413	0 0.238	- 0.051	0 0.069	- 0.023
Weight of pods vs no. seed diseased/pod	0 0.577	0 0.898	0 0.752	0 0.150	0 0.751	0 0.744	0 0.230
No. seed diseased vs no. seeds immature	0 0.523	0 0.558	0 0.806	0 0.810	0 0.545	0 0.077	0 0.620

CHARACTER/SPECIES	AS	AND	ANY	AC	AJ	AE
Length of pod vs no. seed/pod	*	*	*	*	*	+ 0.019
Weight of pod vs no. seed/pod	+ <0.001	+ <0.001	0 0.808	+ <0.001	+ <0.001	+ <0.001
No. seed immature/pod vs no. seed/pod	0 0.702	+ 0.001	+ <0.001	+ <0.001	0 0.244	0 0.452
Weight of pod vs no. seed immature/pod	- <0.001	- 0.003	0 0.711	0 0.302	0 0.458	0 0.303
Weight of pods vs no. seed diseased/pod	+ < 0.001	0 0.933	0 0.575	+ 0.0525	0 0.397	+ 0.053
No. seed diseased vs no. seeds immature	+ 0.022	0 0.369	0 0.062	0 0.608	0 0.065	0 0.959

Species legend as in Figure 4; P = < 0.05 positive (+) or negative (-) relation; P > 0.05 no (0) relation; * = not available.

Acacia acuminata had 9.2 seeds per pod and the pods were 6.4 cm in length and weighed 69.6 mg. Mean seed weight was 3.85 ± 1.34 mg. This is less than half the weight of the seeds collected in 1996 (8.95 ± 0.23 mg). No seeds germinated, whereas 42.3% of 1996 seed germinated. There were 2.3% diseased and 7.5% immature seeds per pod. Larger numbers of seeds per pod were associated with longer, heavier pods; there were more immature and infected seeds with larger numbers of seeds per pod. Therefore competition for resources between seeds occurred. Infections in one seed may be associated with infection of more seed in the same pod.

Acacia lasiocalyx had 9.85 seeds per pod. The pods were 10.7 cm in length and weighed 171 mg. Mean seed weight was 13.21 ± 8.66 mg. Larger number of seeds per pod were associated with longer, heavier pods and more immature seeds were found in these pods. However it was also found that more immature seed were associated with lower pod weight. There were 9.3% diseased and 2.9% immature seeds per pod. Of the 13 *Acacia* species studied, *A. lasiocalyx* had the third largest number of seeds per pod; the heaviest seeds and pods; and the least number of immature seeds.

Acacia fauntleroyi had 10.2 seeds per pod and the pods weighed 144.3 mg. Mean seed weight was 1.78 ± 1.29 mg, much lighter than the weight of seeds collected in both 1996 (3.38 ± 1.54mg) and 1999 (8.30 ± 2.00 mg). Seeds collected in 1998 were significantly lighter than 1996, and the 1996 seed lighter than 1999 (all $P < 0.001$). This species had the third highest number of immature seeds (30%). Larger numbers of seeds per pod were associated with heavier pods; and more immature seeds were associated with lighter pod weight. It was also found that more immature seeds were associated with more infected seeds. No seeds collected in 1998 germinated, while seeds collected in 1999 produced up to 100% germination.

Acacia prainii had 7.7 seeds per pod and the pods weighed 53 mg. Mean seed weight was 1.66 ± 1.08 mg, much lighter than the weight of seeds collected in 1996 (3.12 ± 1.26 mg) and 1999 (8.00 ± 3.40 mg). There were some 10.6% diseased and 25.3% immature seeds per pod, resulting in 35.9% of the seeds being aborted. Larger numbers of seeds per pod were associated with heavier pods and more of these seeds were immature. More immature seeds were associated with lower pod weight. There was no germination from seeds collected in 1998 whereas, of seeds collected in 1996, 52.3% germinated and up to 100% seed germination was recorded from seed collected in 1999. At SRNR, most mature plants of *A. prainii* become infected by the rust fungus (*Uromycladium tepperianum*). Symptoms include a distinct lack of foliage and many brown, globose, corky galls on stems, phyllodes, peduncles and fruits. Some

inflorescences are also deformed, witches brooms develop and juvenile foliage is produced. The latter symptom suggests hormonal dysfunction (Berg 1977).

Acacia sessilispica had 6.4 seeds per pod and the pods weighed 12 mg. Mean seed weight was 1.46 ± 1.92 mg, much less than seed collected in 1996 (3.13 ± 0.83 mg). There were some 10.7% diseased and 33.8% immature seeds per pod resulting in 44.5% of seeds being aborted. Of all *Acacia* species investigated, *A. sessilispica* had the highest percentage of immature seeds and no seeds collected in 1998 germinated. Larger numbers of seeds per pod were associated with heavier pods. More immature seed were associated with lower pod weight. More infected seed was associated with heavier pods and more immature seed with more infected seeds.

Acacia densiflora had 5.7 seeds per pod and the pods weighed 21 mg. Mean seed weight was 1.30 ± 1.00 mg, much less than the weight of seeds collected in 1996 (2.84 ± 0.47mg). There were some 4.0% diseased and 24.4% immature seeds per pod. Larger numbers of seeds per pod were associated with heavier pods and more immature seed. More immature seeds were associated with lower pod weight. Seeds collected in 1998 did not germinate, whereas 65.3% of seeds collected in 1996 germinated.

Acacia nyssophylla had 10.6 seeds per pod and the pods weighed 50.7 mg. Mean seed weight was 1.78 ± 0.59 mg and 54% of seeds germinated. There were some 21.2% diseased and 32.6% immature seeds per pod. Of all *Acacia* species studied, *A. nyssophylla* had the greatest numbers of immature and infected seeds, with a total of 53.8% seeds aborted. Greater numbers of seeds per pod were associated with more immature seeds. More immature seeds were associated with more seeds being infected.

Acacia coolgardiensis had 8.5 seeds per pod and the pods weighed 35.3 mg. Mean seed weight was 2.76 ± 0.87 mg and 42.9% the seeds germinated. There were some 15.3% diseased and 29.1% immature seeds per pod. This species had the third highest number of immature seeds (44.4% of the seeds aborted). Greater numbers of seeds per pod were associated with heavier pods and more immature seeds. More seed infected was associated with heavier pods.

Acacia jibberdingensis had 7.5 seeds per pod and the pods weighed 19.9 mg. There were some 9.5% diseased and 22.5% immature seeds per pod. Mean seed weight was 2.29 ± 0.43 mg. There was no germination from seeds collected in 1998. Greater numbers of seeds per pod were associated with heavier pods and more immature seeds were associated with more infected seeds.

Acacia eremophila had 8.2 seeds per pod. The pods weighed 16.4 mg and they were 4.4 cm in length. Mean seed weight was 1.67 ± 0.52 mg and 29% of seeds germinated. There were some 5% diseased and 19.5% immature seeds per pod. Greater numbers of seeds per pod were associated with heavier and longer pods. More infected seed were found to be associated with heavier pods.

DISCUSSION

Reproductive characteristics of *Acacia* species between years

A reproductive success criterion (RSC) of each *Acacia* species was calculated based on the relative numbers of pods produced, pods per inflorescence and inflorescences initiated that produced a mature pod. This procedure suggests that reproduction varies considerably among species and between years. Reproduction was better in 1999 than in 2000. It appears that good rainfall is an important requirement for flowering and is critical for good fruit set in many *Acacia*, since all species suffered from the drought of 2000 but produced good pod numbers in 1999. It seems that a wet winter is required to induce flowering (inflorescence formation) and that further rain is required after flowering to promote pod development and good seed. In the absence of the latter, a proportion of pods dry off without attaining good seed set.

Other studies, in a range of species, suggest that a general response of flowering to rainfall occurs. Morgan (1998) suggested that rainfall stress is an important overriding determinant of plant fecundity. Preece (1971) found that irrigation stimulates heavier flowering and fruiting in Mulga, *Acacia aneura*. Davies (1968) reported that rainfall stimulated flowering in arid zone species but that more rainfall was necessary for good seed. Porter (1978) found that cool, wet winters favour flower and bud formation in spring for *Eucalyptus sideroxylon*. For Myrtaceous species generally, Law *et al.* (2000) noted that high autumn rainfall is usually followed by prolific flowering in late spring. Pook, Gill & Moore (1997) found that flower buds and fruits of *Eucalyptus maculata* in southern N.S.W. were destroyed by severe drought.

In a comprehensive glasshouse study on faba bean (*Vicia faba*), Xia (1997) showed that water stress applied in the period between pod development and full pod maturation reduced seed yields by up to 45%, and water stress imposed after the flowering period reduced pod and seed number per plant up to 38%. That study showed that drought during pod-filling significantly reduces seed weight compared to the un-stressed control. According to Mwananwenge *et al.* (1999), the early podding stage of development is the most sensitive to water deficit in faba bean. Similarly Xia (1994) reduced pod set by imposing water deficits, particularly during the reproductive phase due to the abortion of flowers and small pods. The precise stage of generative development that is most sensitive to drought in *Acacia* awaits further investigation.

Although all wattle species suffered from the drought in 2000, there were differences in degree of susceptibility. *Acacia fauntleroyi*, *A. neurophylla*, *A. acuminata* and *A. steedmanii* were the least affected. Of these, *A. fauntleroyi*, *A. acuminata* and *A. steedmanii* may avoid

drought damage to some extent because they flower earlier. Only *A. neurophylla* seems to have considerable tolerance to drought. *A. stereophylla* was severely affected and failed to develop pods. The explanation for poor seed set, even in 1999, at the time of relatively heavy rain, is not known. It is possible that a combination of inadequate pollination and embryo abortion due to selfing may have affected seed quality, as the population size is relatively small. Species most affected by the severe drought of 2000 included, *A. hemiteles* which did not flower; only 0.6% and 0.7% of inflorescences developed a pod in *A. lasiocalyx* and *A. saligna* respectively. *Acacia hemiteles* may be especially drought-sensitive and it is likely that, for this species, a wet winter is necessary to produce new shoot growth. Observations in the field suggest that floral buds are produced only on new shoots.

Apart from *A. stereophylla*, there was no apparent effect of population size on seed set and pod development. In most species only small fractions of the inflorescences initiated developed to a pod. In *Acacia brachybotrya* (central N.S.W.), Cunningham (2000) found that habitat fragmentation was associated with a decline in pollination and subsequent fruit set. Low reproduction obtained in our study could be associated with the plants present being in fragmented habitats. The reserve is relatively small and surrounded by cleared farmland. Low seed production coupled with small population size may result in seed production falling below a threshold level necessary to maintain population size.

For species such as *A. steedmanii*, *A. fauntleroyi*, *A. neurophylla* and *A. lasiocalyx*, seed set appears sufficient to replace senescing adults but recruitment (seedling establishment) does not occur every year. These species had nil to very few seedlings in the field. Natural regeneration failure may be due to high seed predation, unsuitable seedbed and competition from established vegetation. From time to time some renewal probably results from natural regeneration after fires induced by lightning. In order to maintain these populations, it may be necessary to provide conditions advantageous to seedling recruitment as an important component of any conservation strategy; if not, local extinction of small populations may occur. An obvious artificial strategy is to burn small areas, in different places, from time to time.

Effect of phyllode and branch positions on reproductivity

The number of phyllodes per branch affected plant reproductivity. Plants bearing more phyllodes initiated more inflorescences; more inflorescences set pods; flowering was earlier; and fewer inflorescences dried off. These observations suggest that leaves/phyllodes donate carbohydrates (and nutrient) to fruits (Hocking and Pate 1977) and resources tend to flow into fruits from the nearest phyllodes (Mooney 1972). Preston (1999) noted that current assimilates flow from a source leaf into the nearest most active sink that has a direct vascular connection to the source leaf (Watson and Casper 1984; Wardlaw 1990). Stephenson (1980) found that energy necessary to develop and mature fruits on Cigar Tree, *Catalpa speciosa*, comes from leaves on the same branch that bears an infructescence. Leaves are a source of carbohydrates that may be expended on flowering, whereas reproductive structures may be significant resource sinks (Stephenson, Devlin and Horton 1988). Therefore, in *Acacia* any damage to phyllodes caused by disease or herbivory could reduce primary resources and this would be reflected in reduced plant reproductivity.

Branch position also affected plant reproductivity. Generally, those branches in the upper part of the crown bear heavier inflorescences. However, the pods that develop in a particular species tend to be present in greater numbers at central parts of the crown. Generally, in *Acacia*, flower production is virtually confined to new shoots produced after the previous season. Only plants with abundant new shoots can bear many flowers. It is proposed that when lower parts of the crown initiate fewer new shoots than the upper parts, fewer flowers are initiated in the lower crown. More pods develop in the central than distal parts of the crown. Fewer inflorescences initiated in some species could result from smaller phyllodes at distal parts as they come from newer shoots. Furthermore, the difference in form or architecture of branches among the species may affect resource partitioning which in turn, reduces reproductive capacity (Lechowicz 1984).

In *Rosa* × *hybrida*, the stem is characterised by three distinct zones, one located at the base of the stem, one at the middle and one at the top (Erwin *et al.* 1997). Axilliary shoots arising from each zone differ. The distal zone has higher axilliary shoot and flower number. The axilliary shoot number depends on mother shoot vigour, the presence or absence of leaves and the growth status of the remaining parts of the plant. Leaf removal decreases the flower number per mother stem. The removal of leaves also decreases the axilliary shoot number. Defoliation may reduce carbon allocation to inflorescences immediately because it reduces photosynthesis.

Plant architecture may constrain flower production by limiting the number of meristems available for flowering. However, Preston (1999) noted that, although meristem number limits inflorescence number, inflorescence number does not necessarily limit flower or seed number. In compensation for limited number of inflorescences, individuals can increase the number of flowers or seeds produced by each inflorescence. Cunningham (2000) found that inflorescence production in the palm *Calyptrogyne ghiesbreghtiana* was correlated with trunk diameter and leaf area. A large leaf area and thick trunk may help a plant harvest light and store carbohydrates. Preston (1999) suggested that plant architecture also influences carbohydrate translocation patterns, and the location of the source leaf also significantly affects the pattern of carbohydrate translocation.

Effect of frost on reproductive characteristics

Of pods collected in 1998, all species produced apparently mature seed of low weight. There were many immature and diseased seeds and poor germination resulted. Many of the pods contained empty locules or locules that contained seeds that had started to develop but had died before full maturation. A late spring frost in 1998 is believed responsible for limited seed development. Of 13 species examined, 9 had more than 20% of seed produced aborted. Only *A. neurophylla*, *A. nyssophylla* and *A. coolgardiensis* had germination of more than 40%. *Acacia prainii*, *A. fauntleroyi*, *A. sessilispica*, *A. acuminata*, *A. jibberdingensis* and *A. densiflora* were severely affected, with no germination. All other species examined had less than 30% germination. Throughout the central wheatbelt, late spring frost in 1998 also caused much damage to crops.

All species produced many diseased seed. In some species, the number of immature seed was associated with number of infected seed. Damage to seed by frost may have provided foci for seed infection. A greater number of seeds per pod was associated with longer, heavier pods, suggesting that more resources were devoted to larger pods. As a greater number of seeds per pod was also associated with more immature seeds, there is an indication that competition occurs for resources within seeds in the pod. In some species, a greater number of diseased/infected seed per pod was associated with heavier pods, suggesting that in the case of infected seed/pods, plants devoted more resources as a response to infection stimuli.

The ecological and economic effects of frost are best known for crop plants. For native species such as *Acacia*, information is very limited. At the cellular level, frost can cause formation of ice crystals within or between cells. This can cause physical damage and trigger physiological problems through loss of solute. At the organ level, consequences of frost are primarily mediated through its effect on sensitive parts of plants. Reproductive organs of plants are usually most sensitive to frost (Sakai, Paton and Wardle 1981). Flowers and ovaries are often killed when older leaves are not affected, and frost damage can become a site for infection of buds or flower stalks. Inouye (2000) found that frost kills or damages flower buds and open flowers but causes minimal damage to leaves and stems in Aspen Sunflower, *Helianthella quinquenervis*, where late spring frosts kill some developing buds. Late frosts during spring are occasionally a principal cause of fruit mortality in Red Pine, *Pinus resinosa*. Trees located on lower ground lost all first year conelets to late spring frost, whereas trees on higher ground abscised conelets from only the lower part of their crowns (Hard 1963).

One possible effect of global climate change is that the frequency and distribution of frost events will change. Increased length of growing season in Europe is one indication of a change that may result in more frequent spring frost damage to plants (Menzel and Fabian 1999). A change in climate accompanied by an increase in the frequency of late spring frost has been recorded previously in Virginia, U.S.A. (Inouye 2000). If global warming results in earlier flowering in temperate species, flowers might become more susceptible to frost damage.

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The tourism potential of *Acacia*

CHRIS TATE[1]

[1] Western Australian Tourism Commission, 16 St Georges Tce, Perth, Western Australia 6000

SUMMARY

In an increasingly competitive national and international marketplace, destinations must promote what is best or unique about their product. Developing a tourism attraction in inland Western Australia has proven difficult, but tourism can succeed with co-operation between local government and the community by providing attractions combined with public amenities that can benefit both ratepayers and visitors. The Dalwallinu community can take advantage of wildflowers, and wattles in particular, to increase visitor numbers to the area. Already it conducts an annual Wattle Festival, has undertaken street plantings of wattles and has built town entry statements that feature the wattle. Other initiatives based on this one group of plants are suggested for increasing tourism to the region.

INTRODUCTION

Tourism is the fastest-growing industry in the world and nature-based tourism is the major component. The major factor in the growth of nature-based tourism is an increased awareness of the need to conserve the environment and research has shown that tourists today are more environmentally conscious.

As travellers become more experienced, many are looking for more personalised, interactive experiences. To sit and watch is no longer sufficient. We need to provide for people to learn more about the destination through interaction, rather than through passive viewing. Travelling is commonly seen as enriching life's experience, leading to personal growth rather than simply a relaxing holiday. The desire to seek personal growth through travel is particularly prevalent in more experienced travellers.

In increasingly competitive national and international marketplaces, it is essential to say what is best or unique about a destination. The newness of destinations like Western Australia means that the tourism industry here can capitalise on overseas trends and reinforce those aspects that are being done well. We can find our own niche in an increasingly competitive global marketplace. Overseas there is a trend toward smaller-scale developments to cater for nature-based tourists, rather than appealing to larger groups. The focus is on providing a quality experience in a natural setting. Authenticity is a major factor in creating a strong sense of place in the development of facilities.

Western Australia's positioning is based on the pristine environment, natural attractions, blue skies, warm sunshine and friendly people. For both domestic and international tourists, there is also a growing interest in the uniqueness of heritage. The goal of tourism is business (i.e. economic) development.

Statistics from the Western Australian Tourism Commission indicate that more than 70% of tourists in the State are from the Perth metropolitan area, and that interstate and international visitors form only a small percentage. Further, most people from Perth are reluctant to travel inland during the summer, preferring to holiday on the coast.

The most popular region in the State is the South West corner, due to its closeness to Perth, the variety of attractions and activities on offer, and the high quality of products and services. Developing a tourism attraction in inland Western Australia has proven difficult. Even reaching Perth is expensive–it's is the most remote capital city in the world, closer to Jakarta than to Sydney.

Many rural communities are in decline–currently, 60% of our small towns are dying, losing population (especially young people) and business. Broad-acre farming and improved technology have reduced the labour force in rural Australia. Shire councils and community groups are looking to tourism to create employment and increase economic development. To assist tourism to succeed there must be community support and involvement. Local government will have to provide public facilities and amenities that benefit both ratepayers and visitors.

Regional communities should not believe that a tourist attraction built in isolation, without complementary attractions, will necessarily be successful. Visitors do not usually travel large distances just to see a stand-alone feature. There must be a broader visitor base to contribute to the attractions. Wildflowers are the State's major tourist attraction and provide a window of opportunity for the Dalwallinu region. People expect to see carpets of flowers in a kaleidoscope of colours, but the wildflower season is unpredictable and relatively short due to seasonal, weather conditions. As they are, for most of the year wattles are generally unremarkable and unlikely to attract visitors in their own right. The Shire could consider value-adding and expanding the attractions to hold visitors longer.

BE TOUCHED BY NATURE . . .

Western Australia is developing a series of programs that combine tourism with environmental enhancement. Tourists can be given a unique opportunity to interact with the environment in such a way that they both gain enjoyment and contribute positively towards it. These programs allow travellers to feel extremely positive about their interaction with the environment. They learn about, appreciate and contribute to W.A. at a more than superficial level. This is a tourism initiative to create a competitive advantage by good environmental management of the State's tourism assets. The pristine coastline, vast rugged outback and unique flora and fauna make W.A. a diverse, popular holiday destination. There is enormous potential to develop new destinations and markets that will provide visitors with a travel experience not available anywhere else.

Today's tourists demand a more personal travel experience. They want to be active in the community, to learn about the local culture and heritage, and to be involved in the natural environment that makes the region unique.

The demands of this growing market will be met through a series of new, nature-based tourism products, developed through the Western Australian Tourism Commission in association with other stakeholders. The products encourage visitors to establish an emotional relationship with the State's natural beauty by taking part in projects that help preserve, protect and enhance the environment. Tourism can be a tool for conservation.

The philosophy is simple:
Enjoy Western Australia ... ***Be Touched By Nature!***

Examples include :

Lake Monger

Lake Monger lies in the inner Perth suburb of Mount Hawthorn. Due to environmental degradation, reeds and other native plants as well as animals were disappearing from the Lake, and the Black Swan population was dwindling. The Black Swans Nature Based Tourism project gave visitors the opportunity to assist by planting native reeds along the lake shore to encourage the growth of a natural water filtration system and create new nesting areas for the Black Swans.

The Western Australian Tourism Commission developed the project in close co-operation with the Town of Cambridge, with scientific advice from Dr Jenny Davis, Head of the School of Environment Science at Murdoch University, who had been working on the rehabilitation of the Lake Monger wetlands since 1985.

Summer of Turtles

Visitors to Western Australia's North-West are to be given a remarkable opportunity to experience one of nature's most extraordinary events. As part of their annual breeding pattern Green Turtles visit several beaches along the North-West coast to lay eggs. The Summer of Turtles–a joint project between the Western Australian Tourism Commission and the Department of Conservation and Land Management–will give visitors the chance to observe and monitor the egg laying.

On the trail of the Red-Tailed Black Cockatoo

Walkers on the Bibbulmun Track have the opportunity to help protect one of Western Australia's most spectacular native birds by taking part in a research project that monitors the bird's movements.

The Red-Tailed Black Cockatoo nests along many sections of the Bibbulmun Track and is often seen by walkers as it feeds on the seeds of the Marri, Jarrah, Blackbutt, Karri, Sheoak and Snottygobble trees. Timber-felling, clearing and fires threaten its natural habitat, and the European honeybees, possums and even ducks, compete to nest in the hollows of large old trees. Numbers have fallen by 30 per cent in recent years.

The Bibbulmun Track Walking Pack includes a map holder, day-walk itineraries, track map, postcard and a bird sighting report card. Walkers record where they see or hear the bird and its nests, and the card is forwarded to researchers. By monitoring the bird's movements they hope to understand its requirements and take action to prevent a further decline in numbers. A donation from the sale of each kit is used to establish other nature conservation projects.

On the Trail of the Red-Tailed Black Cockatoo is a joint project between the Friends of the Bibbulmun Track, the Department of Conservation and Land Management, the Western Australian Museum and the Western Australian Tourism Commission.

Twin Karri Boardwalk

In the southern forest region near Northcliffe, tourists had the opportunity to help protect an ancient Twin Karri under threat from root damage. Visitors using nature trails in the Northcliffe Forest Park were invited to participate in building a boardwalk around the root system of a 450-year-old tree, located in 245 hectares of old-growth forest. They could select a salvage log or piece of recycled timber and stay to see their plank added to the boardwalk. An early trial, now completed, the project received widespread support from tourists, community members and local tour operators.

Scatter the Silky Pear, recreate Kalgoorlie's bushland

Visitors to Kalgoorlie are invited to assist in the regeneration of a bushland park of 200 hectares by scattering the seeds of one of the town's most significant native plants. Karlkurla [pronounced *gull-gurl-la*] Bushland Park gets is name from the Karlkurla vine or Silky Pear (*Marsdenia australis*). Karlkurla is also the Aboriginal name for Kalgoorlie. The area was cleared for timber etc. 100 years ago but in the 1970s was designated a Dust Abatement Zone and replanting begun to control dust storms. The aim now is to recreate the bush as it was before clearing. The Karlkurla Bushland Park is a unique open space providing enormous opportunities for education and recreation. A brochure containing a small seed pack and explaining the history and significance of the Karlkurla vine and Park is sold for a nominal fee. Tourists scatter the seeds at designated spots through the park and help to recreate Kalgoorlie's bushland. Proceeds will be used by the Kalgoorlie-Boulder Urban Landcare Group to assist with the ongoing conservation, protection and preservation of the bushland.

HOW CAN DALWALLINU INCREASE THE TOURISM POTENTIAL OF ACACIAS?

The Dalwallinu region has a wonderful array of wildflowers and landscapes, and there is great potential for exploiting the intrinsic interest of wattles as well as their commercial potential. Currently one needs an expert to explain this, but tourists generally do not have the luxury of a botanist to accompany them. Selected sites could have quality interpretive shelters and walk trails installed to educate and retain tourists in the region for longer periods.

Already, Dalwallinu has built entry statements featuring the wattle and it has the annual Wattle Festival. Acacias have also been planted as street trees. By providing quality interpretive information the wildflower season could be extended from a couple of weeks a year to an all-year tourist attraction. To meet the visitor's expectations, the wattle theme must to be visible and interactive.

To extend the visitors stay the region should provide :

- good access
- a range of interesting activities
- interactive attractions
- amenities
- compatible accommodation options, i.e. bed-and-breakfast, farmstays, motels, camping, caravan parks.

A tourism strategy has been developed to prioritise projects and identify funding and other resources required. General benchmarks for sustainable or low-impact, tourism development include:

Sustainable design: creation of a strong sense of place based on the site itself, through good design, choice of materials, building form and other architectural factors that result in a good feeling for the visitor.

Interpretation: leading to heightened awareness, appreciation and understanding of environmental processes. The more personal the interpretation, the better the customer's experience.

Environmental return: businesses that derive their very living from the physical and cultural environment willingly put something back. Being environmentally responsible makes good business sense.

Quality services: food, beverages and other services require a high degree of quality, presented in a manner that is appropriate to the setting.

Some suggested initiatives to value-add to the wattle theme are:

- Increase activities, e.g. provide an interpretive, educational centre containing photos of various acacias, dried samples, illustrations, a computer identification system, examples of commercial by-products, other flora and fauna dependant on wattles
- set up an interpretive display of Aboriginal uses of wattle seeds and wood
- establish an arboretum containing all local wattle species
- develop wattle recipes or cookbooks
- create walk trails with clear, concise signage and interpretive information
- incorporate a wattle motif into wall tiles, paving slabs, street signs
- adopt the wattle motif in staff uniforms and in window displays of retail outlets
- develop merchandise, souvenirs and wattle-seed foods
- display banners featuring wattles in the main street to provide colour and interest.

To sum up, it may be possible to increase the number of visitors and their length of stay by providing quality products and services that are accessible all year round, based on wattle themes.

Potential of Australian *Acacias* in combating hunger in semi-arid lands

ANTHONY RINAUDO[1], PRAKASH PATEL[2] AND LEX A.J.THOMSON[3]

[1] World Vision, 1 Vision Drive, East Burwood, Victoria 3151; e-mail: rinaudot@wva.org.au
[2] Project Ecolake, World Union, Sri Aurobindo Ashram, Pondicherry, 605002, India; e-mail: lapointe@auroville.org.in
[3] CSIRO Forestry and Forest Products, PO Box E4008, Kingston, Australian Capital Territory 2614;
e-mail: Lex.Thomson@ffp.csiro.au

SUMMARY

People living in semi-arid regions of the developing, tropical world who are reliant on annual crops and / or pastures (for livestock) for food are particularly vulnerable to hunger and periodic famine.

A number of species of edible-seeded Australian acacias thrive under adverse conditions; conditions under which annual plants barely survive. These include ***A. colei***, ***A. coriacea*** sens. lat. (including ***A. sericophylla***), ***A. elachantha***, ***A. torulosa***, ***A. tumida*** and ***A. victoriae***. The seeds of these species are tasty, safe to consume as a moderate component of human diets and nutritious, being high in protein, carbohydrates and fats. In many regions, such as semi-arid tropical west Africa, the seeds ripen at a time of low labour demand when non-irrigated crops are not being cultivated. Being perennial and thus having an established root system, mature acacias can take advantage of rains that would be ineffective for annual crops (e.g. out of season or poorly distributed rains). Acacia seeds are easily harvested and processed into flour using simple, existing local technologies. The flour can be incorporated into local dishes and in 'non traditional' foods such as spaghetti, bread and biscuits. The seed also has great potential as feed for livestock. Being hard-coated, seeds can be stored for many years as a reserve for famine. Acacias can also supply various other products, especially fuelwood, and services such as improvement of soil fertility through fixation of atmospheric nitrogen.

This paper reviews current knowledge and trials and the use of edible acacias in Africa and India. Certain Australian species have a vast potential as new food crops, worthy of larger scale promotion, particularly in semi-arid regions of the world.

INTRODUCTION

The seeds of certain Australian acacias have formed a part of the traditional diets of Australian Aborigines in different parts of Australia. The most well-documented usage, which continues today, is from central and north-western Australia (e.g. O'Connell ***et al.*** 1983; Latz 1984; Cane 1987; Smith and Kalotas 1985; Goddard and Kalotas 1988; Devitt 1992), although ***Acacia*** seeds were consumed in other parts of Australia, e.g. Maslin ***et al.*** 1998. Many parts of the world that are subject to periodic or chronic famine, such as the Sahelian zone of Sub-Saharan Africa and dry regions of southern India, have climates similar to those of subtropical, arid and semiarid regions of Australia. Accordingly, certain ***Acacia*** species from Australia's hot, dry regions are considered to have potential to provide human food and a range of other products and services, such as fuelwood and charcoal, soil stabilisation, windbreaks, soil improvement and nitrogen fixation (Thomson 1992; Thomson ***et al.*** 1994, 1996).

In 1989, during a visit to west Africa sponsored by AusAID and the Australian Centre for International Agricultural Research (ACIAR), it was observed that species such as ***A. colei*** and ***A. tumida***[4], were producing very heavy seed crops less than two years after planting and might have potential as new human foods in the region (Thomson 1989). This potential has been explored actively over the past decade by the Society for International Ministries (SIM[5]) in the Maradi district of Niger Republic (Rinaudo 1999) and by Project Ecolake in Tamil Nadu, India (see two case studies in this paper). This development work has been backed by scientific research by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Forestry and Forest Products and its research partners, especially Obafemi Awolowo University in Nigeria, to confirm the safety of using Australian acacia seeds as human food in west Africa (Harwood ***et al***. 1999).

Staff of the Maradi Integrated Development Project (MIDP[6]) searched widely for suitable indigenous plants with food potential both before and during the acacia trials, resulting in a number of indigenous annuals and

[4] These species had been introduced by the Centre Technique Forestier Tropical (now CIRAD-Forêt) with the principal objective of identifying new animal fodders (e.g. Cossalter 1987)

[5] Recently renamed 'Serving in Mission.

[6] The Maradi Integrated development Project is managed by SIM.

fruiting trees being grown successfully, e.g. ***Ziziphus*** spp., ***Poupartia birrea***, ***Adansonia digitata***. In terms of growth rate, seed yield, nutritional value and capacity for long-term storage, however, none has yet been found to match the potential of edible Australian acacias. Most African acacias have toxic seeds and, in the few cases where they are used for human food, are subject to an elaborate detoxification process. An example is ***Faidherbia albida*** (syn. ***Acacia albida***), eaten in the Gokwe communal lands of Zimbabwe in times of food shortage (House and Harwood 1992). An exception is the non-toxic ***Acacia macrostachya*** which is eaten in Burkina Fasso. Although the species is also indigenous to the Maradi district there is no record of it being eaten there. Two-year-old trees of ***A. macrostachya*** reached barely one metre and failed to set seed, in contrast to ***A. colei*** which routinely reached 3-4 metres and yielded four to six kilograms of seed at the same trial site. The sharp, curved thorns of ***A. macrostachya*** also make harvesting difficult and disqualify it as a candidate for intercropping, though it may be suitable as a hedge that provides both protection and food. ***Boscia senegalensis***, which was also tested, produces a fruit that is also a traditional famine food in Niger. The seeds are highly toxic and must be soaked in changes of fresh water for several days. In rural districts water is often scarce, however, and inadequate soaking has resulted in deaths. Further, the seeds have a low germination rate (<5%) and growth rates are slow.

Although many indigenous species were tested in Tamil Nadu, India, their performance in terms of survival, growth rates and yield were poor compared to some Australian acacias grown under rainfed conditions on highly degraded land. Several Australian acacias showed promise for afforestation under these conditions, producing high yields of fuel wood and fruit. Seed pods of the indigenous ***Acacia leucophloea*** and ***A. nilotica*** are used for animal feed on some areas but proved less drought-resistant than ***A. colei***. Neither species is used for human food. Likewise, ***Prosopis cineraria*** is used for animal food and possibly human consumption in times of severe drought, but it did not perform as well as the hardiest Australian acacias. ***Prosopis juliflora*** occurs throughout India and is used for fuelwood and animal feed but is not accepted as human food.

The uses and characteristics of 44 ***Acacia*** species with potential for human food and originating from Australia's tropical and sub-tropical dry-zones have been documented (Thomson 1992). The species with the most promise for human food include ***A. colei***, ***A. coriacea sens. lat.*** (including ***A. sericophylla***), ***A. elachantha***, ***A. torulosa***, ***A. tumida*** and ***A. victoriae***.

Advantages of these species include:

1. Perennial habit

Some species, but probably not ***A. colei*** (see Harwood 1994) have potential to exploit soil water below the crop root zone and to produce seed in years when rainfall is distributed erratically and / or when untimely (for annual crops) and when annual crops fail due to moisture stress. Nevertheless, the heaviest seed crops in species such as ***A. colei*** follow good rainfall (totalling in excess of 300-400 mm), especially when distributed between the time of flower initiation and early to mid fruit set.

2. Adaptability to infertile and otherwise non-arable sites

Many of the promising acacias with human food potential, including ***A. colei***, ***A. elachantha***, ***A. sericophylla***, ***A. torulosa*** and ***A. tumida***, are very well adapted to infertile sands which are not well-suited to agricultural crops. In northern Nigeria (north-west of Kano), ***A. colei*** was grown successfully in areas with loose, infertile sand which had become unsuitable for local crops. The same species grows well in claypans with additional run-off water in Niger. ***Acacia ampliceps*** thrives in highly alkaline soils (pH >10) and is moderately salt-tolerant, while ***A. thomsonii*** is well adapted to rocky soils with a lateritic hardpan close to the surface (Thomson ***et al.*** 1994). Adaptation to non-arable sites is an especially significant attribute considering the widespread and ongoing land degradation and increasing use of marginal land for farming in tropical regions. Also, poor farmers usually cannot afford to set aside potential cropland for tree planting.

3. Nutritious, safe seeds that can be incorporated into a wide range of dishes

The ***Acacia*** species dealt with in this paper include those long consumed by Australian Aborigines (see earlier references). In recent years there has been a considerable research effort into the safety and nutritional aspects of Australian acacia seeds, notably ***A. colei*** as the main species being consumed in Africa. The conclusions from these investigations are that ***A. colei*** flour will be useful both as a famine food and as a supplement to regular human diets, if incorporated at not more than 25 percent of the total diet by weight (Harwood ***et al***. 1999 and references cited therein). This is based on chemical tests, animal feeding trial results, a human volunteer trial and insights from Australian Aboriginal diets.

Acacia colei, and to a lesser extent ***A. tumida***, are the only species to have been tested extensively for anti-nutritional effects and toxicity. These species were chosen because, at the time, both were performing well in trials in Niger and showed promise as food crops. Both CSIRO and MIDP needed to be sure of their safety for human consumption before promoting them. The results from ***A. colei*** cannot be extrapolated to other species, hence each must be tested independently, but the expense and time are fully justified. Although there is some assurance in knowing of species that were eaten by Australian Aborigines, testing for the many unknowns involved is still justified. If a species must be cooked to destroy anti-

nutritional properties then consumers must be warned not to eat green seed. During a famine some people may have no option but to eat a diet of only acacia. ***Acacia colei*** has been shown to be safe at concentrations up to 25%, but the effect of eating higher concentrations over a long period is unknown. Project Ecolake has been incorporating seed of ***A. colei*** (and its flour) into recipes for more than 10 years. Seed of ***A. tumida***, ***A. torulosa*** and ***A. ampliceps*** has also been used occasionally, with no ill effects. Project Ecolake has repeatedly tried, unsuccessfully, to interest the Indian Government in an official study of the potential and safety of Australian acacias, hence their potential has not been promoted there. Given the fact that, in many poor regions of the world the only option during drought is to eat bran, grass, tree leaves etc., there seems to be an urgent need to investigate further the safety of promising species.

4. Seeds with good harvest characteristics

The seeds of most acacia species can be quickly and efficiently harvested at full maturity without the need for any specialised equipment, e.g. when a crop is heavy one person can harvest 3-5 kg of clean seed of ***A. colei*** or ***A. tumida*** per hour. Small seed-bearing branches can be cut and beaten on sheets, or bushes can be beaten or shaken directly onto large sheets. In Niger, farmers prefer the curly-podded form of ***A. colei*** (var. ***ileocarpa***) because less seed is lost through shattering prior to harvest. In Australia the curved-podded form is preferred by seed collectors because the seed is more easily and completely dislodged from the pod during beating. In Niger, all phases of ***Acacia*** seed preparation (harvesting, threshing, cleaning, milling or cooking) can be undertaken without need for new or specialised skills or equipment.

5. Long-term storage of seed

Acacia seeds that have matured fully on the bush and have been properly dried have a hard seed coat. Such seed can be stored in closed containers without deterioration for many years (e.g. 5-10 years) in dry conditions at ambient temperatures. There is less risk of seed spoilage from moulds if the aril is removed prior to storage. The aril attracts weevils, the waste products of which encourage moulds and hence seed spoilage. The arils are easily removed by placing the seeds in water and rubbing them between the hands. Most arils are poured out with the water, and those remaining may be separated by winnowing after drying the seeds.

6. Seeds produced in large quantity from an early age

Under field conditions on sites near Maradi, yields of up to 6 kg per tree (***A. colei*** and ***A. elachantha***) have been realised (SIM Niger 1996). More commonly, average yields of 1.8 kg per tree have been measured on trees 2-5 years old planted in rows 8 metres apart (25 metres between rows), receiving 300–400 mm of rain, regular cultivation and annual pruning. Rainfall level, plant spacing, level of weed and crop competition and the practice of pruning have a strong influence on crop yields.

7. Ability to provide other products and services

Acacias can also make a valuable contribution to local wood supplies, especially in areas where there is severe pressure on native vegetation for wood products. A number of acacias highlighted in this article (***A. colei***, ***A. tumida***, ***A. elachantha***) produce large quantities of biomass in the early years of growth, thus providing firewood and light construction timber and ultimately making significant contributions to rural incomes. In Niger, an erect form of ***A. torulosa*** with very straight branches, known as 'dogon torulosa' (tall ***torulosa***), has become very popular for local building purposes. By harvesting planted acacias, some harvesting pressure can be taken off native vegetation. Millet crops in Niger are often buffeted by damaging winds of up to 70 km / hr. To counter this, Acacias planted in rows can form effective windbreaks. Dried foliage of ***A. colei*** can be used as low-grade animal fodder, and other species such as ***A. ampliceps*** and ***A. victoriae*** are good browse species. Tannins, gums and compounds with medicinal properties are all untapped resources in a number of these species.

8. Ability to fix nitrogen and improve organic matter content of soils

In developing countries, few poor farmers can afford costly inputs such as artificial fertilisers. Cultivated soils in hotter climates generally have low organic matter content. These problems may be addressed at least partially by acacias which, given the correct strain of rhizobium bacteria, can fix atmospheric nitrogen and, through leaf fall and root / nodule breakdown, raise soil nitrogen and carbon levels.

9. Reduced risk of famine

Acacias are unlikely to be susceptible to many of the common crop pests and diseases. Indeed, trees planted in Niger have been little affected by insects, including attacks from termites and locusts. They are unrelated to common grain and root crops grown in Africa and fruit at times different from those crops.

10. Foliage of most Australian *Acacia* species is not attractive to livestock

Tree planting in many developing countries has been rendered impossible or very expensive because of destruction of young plants by wandering stock. In Niger, plants of ***Acacia colei***, ***A. torulosa***, ***A. elachantha*** and ***A. coriacea*** have survived without protection from livestock, even where there is little fodder available.

Disadvantages

1. Short life span

Most of the promising species being used, such as ***A. colei***, ***A. elachantha*** and ***A. tumida,*** are relatively short-lived, with lifespans of only three to ten years. Dieback and death are hastened by moisture stress, associated with close spacing and intense inter-plant competition and / or drought. Life span may be increased, however, by pollarding the main branches (while retaining some live branches) at the end of fruiting and onset of the dry season. Sandplain forms of ***A. tumida*** may be coppiced successfully and rejuvenated, and ***A. ampliceps*** may live for 20 years or more in better-watered sites. ***Acacia ampliceps*** also regenerates by means of root suckers. ***A. coriacea sens. lat***. is generally long-lived, the gnarled sandplain forms (described as ***A. sericophylla***) living for many decades and having the potential to supply food over a similar time-frame.

2. Competition with agricultural crops

A. colei and ***A. tumida*** have shallow, wide-spreading root systems that compete heavily with nearby crops. Farmers who have planted their fields to millet for generations will not readily adopt tree crops that depress yields of traditional crops without seeing clear benefits. Research is required to select acacias that are more compatible for interplanting with agricultural crops. Preliminary results from Niger indicate that species with deeper root systems and which cast less shade, such as ***A. coriacea*** and ***A. torulosa***, show promise in such systems. In the meantime, planting competitive species should be concentrated on marginal and non-arable lands and around villages.

3. Propagation difficulties where water is limited

Australian acacias are generally easy to propagate from seed in nurseries. However, water is typically in scarce supply in areas where the plants are raised in Africa, and water tables are often deep (e.g. 30-100 metres in Niger), making nursery operations difficult. While direct sowing has been successful in wetter areas of Senegal and in northern Nigeria, it has not worked in zones with extended dry seasons and large numbers of free-range livestock. Even though trials at Maradi have failed to establish acacias by direct seeding, the technique should not be discounted without further trial in other areas where acacias might be grown. This is because the process of raising plants in a nursery and transplanting them to the field can be a stumbling block to poor farmers who already have heavy demands on their time.

4. Potential weediness

Caution must be exercised when introducing acacias into a new area as they are a pioneer species and have the potential to spread rapidly. For example, Australian species such as ***A. cyclops*** and ***A. saligna*** have become environmental weeds in the Republic of South Africa (Roux and Middlemiss 1963). The likelihood of a species becoming a weed in a new environment is highly dependent on factors such as climate, pressure from livestock and the availability and demand for firewood. Thus, in Ethiopia, we have observed that ***A. saligna*** is a widely used species for agroforestry and revegetation but is not considered a weed. During 20 years of careful observation around Maradi in Niger, Australian acacias have shown no tendency to become weedy.

CASE STUDIES

In researching this paper, various scientists, institutes and projects were contacted in countries in tropical, dry zones where Australian acacias were known to have been trialled successfully and adopted, at least to some extent for firewood, reforestation and land restoration purposes. The objective of these communications was to identify any countries and regions where these species were additionally being adopted as human food sources. Countries contacted included Cape Verde Islands, Burkina Faso, Cameroon, Ethiopia, India, Kenya, Mali, Nigeria, Niger, Senegal, Sudan, Tanzania and Zimbabwe. The only two examples where acacias were being adopted to any extent for human food were those already known prior to the survey, viz. SIM in the Maradi district of Niger and by Project Ecolake in Tamil Nadu, India. World Vision Australia is seeking ways of testing the concept of edible acacia seeds in receptive African countries. The International Centre for Research in Agroforestry (ICRAF) and national research partners are actively exploring the potential of ***Acacia colei*** as a short duration improved fallow[7] in the Sahel (Amadou Niang[8], personal communication).

1. Maradi district, Niger Republic

Niger Republic is a landlocked nation in west Africa which has a mainly dry climate with considerable temperature ranges. Some 200-600 mm of rain falls during three to four months of the year (June-September). There is a (relatively) cool season, when temperatures drop considerably, particularly at night (November to February) followed by a hot season, when average daily maximum temperatures exceed 40° C in the shade (Renaudeau 1978). At Maradi, the seasonal rainfall and temperature profiles are similar to those at Halls Creek, in the far north of Western Australia.

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[7] Improved fallow is used as an improvement in shifting cultivation by shortening the fallow period and increasing biomass and nutrient accumulation. Improved fallow also restores land that is not cropped for a few months to three years in the same way, and it smothers weeds. Species that grow quickly and fix nitrogen are used in the technique. See http://www.icraf.cgiar.org.

[8] ICRAF, Mali

Initial interest in acacias in Niger came out of a realisation that famine could occur in any year as long as farmers relied on annual crops in the uncertain climate. In one season in 1988, farmers had to replant their millet (***Pennisetum glaucum***) crops 5-8 times due to drought, windstorms and / or pests. Average yields of millet are low (approximately 300 kg / ha), even in good years. Few of the options remaining to perplexed farmers (including exodus, sale of assets, and hunger) are acceptable.

Collaborative efforts between CSIRO's Australian Tree Seed Centre (ATSC), the local community, the Nigerian Government and SIM has resulted in an understanding of the potential and limitations of a number of Australian edible-seeded Acacias. Of the species tested so far, ***A. colei*** and ***A. elachantha*** excel in terms of ease of propagation, growth rate, survival and seed production. These species have shown the most potential for development as a new food crop, with good agronomic, harvesting and food characteristics. ***Acacia torulosa***, a species which had grown well in windbreaks at the ICRISAT Sahelian Centre in Niger, was trialled much later and is also showing promise.

Acacia colei was planted quite widely in southern Niger during the late 1980s, as a fast-growing small tree for windbreaks and firewood production, and its potential to produce seed had already been established. Trials were commenced in 1992 to determine whether there were other species, also suited to local conditions, that might be superior to ***A. colei***. Results from these trials formed the basis of widespread promotion of ***A. colei*** around Maradi. Selection of ***Acacia*** species and provenances to suit local agro-climatic conditions can mean the difference between success and failure. For example, ***A. colei*** thrives on the slightly acidic sandy soils of Maradi district. While ***A. ampliceps*** and ***A. victoriae*** survived in this district, they did not perform well. In the alkaline, potash-rich soils of the Lake Chad region of eastern Niger, however, ***A. colei*** was a total failure but ***A. ampliceps*** and ***A. victoriae*** proved well-adapted and grew quickly (SIM Niger, 1999). There are marked differences in performance between provenances of the same species. This highlights the need to test a wide range of species and provenances.

One component of SIM's Maradi Integrated Development Project (MIDP) 'Food for Work' program during the famine of 1994 required farmers to raise and plant acacia trees on their own land. Through this and subsequent programs, well over 100,000 acacia trees were planted. In addition, workshops on how to cook acacia seed were conducted in key villages to introduce people to the new food and preparation methods.

A milestone was passed when a three-week human volunteer trial was conducted in 1995 (Adewusi ***et al***. submitted). As it was a completely new food, the community held doubts about acacia's safety and authorities could not give endorsement without scientific testing. The trial received official approval and almost unanimous backing from Government agencies (health, agriculture, forestry, State Government) and traditional leaders. People fed on diets incorporating 25% flour from seed of ***Acacia colei*** put on more weight than those on traditional 'control' diets and experienced no ill effects, and the results were welcomed by the local population.

Today, people in more than 55 villages harvest and eat acacia seed (Tiedjani Abas, Institut National de Recherches Agronomiques du Niger [INRAN], Niger Republic , personal communication 2001). Members of one village have an open day each year at harvest time when all residents are free to collect seed. In this village acacia seed is not regarded as a famine food, but rather a much sought-after, regular part of their diet. Children have become particularly adept at harvesting the seed and rapidly preparing a tasty snack (seed is ground, roasted and salted). Because of the widespread 'food for work' plantations, many farmers have a daily reminder of the potential of these trees. In 1998, despite good rains, both millet in control plots and millet grown between rows of ***A. elachantha*** barely produced any grain. This was the result of a late start to the rains and insect attacks. The acacias were not affected by this and produced good quantities of wood and edible seed. Noticing that goats ate the fallen seed of acacias, some farmers have begun collecting seed and feeding it as a supplement to their goats during the 8-month dry season when fodder is scarce and of poor quality. Farmers have even begun purchasing acacia seeds as a food supplement for goats.

Another significant turning point occurred in 1998 when the Australian Government sponsored a cultural exchange visit. Rosie Nangala and Kay Napaljarri, two Aboriginal women from Central Australia, travelled to Niger to share their knowledge on various acacia species and how to prepare them for eating. Rosie and Kay's visit and shared experiences demonstrated that acacia seeds were an important traditional food item in Australia.

Poor farmers are particularly interested in growing acacias as a multi-product cash crop. However, it may be difficult to create a market for acacia seed until it is more widely used, and this is likely to occur only gradually. Acacia seed has not yet entered the formal market place on a regular basis but there are increasing instances of farmers buying seed from each other for human and animal consumption. On occasion, women have sold popular deep-fried bean cakes made with 15-25% acacia flour. Two charismatic farmers (Barro Mahaman and Dan Mani Idi) have become unofficial champions of acacias through their sheer inventiveness and enthusiasm. Both men made up new acacia recipes and consumed acacia foods regularly, introducing them to their neighbours in the process. Two popular, readily sold products are a coffee substitute (not containing caffeine) and 'Bitamin' (a mixture of acacia, corn, bean and peanut flour for malnourished children). Such developments may be the essential first steps towards more widespread acceptance of acacia seeds as human foods.

The short lifespan of ***Acacia colei*** (5-10 years) has been seen as a major obstacle to its use, particularly by the Nigerien Forestry Department. However, ***A. colei*** should be considered as a short-lived perennial crop, like pigeon pea, rather than as a long-lived tree. ***Acacia colei*** need be planted only once in about every 5-7 years, whereas millet

may have to be replanted up to seven times in one year if conditions are unfavourable. A number of management strategies can be implemented to reduce the negative impact of a short lifespan or even slightly lengthen the lifespan. By minimising stress through planting at recommended distances, regular weeding, pruning and digging micro-catchments, ***A. colei*** will live longer. A few replacement trees could be planted annually, ensuring stable seed production each year. Also, short-lived, early-producing species such as ***A. colei*** could be grown along with longer-lived species such as ***A.coriacea*** and ***A. torulosa***, which take longer to bear seed.

Another blockage in the minds of some Nigeriens was the fact that acacia seeds are not incorporated in 'mainstream' food items in Australia. While this is true, acacia seeds are being used increasingly by the rapidly expanding 'bush tucker' industry, especially as flavouring agents and in gourmet products. They may become increasingly popular, as shown by Coles Supermarkets' 'Taste of Australia' campaign, which is promoting native products, including foods incorporating acacia seed flour.

In traditional societies there is considerable social pressure working against anyone who dares to be different. In the Maradi district, nomadic Fulani cattle herders look down on any type of farming and actually despise anyone who would cultivate trees for a living, as their traditional, sedentary enemies do. For Hausa people, whose identity as farmers is often linked to their ability to grow millet, it is ludicrous to think of spoiling good farmland by planting trees on it. For both groups, there is a need for good understanding of the advantages of growing acacias in order to be motivated and committed to plant them. In fact, hunger–the great leveller–has made deep inroads into such attitudes and traditional thinking and modes of behaviour are changing by necessity. As an example, in some areas greater attention is now being paid to the protection of coppice and management of indigenous trees on farmlands.

2. Tamil Nadu, India

During the 1980s, Project Ecolake[9] introduced several Australian ***Acacia*** species for the purpose of rain-fed afforestation. In 1990, project staff learnt of their potential food value from the ATSC. This was an unexpected but most welcome development. It offered some hope of addressing concerns about food security by using wastelands for social forestry, with the expectation of producing additional protein-rich food in regions traditionally experiencing scarcity. In the case of ***Acacia colei***, annual yields of seed have been estimated roughly as up to 1000 kg per hectare from age 3-4 up to about age 8-9, but appropriately-designed trials are needed to verify such estimates.

A wide range of dishes were prepared using seeds or flour of selected Australian acacias. The main species used have been ***Acacia colei***, along with ***A. tumida, A. ampliceps*** and ***A. torulosa***. This research established the palatability of dishes made from acacia seeds and seed flour, including a number of Indian and Western preparations, most commonly biscuits and cakes. The percentage of ***A. colei*** content in the flour generally ranged from 50% to (exceptionally) 100%. In ***ad hoc*** taste trials most people were well satisfied with the taste. However, when the seed coat was not removed from the flour, the resultant dark colour often caused some people to hesitate in eating dishes that have a lighter colour when prepared with traditional ingredients. Removing the seed coat by sieving, either before or after grinding into flour, took care of this problem. Some people experience a slightly itchy tang that persisted for some time after eating some dishes. This is presumably caused by tannin in the acacia seeds and may be relative to the proportion of flour used, removal of seed coats, and the method of preparation.

Project Ecolake has sought to spread awareness of this new food source by making presentations to many visiting groups including about 25 Indian Forest Service officers each year from different parts of the country. Items made from acacia seeds and flour have always been appreciated by the groups. The Project has endeavoured to interest the Government of India (Ministry of State for Wasteland Development) in the development of Australian acacias as human food, through having an official assessment of their potential. Discussions have taken place with experts including scientists of the Tamil Nadu Agricultural University. While there is consensus in favour of the use of acacias as a food source, the Project felt that it would not be appropriate to encourage wider consumption until there had been an official Indian Government clearance in the matter of food safety. Accordingly, in December 2000 samples of ***Acacia colei*** seed, flour and two batches of biscuits made using the flour in different proportions were sent to the Central Food Technological Research Institute, Mysore, for analysis. Their evaluation was as follows:

Test parameters	*A.colei* seeds	*A.colei* seed flour	*A.colei* biscuits
Protein (estimated as N ´ 6.25, % w/w)	25.40	22.10	13.40
Carbohydrates (estimated by difference, % w/w)	47.03	46.06	46.14
Extracted fat (% w/w)	15.80	13.80	30.53
Energy kJ per 100 g (derived)	1808	1661	2185
Crude fibre (% w/w)	6.70	10.90	2.33
Moisture (% w/w)	2.35	4.42	5.70
Total ash (% w/w)	2.72	2.72	1.90
Acid insoluble ash (% w/w)	0.01	NIL	0.12

After about a decade of exploring the use of ***Acacia*** seeds and seed flour in a wide range of both savoury and sweet dishes, Project Ecolake staff are convinced of the potential of Australian acacia seeds as a food source. Species such as ***A. colei*** could make significant contributions towards meeting food shortfalls in drought-prone areas of the tropics.

[9] Location: Sri Aurobindo Ashram, Pondicherry, Tamil Nadu.

POTENTIAL OF AUSTRALIAN *ACACIAS*

A number of factors give edible-seeded acacias the potential to become a significant food crop. Enough is known about them to warrant introduction, testing and promotion in new areas. In Africa, 56% of the population depends upon agriculture (FAO 2000). For most, food security is tied to a small selection of mostly annual crops. In Africa, five cereals (maize, sorghum, wheat, millet, rice) account for 94% of all cereal production and two root crops (cassava and yams) account for 80% of root crop production (FAO 1999). Commonly, these crops are growing under unfavourable agro-climatic conditions. In these environments such high dependency on a limited number of crop species is risky and increases the possibility of periodic famine.

Those areas in Africa that are climatically suitable for growing ***Acacia colei*** are shown in Figure 1[10]. According to this modeling, parts of 26 African countries are suitable for growing ***A. colei***, which is just one of 44 tropical and subtropical Australian ***Acacia*** species with food potential. In 14 of these countries, over 35% of the population are undernourished, in another seven countries, between 20 and 34% are undernourished and in three others, 5-19% are undernourished (World Food Program, 2001).

Changing world conditions, in particular the effects of climate change (CGIAR 2001; Nash 2000.) and the HIV/AIDS pandemic, will have a great influence on peoples' ability to meet food needs using conventional crops and farming methods. While not immune to the vagaries of the weather, acacias, being perennial and for some species having a deeper root system, are better suited to grow and produce seed consistently despite excessive rain, drought or erratic rainfall.

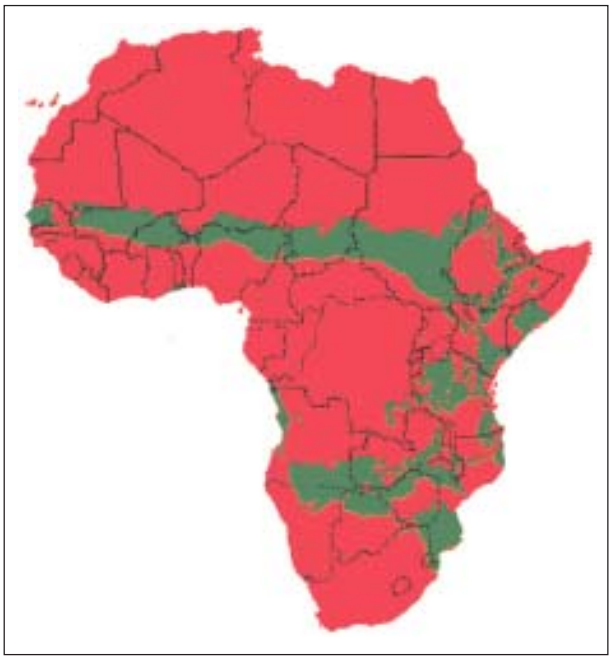


Figure 1

[10] Prepared by Trevor Booth, CSIRO.

The green revolution that dramatically increased grain crop yields in the tropics and subtropics bypassed Africa (Vietmeyer 1996). If there is to be a 'green revolution' for the arid and semiarid subtropics, it will have to be through plants that thrive under such conditions, yield well and require minimal inputs. Millions of third-world farmers have no access to the usual green revolution inputs. Increasingly they are farming on exhausted, marginal lands under adverse climatic conditions that are unsuitable for conventional crops. For them, a biological revolution is needed, in which plants are selected and bred to suit the prevailing environmental conditions, rather than a green revolution to suit the plants, in which the crop environment is modified (through irrigation, fertilisers and pesticides). Nevertheless, if acacias do yield large amounts of seed, and this is withdrawn from the farming areas where they are grown, without replacement of nutrients (P, K, Ca etc.), yields will not be sustainable in the longer-term in the infertile, sandy soils of the Sahel.

FUTURE RESEARCH NEEDS

Individuals working alone will always be confronted by the questions: 'Where in the world are these seeds eaten?' and 'Who else is promoting this new food?' Without wider support, many who see the potential of acacias for human food in their region will not receive the backing or approval they need to start experimenting. In an article in ***Unasylva***, Harwood ***et al.*** (1999) called on national agricultural research agencies, Non-Government Organisations (NGOs) involved in rural development, the Food and Agriculture Organisation of the United Nations (FAO), the Future Harvest Centres, and bilateral and multilateral donor agencies to seriously examine the potential of acacias. Until now there appears to have been little response despite the positive results of research. CGIAR chairman, Ian Johnson has stated that 'a warmer world will surely impact yields of staple crops, increase the incidence of pest attacks, and exacerbate drought, all with profound effects on the well-being of small farmers in developing countries (CGIAR 2001).' Further research and development of acacias for human food is an obvious field for support from the CGIAR (especially ICRAF) and/or ACIAR given the interest in these species in the developing tropical world and likely mutual benefits from such work.

Areas for research include:

- for each new provenance to be introduced, to determine optimal management practices, including planting methods, spacing, planting system (orchard, intercropping, improved fallow, etc), cultivation and pruning regime etc.

- a cost-benefit analysis for acacias compared to alternative systems. The investment of funds and labour and the output in terms of seed yield, firewood, organic matter for mulch, fodder, soil stabilisation, increase in soil fertility and environmental protection over a number of seasons must be measured. In India, lentils are an important source of protein for a large part of the population, yet they are often too expensive for poorer people to purchase regularly, consequently there is widespread protein malnutrition. Project Ecolake staff have estimated that substituting ***A. colei*** for lentils provides comparable nutritional intake for about one third of the cost.
- selection and breeding of acacias for consistent high yield and for specific agro-climatic situations.

CONCLUSIONS

We now have a decade of experience with the research and development of selected Australian acacias for human food in tropical dry zones. This work has been undertaken mainly in Australia, Nigeria, Niger and India by CSIRO Forestry and Forest Products, Obafemi Awolowo University, Tamil Nadu Agricultural University and the NGOs, SIM and Project Ecolake. This work has built on a foundation of Australian Aboriginal traditional knowledge and use of acacia seeds as food. The main conclusions to date are:

1. Certain *Acacia* species, such as *A. colei* and *A. tumida*, have a demonstrated potential to provide human food in tropical dry zones.

They can make important contributions to human food production in regions with erratic rainfall and infertile soils, where cultivation of traditional agricultural crop species is risky or impossible. Appropriately managed, widely spaced plantings (e.g. 100-150 plants per hectare) can be expected to yield around 200-300 kg per hectare for 3 or 4 harvests over a period of 7-10 years in drier climates and >500 kg per hectare in wetter climates.

The seeds have been shown to be nutritious and amenable to incorporation in a diverse range of food products, including over 20 local dishes in Niger and both savoury and sweet local dishes in India, as well as pasta, bread, biscuits and coffee substitutes. Animal and human feeding trials in west Africa have shown that seed of ***Acacia colei*** can be incorporated safely into millet and / or sorghum-based diets at rates of up to 25% by modifying traditional recipes (Harwood ***et al***. 1999). The taste of acacia food products has been found acceptable to people living in regions prone to famine and malnutrition, including west Africa and India. In fact, the seeds are tasty and are accepted as a regular food in Niger, not just as a famine food.

2. Planting Australian *Acacias* in tropical, dry zones of developing countries will provide several products and services, food being an important one of these.

Because of the difficulties and expense of establishing perennial plants in such environments growers will be seeking to optimise their returns from such activities. Other products include fuelwood and charcoal from prunings and final harvest and improvement of soil fertility / organic matter from nitrogen fixation. Judiciously spaced windbreaks of appropriate acacias could enhance food security by reducing wind speeds and by yielding edible seeds. The objective should be not to replace traditional crops with acacias but to complement them and provide a back-up food for when they fail.

3. Broad-scale adoption of *Acacia* seeds as human food has yet to occur.

CSIRO and its NGO partners have adopted a conservative approach to promotion of these species. Firstly, it had to be established that the seeds of the species with potential for human food were going to be safe at reasonably high levels of intake. This work has now been undertaken in Niger, west Africa, while official acceptance has yet to be obtained in India. Secondly, it was felt that a gradual, progressive process of adoption and transfer of information from areas such as Maradi, as opposed to broad-scale promotion, was more likely to lead to a sustainable adoption of acacia seeds for human food. This would reduce the associated hazards and risks of large-scale promotion from an inadequate research and development base.

Based on a decade of overall positive experience in Maradi and Tamil Nadu it would now seem that the time is right to promote more widely these species in famine-prone parts of dry, tropical Africa and elsewhere. Such work should be based on a thorough examination of the factors that have either promoted or hindered the planting and uptake and adoption of acacias to produce human food in the Maradi district. It is recommended that ICRAF conduct such a study in co-operation with the relevant national authorities and SIM.

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Domestication of wattles with edible seeds for the wheatbelt of Western Australia

MAURICE W. MCDONALD[1], BRUCE R. MASLIN[2] AND LEX A.J. THOMSON[1]

[1] CSIRO Forestry and Forest Products, Australian Tree Seed Centre, PO Box E4008, Kingston, Australian Capital Territory 2604; email: Maurice.McDonald@csiro.au

[2] Department of Conservation and Land Management, Locked Bag 104, Bentley Delivery Centre, Western Australia 6983; email: brucem@calm.wa.gov.au

SUMMARY

This paper reviews species with potential for edible wattle seed production for the wheatbelt region of Western Australia. It identifies that market demand for seed products is a major constraint to any large-scale plantings aimed specifically at wattle seed production. Comprehensive analyses of seeds for anti-nutritional or toxic components and taste appraisals of newly targeted species are also an imperative. To date there has been insufficient research to guarantee uniformity and consistency of seed yield using wattles new to domestication. These issues must be addressed if economic gain from growing edible wattles is to be achieved. In the meantime the most significant benefit from cultivating them will be to incorporate them into plantings aimed at ameliorating land degradation. Attributes and relevant details are presented for 22 endemic species considered the most promising for the production of seed for human food in the wheatbelt of Western Australia. Four of these species, namely, ***A. anthochaera, A. microbotrya, A. murrayana, A. saligna*** and ***A. victoriae***, were considered the best prospects and are discussed in detail.

INTRODUCTION

A great deal of what we know today about edible wattle seed has been built upon the traditional knowledge of ***Acacia*** species by Australian Aborigines. This knowledge draws on over 40,000 years of traditional utilisation of our native flora. Information presented in the recent book ***Edible Wattle Seeds of Southern Australia*** (Maslin ***et al***. 1998) was very much reliant on this knowledge. Our aim in this review is to use that information to outline the domestication potential of the most promising edible-seeded wattles for cultivation in the Western Australian wheat-sheep agricultural region (i.e. the 300-500 mm rainfall zone in the south west of the state).

A major impetus for compiling ***Edible Wattle Seeds of Southern Australia*** came from research on the use of wattles in the Sahelian region in West Africa. In the 1970s, Australian wattles from the seasonally dry tropics, such as kalkardi (***Acacia elachantha***) and Cole's wattle (***A. colei***), were introduced into the Sahel for fuelwood, windbreaks and amenity plantings (Cossaltar 1986; House and Harwood 1992). Subsequently, during years of drought-induced famine, seeds from these species were trialed as a source of human food in the Maradi region of Niger (Thomson 1992; Harwood 1994; Rinaudo ***et al.*** these proceedings). When staple grain crops failed, CSIRO researchers, aware of the traditional Australian Aboriginal use of ***Acacia***, recommended that seeds from the introduced Australian species be tried as an alternative food. People in the Sahel processed the seeds using local cereal-grinding technology normally used for processing their staple grain crop, millet. The ground wattle seed flour was then incorporated into local recipes. Based on the success of this development the future domestication of edible-seeded wattles in the Sahel appears promising. The species being used having many attributes that facilitate their domestication. With appropriate silvicultural management they are easy to establish, fast-growing, show excellent survival and are heavy seeders within two years of planting (Harwood ***et al.*** 1999). They also exhibit unusual levels of phenotypic uniformity, a trait probably linked to their polyploid origins (Thomson 1992). With the promise shown by edible wattles in Sahel, the advent of a local bushfood industry in Australia and the regional need to grow plants to reverse land degradation, we felt it timely to compile ***Edible Wattle Seeds of Southern Australia*** to help guide further R&D on these species.

There are major constraints on the cultivation of edible wattles in southern Australia. Our aim here is not to review the economic viability of edible wattle seed production, although the market demand for seed products is a major constraint; ascertaining size and viability of this market is essential prior to any large-scale plantings aimed specifically at wattle seed production. Comprehensive analyses of seeds for anti-nutritional or toxic components and taste appraisals of newly targeted species are also imperatives. Variable and unpredictable attributes must also be anticipated in the domestication of wild plants. To date there has been insufficient research to guarantee uniformity and consistency of seed yields of wattles new to domestication. These issues must be addressed if growing edible wattles is to be economically viable. In the meantime the most significant benefit will be to incorporate edible wattles into plantings aimed at ameliorating land degradation.

NUTRITIONAL VALUE AND WATTLE SEED PRODUCTS

The nutritional value of wattle seed is comparable to other legume seeds except that they contain higher levels of dietary fibre. In a study of 26 tropical and arid zone species, Brand and Maggiore (1992) showed that the seeds averaged 23% crude protein, 26% available carbohydrate and 32% fibre. Potentially toxic compounds were absent or present at non-harmful levels. Positive results for nutrition content, non-toxic components and palatability were also obtained from dietary trials and nutritional studies of ***A. colei*** in West Africa (Harwood ***et al.*** 1999). However, insofar as temperate species are concerned very little is known about the nutritional status of wattle seeds or possible toxicity problems, and there is a need for research in these areas before major investment is made in developing large-scale seed production.

In Australia, the main potential products from the seeds of edible wattles include: flavouring agents (especially in dairy products such as cream and ice cream), beverages (where ground roasted seeds are used as a coffee substitute), as a stable carbohydrate (biscuits, breads and pasta) and as a low-glycaemic index food for diabetics.

Desirable attributes for domestication of edible-seeded wattles

There are almost 1000 species of ***Acacia*** in Australia, representing great diversity in morphological, ecological, biological and utilisation characteristics (e.g. Maslin 2001a; McDonald ***et al***. 2001). To identify which species might be suitable for producing commercial quantities of seed under cultivation for human consumption, the following attributes were considered:

Nutrition and toxicology–Of primary importance was the need to select species with nutritious, palatable seeds with no anti-nutritional or toxic components. High priority was thus given to species traditionally consumed by Australian Aborigines. We reasoned that species recorded as edible by Aborigines have been under an ongoing selection process over the past 40,000 years and could be presumed relatively safe to eat. We relied heavily on information in the public domain but unfortunately such information was not available for all the species that warranted consideration. Some potentially promising species were not described until recently so there were no historical records to draw on. Other species warranted inclusion because they were close relatives of species recorded as having been consumed. In these cases we had to make the assumption that their seed was nutritious and edible. This strategy was adopted in anticipation that a thorough assessment of the nutritional and toxicological characteristics of seeds would be undertaken on any species targeted for incorporation into human diets. This applies to all the species treated here.

Growth habit–Species must have appropriate growth attributes and present pods in a way suitable for easy harvesting. For example, compact, multi-stemmed shrubs with vigorous coppicing ability and with pods on the branch tips (i.e. borne on terminal racemes) were ranked highly. The ability to produce coppice regrowth could be important in circumstances where large-scale plantings required the development of broad-acre mechanical harvesting techniques. Species with a single, well-defined trunk would tend be suited more to harvesting by mechanical shaking techniques. Species with moderate to long life spans of around 10-20 years and fast growth rates were also ranked highly. Short-lived perennials would have high recurrent re-establishment costs and slow-growing plants would be economically unproductive.

Pod characteristics–A fundamentally important selection criterion was the ability of plants to produce heavy seed crops with pods that ripen simultaneously on a reliable, annual basis. Species with pods that ripen over a long period of time would be difficult to harvest. The ability of wattles to be reliable seeders appears to be correlated with their taxonomic group. For example, species with one-nerved phyllodes (such as ***A. victoriae*** and A. ***microbotrya***) tend to be more reliable seeders that those with multinerved phyllodes. Species such as Jam (***A. acuminata***) and Western Myall (***A. papyrocarpa***) fall into the latter category. Although the latter two are heavy seeders and their seeds palatable, their fruiting behaviour tends to be erratic and possibly related to the timing, frequency and intensity of rainfall. Such species were not rated highly for commercial plantings.

Seed characteristics–Acacias vary considerably in the size of their seed and how the seeds are shed from the pods. Species with large or moderately large seeds were generally ranked more highly than smaller-seeded species or those with thick seed coats. The length of time that the seeds are retained in the pods after they have ripened is an important consideration. The longer the seeds are retained the better, because this will extend the period over which the seeds can be harvested. The relative ease with which the seeds can be extracted from the pods after harvesting is important; seed loss before and during harvest due to the dehiscent nature of the pod must be considered.

Silviculture–Ease of establishment in cultivation was an important consideration. In most cases this was difficult to assess because field trials have not yet been carried out. Wattles have hard seed coats, i.e. the seed is easy to handle and store and is well-suited to direct seeding techniques, but usually requires some form of pre-treatment to ensure rapid, uniform germination. Pre-treatment techniques such as tumbler scouring can be used on a large scale to enhance germination of most species.

Ecology–Species known to occur in a range of different soil types and are adapted to a wide climatic range were ranked more highly than those with narrower ecological tolerances. Such species have a greater chance of success when cultivated over a wide range of growing

conditions. Despite the natural ecology of species, however, the adaptability of some species will not become known until the plant is cultivated over a range of growing conditions.

Weed potential*–**There are well-known examples of wattle species becoming serious environmental weeds. For example, Australia's official floral emblem ***A. pycnantha has been grown widely as an ornamental and is now considered a weed in many parts of southern Australia. While this species can produce large quantities of seed and there are reports of it having been consumed by Aborigines, it is not recommended for cultivation in Western Australia. More research is required to determine if all cultivated edible wattle species will become weeds.

Taste*–**An important attribute that was not critically assessed in ***Edible Wattle Seeds of Southern Australia is that of taste. There appear to be significant differences in flavour between various species and it would be useful to undertake a more systematic evaluation of these. For example, Mulga (***A. aneura*** sens. lat.) is recorded as having a 'peanut butter' flavour by Latz (1995) and could find a niche market as a novelty table spread. Similarly, some species such as ***A. retinodes*** are considered to have a more pleasing taste than others. Wider public acceptance of this 'new' food could be encouraged if palatability differences are explored and exploited.

Polyploidy*–**The most successful tropical dry zone species used for edible seed production are polyploids. Plants of the hexaploid ***A. colei (Moran ***et al***. 1992) from individual provenances are very uniform in their growth rate, habit and seed crop when cultivated on uniform sites. These characteristics, very desirable for commercial seed production, are linked to their genetic uniformity and an apomictic or asexual mode of reproduction that is typical of polyploid plants (Grant 1981). Research to screen the ploidy level of species targeted for domestication in southern Australia could therefore be rewarding. An understanding of the breeding system is essential for selection and breeding programs.

Taxa in the ***A. aneura*** group are known to comprise polyploids and could be grown for seed production, but growth rates are slow and heavy pod production in natural populations is dependent on both winter and summer rainfall. ***Acacia cowleana*** is part of the ***A. colei-A. elachantha*** species complex (McDonald and Maslin 1997) and is a known polyploid (***2n*** = 78 ***fide*** Moran ***et al.*** 1992). It occurs mainly in the northern arid zone but some of its southern populations (e.g. from the Alice Springs region) could warrant trialing for seed production in southern Australia.

Hybrids*–**The two most promising species identified in ***Edible Wattle Seeds–***A. victoriae*** and ***A. murrayana***– are taxonomically related**.** The potential to manipulate hybrid crosses between these two species warrants investigation. It is possible that hybrid plants might have wider edaphic tolerances, faster growth rates and higher seed production than either parent species. Producing such hybrids, however, would likely be a long, costly task.

SPECIES SUITABLE FOR THE WHEATBELT OF SOUTH-WEST WESTERN AUSTRALIA

Edible Wattle Seeds of Southern Australia identified 47 species judged to have potential for cultivation in southern semi-arid regions of Australia as sources of seed for human consumption. All of the 18 'best prospect' species belong to a single taxonomic group characterised by one-nerved phyllodes and racemose inflorescences. Racemes support numerous flower heads and as such have the potential to produce many more pods than do simple inflorescences. Racemes of the 'best prospect species' are also terminal or arranged en masse in axils on new shoots at the tips of branchlets. When in flower these species represent some of the most showy, spectacular flowering wattles. This attribute also makes them amenable for harvesting since the pods are held on the outside of the crown.

Table 1 lists the attributes of species that have potential to be grown for edible seed in the low-rainfall agricultural zone (300-500 mm rainfall) of south-west Western Australia. For many species some attributes such as seed yield remain unknown, and others such as frost resistance are categorised only in very broad terms. The most appropriate site for cultivation in the landscape (recharge or discharge zone) is shown for each species. Only three of the species listed (***A. inceana***, ***A. saligna*** and ***A. victoriae***) are recommended for planting in groundwater discharge areas. This is because very few ***Acacia*** species with promising attributes for seed production grow naturally in these zones. A subjective ranking of these species based on their overall attributes is also given. Detailed profiles of five species considered to have the greatest potential for domestication in the Western Australia low-rainfall agricultural zone are presented below.

Acacia victoriae and ***A. murrayana*** are considered the two most promising species. Their seeds were commonly used as food by Australian Aborigines, have good nutritional characteristics and one (***A. victoriae***) is currently the most important edible wattle species in the Australian bushfood industry. Natural populations occur across a wide range of climates, have moderate to fast growth and are moderate to heavy seeders. Both species are easily propagated from seed, and plantations can be established by direct seeding. It may be possible to regenerate over-mature, declining stands of these species by coppicing and / or shallow ripping to induce suckering. Although the two species are taxonomically related and morphologically quite similar, they prefer different soil types and under cultivation have the potential to complement one another. ***Acacia victoriae*** normally grows on heavy clay or clay-loam which may be somewhat saline, while ***A. murrayana*** normally prefers sandy soil or sandy loam. The seeds of ***A. victoriae*** have demonstrable potential as specialty food in Western diets and they command high prices relative to other grain and seed crops. This species is generally regarded as the industry standard.

TABLE 1
Natural attributes of native Western Australian edible wattles with potential for domestication in the agricultural zone.

Species	State	Wheatbelt distribution	Frost frequency	Soil type	Growth habit	Coppicing	Flowers	Seed matures	Planting zone	Rank
A. acuminata (Jul.)	WA	Northern; central; southern	Low	Sandy loam, sandy clay, loam; acid to alkaline	Shrub or tree 3-5(-12) m tall	Weak to moderate	July-Oct	Sep-Dec	Recharge	**2-3**
A. aneura (Jul.)	WA, NT, SA, NSW, Qld	Northern	High	Loam, sand, clayey sand; acid to neutral (alkaline)	Tree or low shrub 2-15 m tall	Nil to weak	Irregular; Mar-May	Oct-Dec	Recharge	**2-3**
A. anthochaera (Phy.)	WA	Northern	Low	Sand, loam; neutral to alkaline	Multi-stemmed shrub or small tree 2-5(-8) x 4-6 m	Unknown	Aug-Oct (Dec)	late Nov-Jan	Recharge	**1**
A. blakelyi (Phy.)	WA	Northern	Low	Sand or loam; acid to neutral	Shrub or tree 2-4 x 2-4 m	Unknown	July-Sep	Nov-Jan (-Oct)	Recharge	**2**
A. brumalis (Phy.)	WA	Northern; central	Low	Sand, clay, loam; some moderately saline	Shrub or small tree 1.5-3 m tall	Unknown	late May-Sep	late Nov-early Jan	Recharge	**2**
A. burkittii (Jul.)	WA, SA, NSW	Northern; central	Low	Loam, sandy loam, (clay); alkaline (neutral)	Shrub or tree 1-4(-10) m	Weak to moderate	July-Sep	Nov-Dec (-Oct)	Recharge	**2-3**
A. hakeoides (Phy.)	WA, SA, Qld, Vic, NSW	Southern	High	Sandy loam (clay); alkaline (neutral)	Multi-stemmed shrub or small tree 1-4 x 3-6 m	Good	(June-) July-Sep (-Oct)	late Oct-early Dec	Recharge	**2**
A. hemiteles (Phy.)	WA	Northern; central	Low	Sand, loam, clay; neutral, acidic, alkaline	Multi-stemmed shrub 0.5-2 x 1-4 m	Unknown	June-Oct main flush Aug-Sep	late Nov-early Feb	Recharge	**2**
A. inceana (Plu.)	WA	North; central	Low	Sand, clay; alkaline; moderately saline	Shrub or small tree 1-3 m tall	Unknown	Sep-Oct	Dec	Recharge-discharge	**3**
A. jennerae (Phy.)	SA, NSW, NT, WA	Northern; central	Low	Sand, loam; acid to neutral moderately saline;	Multi-stemmed shrub 2.5-4 (-6) x 3-6 m	Good	Jan-Aug, main flush April-July	N: Oct-Nov S: Nov-Jan	Recharge	**1-2**
A. jibberdingensis (Jul.)	WA	Northern; central	Low	Sand, sandy loam; neutral	Shrub or small tree 2-4(-7) x 4-5 m	Unknown	June-Oct	Dec-Jan	Recharge	**3**
A. leptopetala (Phy.)	WA	Central	Nil	Sand, clay, loam, sandy loam; neutral to acid	Shrub 2-3 x 2-3.5 m	Unknown	Irregular	?throughout year	Recharge	**3**
A. meisneri (Phy.)	WA	Central	Low	Sandy loam; neutral	Shrub 2-4 x 3-5 m	Unknown	Irregular	Mostly Dec-Jan	Recharge	**2**

TABLE 1 (continued)

Species	State	Wheatbelt distribution	Frost frequency	Soil type	Growth habit	Coppicing	Flowers	Seed matures	Planting zone	Rank
A. microbotrya (Phy.)	WA	Northern; central; southern	Low	Loam (sand, clay loam); acid to neutral	Shrub or small tree 2-5(-7) x 3-9 m	Variable; also root suckers	April-early July	Oct-Dec (-Jan)	Recharge	**1**
A. murrayana (Phy.)	NSW, Qld,	Northern	Low-high	Sand (clay loam); acid to alkaline	Multi-stemmed shrub or tree 2-5(-8) x 3-8 m	Good; also root suckers	Aug-Nov	Nov-Jan	Recharge	**1**
A. prainii (Phy.)	WA, SA, NT	Northern; central	Low	Sand (clay loam); neutral to alkaline	Shrub or small tree 1.5-3 (-5) x 3-5 m	Unknown	mid July-Oct (-Nov)	Nov-Jan	Recharge	**3**
A. ramulosa (Jul.)	NSW, Qld, NT, SA, WA	Northern	High	Sand (clay loam); alkaline (acid)	Multi-stemmed shrub or small tree 2-6 x 3-8 m	Good	(Mar-June) July-Sep	Sep-Nov (-Jan)	Recharge	**2**
A. redolens (Plu.)	WA	Southern	Low	Clay-loam (sandy loam, clay); neutral (alkaline); saline	Shrub 0.5-2(-5) x 3-5 m	Unknown	Aug-Oct	Dec	Discharge	**2**
A. saligna (Phy.)	WA	Northern; central; southern	Low	Sand (clay loam); acid to alkaline; often moderately saline	Shrub or tree 2-5 x 6-10 m	Strongly; also root suckers	Aug-Oct	Nov-Jan	Recharge-discharge	**1-2**
A. scirpifolia (Phy.)	WA	Northern	Low	Sandy loam (clay loam); neutral	Shrub or small tree 2-4 x 3-6 m	Unknown	Aug-Oct	Nov-Jan	Recharge	**3**
A. subrigida (Phy.)	WA	Northern	Low	Sand; acid	Shrub to 3 m tall	Unknown	Sep-Oct	Jan	Recharge	**3**
A. victoriae (Phy.)	All mainland States	Northern	Nil to high	Sand, clay; alkaline (acid); saline	Multi-stemmed shrub or tree 2-5(-9) x 5-10 m	Good	Late Aug -Oct	Nov-Jan	Discharge	**1**

Abbreviations: Column 1 (species): Jul = section Juliflorae; Phy = section Phyllodineae; Plu = section Plurinerves. States: NSW = New South Wales; NT = Northern Territory; Qld = Queensland; SA = South Australia; Vic = Victoria; WA = Western Australia.

Soil type: shows soil texture, pH status and if known to be saline.

Frost frequency: *high* = heavy frosts in most years over a substantial part of natural range; *low* = low incidence of frost in some parts of natural range; *nil* = nil or very low incidence of frost throughout the range.

Rank: refers to domestication potential for edible wattle seed production in the target zone; 1 = has all attributes of a good edible wattle species; 2 = lacks some of the key attributes; 3 = poorly known in cultivation, may lack a number of key attributes.

1. Acacia victoriae F.Muell. ex Benth.

Taxonomy–Acacia victoriae and with nine close relatives comprise the informal '***A. victoriae*** group' (Maslin 1992). The group is closely related to the '***Acacia murrayana*** group'. ***Acacia victoriae*** is a highly variable species. For example, specimens from Queensland and from the Kimberley region of Western Australia have very long phyllodes (to 10 cm). The taxonomic status of ***A. victoriae*** subsp. ***arida*** requires further investigation. Specimens ascribed to this subspecies have densely tomentose branchlets and phyllodes and occur on sandy soil in southern N.T., northern S.A., western N.S.W. and south-west Qld (Maslin 2001a).

Growth attributes–Acacia victoriae ranges from a dense to straggly shrub or small tree, commonly 2-5 m tall but sometimes reaching 9 m tall. It readily regenerates from root suckers and sometimes forms thickets. ***Acacia victoriae*** is usually spiny, with small, pungent stipules that occur in pairs in the axils of the phyllodes. The stipules are usually evident on new growth and especially on young plants, but they are absent in some populations. The foliage provides useful fodder for stock in semi-arid regions (Everist 1969; Askew and Mitchell 1978) and in stocked areas plants with browse lines are common. In natural stands growth is rapid but the species is relatively short-lived (Grice ***et al.*** 1994); 10-15 years appears to be the maximum life-span. Wood from trees in natural stands has a basic density of 800 kg m^{-3} (Ilic ***et al.*** 2001). Maiden (1889) noted that ***A. victoriae*** is an indicator species of underground water and that it has an extremely deep root system, estimated to be in excess of 20 m (although this depth would be remarkable and needs verification).

Occurrence–This has one of the widest distributions of any Australian ***Acacia*** species, occurring in arid and semi-arid areas of all mainland States (map 218 in Maslin 2001a).

Climate–Natural populations of ***A. victoriae*** occur mainly in the climate zone with a hot dry summer and cold winter but extend into the tropical zone with a hot dry summer and warm winter. The mean maximum temperature of the hottest months is 35-39°C and mean minimum temperature of the coldest months is 5-10°C; the mean annual rainfall ranges from 125-300 mm (Doran ***et al.*** 1997). Rainfall seasonality varies from uniform to summer maximum but throughout much of the range rainfall is sporadic and unreliable. Inland sites experience some frosts (about 1-11 per year).

Soils–These range from sandy loam and clay loam to clay, with a pH range of 5.5-9.5. It commonly occurs on soils considered adverse for plant growth including highly alkaline, cracking clay, saline and poorly drained soils.

Phenology and seeds–Acacia victoriae flowers from August to October. Flowering does not appear dependent on the incidence of rainfall (Askew and Mitchell 1978), and this could be linked to its root architecture (see below). Flowering occurs at an early age (less than 2 years). Seeds mature mainly between November and January. ***Acacia victoriae*** has easily harvested papery pods that are held on the tips of the branches. The seeds separate from the pods with minimal mechanical processing. The use of seeds by Australian Aborigines is documented in O'Connell ***et al.*** (1983) and Latz (1995). The nutritional attributes of the seed are excellent: they contain 17% crude protein, 41% carbohydrate and 29% fibre (Brand and Cherikoff 1985).

Silviculture–Acacia victoriae is suitable for cultivation throughout the wheatbelt region of Western Australia on sites where its roots can access groundwater. Field observations from natural stands suggest that the persistence of ***A. victoriae*** in arid regions is due to localised distribution on run-on sites and the ability of its root system to tap groundwater, possibly at considerable depths. The successful cultivation of this species will rely on this critical aspect of site selection. In glasshouse trials ***A. victoriae*** has been ranked as moderately salt tolerant (Aswathappa ***et al.*** 1986). It also has the potential to be cultivated successfully on a range of other adverse soil types as some natural stands occur on highly alkaline, cracking clay and poorly drained soils. Establishment during the rainy season is essential and some irrigation during the early years of growth would facilitate its successful cultivation. Protection from grazing stock is necessary during establishment.

Acacia victoriae is a relatively short-lived species (10-15 years) but coppices well (Chippendale and Jephcott 1963). It has moderate fire tolerance but can be killed by severe drought (Askew and Mitchell 1978). Its moderate life-span and coppicing ability make it amenable for mechanical harvesting of established plantations. Harvesting of coppice regrowth could extend over a number of seasons, likely to be in more than five, but trials are required to ascertain how quickly it flowers and seeds from coppice regrowth.

The wide geographical range of ***A. victoriae*** and its ability to tolerate a range of soil types suggest that selection of suitable provenances may be critical for its successful cultivation.

Genetics–Acacia victoriae is a diploid species (***2n*** = 26) (Hamant ***et al.*** 1975)**.** Research to elucidate its patterns of genetic variation and its breeding system is warranted, particularly as it is currently the main species targeted for domestication.

Limitations–Restricted to cultivation on sites with run-on water or where its roots can tap groundwater.

Further reading–Cunningham ***et al***. 1981; Whibley and Symon 1992; Doran ***et al***. 1997: 350.

2. Acacia murrayana F.Muell. ex Benth.

Taxonomy–Acacia murrayana, ***A. gelasina***, ***A. pachyacra***, ***A. praelongata*** and ***A. subrigida*** comprise the '***A. murrayana*** group', a group which has affinities to the '***A. victoriae*** group' and the '***A. juncifolia*** group' (Maslin 1995: 200, and 2001: 373). Future taxonomic studies of ***A. murrayana*** may recognise infraspecific taxa to accommodate the considerable variation in phyllode shape, width and colour (Maslin 2001a).

Growth attributes–Acacia murrayana is usually a shrub 3-4 m tall with an often-spreading, bushy crown, but occasionally it occurs as a small tree to 5 (-8) m tall. Due to its root-suckering ability this species commonly forms clonal thickets or groves and is sometimes referred to as Colony Wattle. It is documented as having fast to moderate growth rate with a moderate life-span (10-50 years), although longevity of individual bushes is likely to be closer to 10 than 50 years (Thomson ***et al***. 1994). Wood from natural stands has a basic density of 600 kg m^{-3} (Ilic ***et al.*** 2001). ***Acacia murrayana*** coppices well as it is reported to resprout from the base, stem and roots following wildfire (Hodgkinson 1982; Latz 1995).

Occurrence–Acacia murrayana is widespread in the arid zone, extending from the northern wheatbelt in W.A. through central Australia to Qld (map 212 in Maslin 2001a).

Climate–Climate parameters of the areas of natural occurrence indicate that ***A. murrayana*** prefers hot, persistently dry conditions. The climates of its natural range are characterised by hot dry summers and cold to warm winters. The mean maximum temperature of the hottest months is 34-38°C, the mean minimum temperature of the coldest months is 4-6°C and the mean annual rainfall range is 120-500 mm (Doran ***et al.*** 1997: 190-191). Rainfall seasonality varies from uniform to summer maximum but rainfall is sporadic and unreliable throughout its range. The region receives about 1-8 frosts per year.

Soils–These range from deep red sand and sandy loam to clay loam; pH range is 5.5-6.5.

Phenology and seeds–It flowers profusely from August to November, depending on locality. Plants are precocious, e.g. heavy flowering commenced at age 17 months in a trial in southern Queensland (Ryan and Bell 1989). Pods mature over a short time during November to January. For example, in the northern wheatbelt of Western Australia during 1999, peak flowering occurred on ***A. murrayana*** around 12 October and mature pods were present six weeks later, on 24 November (B.R.Maslin unpubl.). Seeds are moderately large (18 000-27 000 per kg) and are separated easily from the papery pods. It is a heavy, uniform seeder, particularly in favourable seasons and especially in moist ecological niches. While foliage is unpalatable, pods are sought after by stock (Mitchell and Wilcox 1994).

Silviculture–Based on its natural distribution, ***A. murrayana*** is likely to be best-suited for cultivation on recharge areas in the northern wheatbelt region of Western Australia. It should perform best on well-drained soils with a relatively high proportion of sand. The ability of its roots to tap groundwater on recharge sites may also be critical for its successful cultivation. Based on glasshouse trials, ***A. murrayana*** is relatively salt-sensitive and is not recommended for cultivation on saline soil (Aswathappa ***et al***. 1986); it is also unlikely to tolerate waterlogging.

Rainfall data might suggest that watering or irrigation is not essential except during establishment. However, the species often regenerates, grows and fruits heavily on well-watered sites along road verges, and supplementary watering / irrigation is likely to enhance growth, longevity and seed production. Its moderate longevity and coppicing ability mean that repeated harvesting over five or more years is likely to be feasible. Plants can be pruned to one main stem, which would facilitate mechanical harvesting including shaking and catching methods or modified combine harvesters.

The wide geographical range of ***A. murrayana*** with associated substantial climatic variation suggests that provenance selection may be critical for its successful cultivation. Its performance in higher rainfall areas, i.e. greater than 300 mm mean annual rainfall, remains to be ascertained. Assessment should be based on a representative range of provenances.

Genetics–There is no published information on the genetic structure, breeding system or ploidy in this species. Such information will be required as part of any domestication program.

Limitations–Although there are no reports of adventive outbreaks from cultivated stands the weed potential of ***A. murrayana*** is relatively high. This is due to its root suckering ability (especially in disturbed sites such as road verges) and its potential for heavy seeding. Site disturbance by fire, overstocking and road works can lead to large populations of ***A. murrayana*** (Mitchell and Wilcox 1994). When cultivated on adverse sites, the survival, drought tolerance and longevity of ***A. murrayana*** are relatively poor (Maslin ***et al.*** 1998).

Further reading–Thomson 1994; Wilcox and Mitchell 1994; Doran ***et al.*** 1997: 190-191; Maslin 2001a.

3. Acacia anthochaera Maslin

Taxonomy–Acacia anthochaera is a poorly known species belonging to the '***A. prainii*** group' (Maslin 2001a). Until recently it was regarded as a variant of ***A. hemiteles*** with long phyllodes. Putative hybrids between ***A. anthochaera*** and ***A. hemiteles*** are known from their zone of overlap. ***A. anthochaera*** is also related to ***A. murrayana.***

Growth attributes–Acacia anthochaera is usually a dense, rounded, multi-stemmed shrub 2-4 m high. It may develop into a tree to 8 m tall, although arborescent plants are not commonly encountered in the wild. It is not known to produce root suckers. Its growth attributes, including coppicing ability, require investigation.

Occurrence–It is endemic in W.A. where its main area of occurrence is in the northern wheatbelt region from near Yuna south to Cowcowing; also found near Galena and Karroun Hill. In some places it extends slightly east of the wheatbelt into more arid areas.

Soils–Grows on flat, low-lying areas in red-brown sand or loam which varies from slightly to moderately saline; it sometimes grows on the margins of salt lakes.

Climate–Natural populations of ***A. anthochaera*** experience hot dry summers and cold winters. The mean maximum temperature of the hottest months is 34-36°C, the mean minimum temperature of the coldest months is 5-6°C and the mean annual rainfall range is 290-325 mm. Rainfall is strongly seasonal with a winter maximum.

Phenology and seeds–Flowers profusely from August to October, with the main flush in September. Flowering is profuse from a young age. It is an abundant seeder in good seasons; pods mature from late November to January. The reliability of annual fruit set is largely unknown but evidence to date suggests that it is fairly regular. Occasional poor fruit set may be related to the timing and / or intensity of preceding rainfall events. Pods are held terminally on the plants, making them readily accessible for collection. The seeds are medium-sized to large (about 20 000 per kg but needs confirmation: see Maslin 1998) and although retained in the pods following dehiscence, are easily separated by shaking techniques or hand stripping. Given its close taxonomic relationship to ***A. murrayana***, a species traditionally consumed by Australian Aborigines, its seeds are likely to have similar nutritional characteristics.

Silviculture–Acacia anthochaera is a hardy, drought-tolerant species that warrants trial on recharge areas of the northern wheatbelt. Compared to the other species profiled in this paper, it has a relatively restricted natural distribution encompassing only limited environmental variation. Accordingly there is likely to be limited variation in provenance.

Genetics–Nothing known.

Limitations–Many silvicultural and genetic attributes are unknown. There is likely to be less scope for selection and improvement than in other more widespread ***Acacia*** species.

Further reading–Maslin 1995; Maslin ***et al.*** 1998; Maslin 1998.

4. Acacia microbotrya Benth. sens. lat.

Taxonomy–Acacia microbotrya belongs to a large species complex comprising 43 close relatives Australia-wide, the informal '***Acacia microbotrya*** group' (see Maslin 1995 for discussion). This species appears to be most closely related to ***A. amblyophylla*** (confined to the Shark Bay region, W.A.) and ***A. jennerae*** (widespread in arid and semi-arid areas from W.A. through N.T. and S.A. to western N.S.W. and south-western Qld, map 108 in Maslin 2001a). Variation patterns within ***A. microbotrya*** are under investigation and current indications suggest that there are three distinct entities in the species. Plants from north of about the latitude of Moora are treated by Maslin (2001a) as ***A. microbotrya*** var. ***borealis***, those from south of Moora as ***A. microbotrya*** var. ***microbotrya,*** and a third entity, restricted to near Dandaragan, may represent the plant previously described as ***A. subfalcata*** Meisn. Resolution of the variation patterns and the taxonomic status of the entities in this species is essential to facilitate its domestication.

Growth attributes–Acacia microbotrya is a reasonably fast-growing species and, according to Gardner (1957), probably lives for 20-30 years under most conditions. Plants referable to var***. borealis*** are usually spreading shrubs or small trees 2-4 m tall, whereas var. ***microbotrya*** tends to be more robust and grows to small trees 3-6(-7) m tall; the Dandaragan variant develops into substantial trees 7-10(-15) m tall. Root suckering occurs in all three variants and is most evident in disturbed sites such as road verges where clonal thickets sometimes develop. Wood density is not known.

Occurrence–Acacia microbotrya is confined to the Western Australian wheatbelt, extending from the Murchison River to near Katanning with scattered occurrences around Ongerup and Lake King.

Climate–The natural range is characterised by hot dry summers and cold winters. Mean annual rainfall range is 350-550 mm.

Soils–Occurs on a range of soil types including sand and sandy loam but most commonly on clay-loam. The pH range is 5.5-6.0.

Phenology and seeds–The species flowers earlier than many other acacias in south-western W.A., mainly from April to July. Pods mature during October–December. Seeds are large to very large (about 14 000 seeds per kg) and it is normally a heavy seeder, although suckering plants in dense clonal populations usually remain in a vegetative phase.

Silviculture–Acacia microbotrya is hardy, drought- and frost-tolerant with a moderate to fast grow rate and warrants trials throughout recharge areas of the wheatbelt. Plants from different parts of the natural range may vary in their suckering ability. Currently ***A. microbotrya*** is used in direct seeding programs for regeneration and shelterbelt plantings in the northern wheatbelt region of W.A. It is useful as a low windbreak and has potential as a short- to moderate-lived Sandalwood host. While some plants of ***A. microbotrya*** produce reasonable quantities of potentially edible gum it is unlikely to have commercial value; according to Anderson (1978), ***A. senegal*** (Gum Arabic) is the only ***Acacia*** gum that has been toxicologically tested to establish its safety as a food additive.

Genetics–A study is in progress to characterise patterns of genetic variation (Margaret Byrne, CALM, ***pers. comm.***).

Limitations–Effective utilisation of ***A. microbotrya*** is dependent on the resolution of its taxonomic variation.

Further reading–Maslin 2001a, 2001b.

5. Acacia saligna (Labill.) H.L.Wendl.

Taxonomy–Acacia saligna is a variable species and a study by the second author and others will be undertaken in 2002 aimed at elucidating the patterns of variation. It has no known close relatives but is superficially similar to ***A. pycnantha*** (see Maslin 2001a for discussion).

Growth attributes–Acacia saligna has a variable growth form but it normally is a shrub or small tree 2–6 m tall, either single- or multi-stemmed; the mature trunk attains breast height diameter of 20–40 cm. Its crown is bushy and spreading or sometimes pendulous. Some populations form thickets due to its root suckering habit. Life span is about 10-20 years (Whibley and Symon 1992), but it coppices well and biomass production can be optimised by regular annual harvesting (Doran ***et al.*** 1997: 210-213). The wood of ***A. saligna*** has an air-dry density of about 600 kg m^{-3} (Marcar ***et al.*** 1995) and has been successfully processed into particle board in Tunisia (El-Lakany 1987).

Occurrence–Endemic in W.A. where it extends from the Murchison River to east of Esperance, with outlying populations on Meka, Murgoo and Jingemarra Stations (Maslin 2001a). Also naturalised throug south-eastern Australia from south-east Qld to S.A. and Tas.

Climate–Climate parameters indicate that natural populations of ***A. saligna*** tolerate a wide range of climatic conditions, characterised by hot to warm, distinctly dry summers and cold to temperate winters. The mean annual rainfall is 280-1210 mm; the mean maximum temperature of the hottest month 26-36°C; and the mean minimum temperature of the coldest month 4-9°C (Doran ***et al.*** 1997). Rainfall seasonality ranges from winter to uniform; naturalised populations proliferate in summer maximum rainfall zones.

Soil–Acacia saligna grows naturally on a considerable range of soil types ranging from deep sand to clay-loam. The pH range is 5.5-7.5. Based on glasshouse salinity trials, ***A. saligna*** was slightly salt tolerant (Marcar ***et al.*** 1995), but based on field trials, House ***et al.*** (1998) reported ***A. saligna*** to be moderately to highly salt tolerant.

Phenology and seeds–Acacia saligna is a moderate to heavy seeder in most years. In Cyprus its seed yield varied from 54-67 kg ha^{-1} for average plantations (Anon. 1955) up to 170 kg ha^{-1} (Michaelides 1979).

Silviculture–Acacia saligna is suitable for cultivation in all wheatbelt regions of W.A. where it warrants trial in both recharge and discharge areas. Under cultivation it grows rapidly and demonstrates tolerance of calcareous, alkaline and moderately saline soils. In some parts of W.A. it is already planted on areas with a high water table to mitigate salinity. Plantations have been established in Western Australia by mechanised, direct seeding in areas with annual rainfall as low as 350-500 mm (Scheltema 1992). Plantations have also been established from rooted cuttings. Although short-lived (typically 10-15 years) it may be possible to rejuvenate declining stands of ***A. saligna*** by coppicing and / or shallow ploughing to induce root-suckering. Michaelides (1979) recommended a short rotation of 5-10 years duration, with regeneration by coppicing. However, considerable provenance variation should be expected when assessing ***A. saligna*** for any of its domestication attributes. For example, natural stands from the Swan Coastal plain region, particularly between Yanchep and Mandurah, comprise the largest plants known and probably represent the most valuable resource for trials aimed at biomass production. Variation throughout its range in attributes such as seed production, root-suckering and coppicing ability warrant investigation. In northern Africa ***A. saligna*** is highly valued as fodder for sheep and goats (El-Lakany 1987; Crompton 1991) and its potential in this role in W.A. is being assessed (Gaye Krebs, Curtin University of Technology, ***pers. comm.***). The foliage and seeds are protein-rich and particularly palatable to sheep and goats (Michaelides 1979).

Protection of newly established plantations from grazing animals is essential. Gall rust may be a serious problem in some parts of W.A., with more than 90% of ***A. saligna*** trees bearing conspicuous woody galls (Berg 1978), and more research is needed to ascertain to the severity of this infection and possible control measures.

Genetics–Preliminary planting trials in Western Australia indicate that there is considerable provenance variation within this species; a study is in progress to characterise patterns of genetic variation (Margaret Byrne, CALM, ***pers. comm.***).

Limitations–Weediness: the species is currently a major environmental weed in south-eastern Australia, the Mediterranean, South Africa, California, Spain and Portugal.

Further reading–Fox 1995; Maslin 1974; Whibley and Symon 1992; Doran ***et al.*** 1997, pp. 210–213.

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Issues in the commercialisation of wattle seed for food

ANTHONY HELE

Principal Consultant, Australian Native Crop Development Service*

*previously Industry Development Consultant – Native Food

Primary Industries and Resources South Australia/Australian Native Produce Industries Pty Ltd

SUMMARY

Wattle seeds are a versatile product with a range of potential uses in the food industry. Small amounts of mostly wild-harvested seed are currently used in baked goods and other products. In common with many other Australian native food crops, the expansion of uses and markets is currently constrained by the inconsistent quality and quantity of wild-harvested supplies.

Commercial cultivation of acacias has commenced and further expansion is likely. To date, most plantings for wattle seed are young and small in scale and tend to have taken a more-or-less horticultural approach to establishment and management. There is also interest in growing wattles as a dryland crop to replace shallow rooted annual crops in lands currently affected by salt (or likely to be so) in the Western Australian wheatbelt and the Murray-Darling Basin.

With this expansion comes normal new industry issues such as market requirements, suitable production areas, input management and pest and disease control. However, with wattle seed a whole set of new crop questions arise alongside these new industry issues.

Crops new to cultivation require the development and testing of production system models that consider a range of interlinked management components, including species selection, planting layout, canopy management, harvesting and rejuvenation methods.

As yet, the most efficient or even the 'best-bet' model for wattle seed production has not been determined and it is likely that a range of approaches may prove successful, depending on markets, geographical area, species, complementary and existing farm management practices and specific production targets. Testing and comparison of current and proposed production system models should be a priority.

INTRODUCTION

Wattle seeds are a versatile product with a range of potential food industry uses, and small amounts of mostly wild-harvested seed are currently used in baked goods and other products. In common with many other Australian native food crops, however, the expansion of uses and markets is currently constrained by the inconsistent quality and quantity of wild-harvested supplies.

Commercial cultivation of acacias has commenced and further expansion is likely. With this expansion comes normal new industry issues such as market requirements, suitable production areas, input management and pest and disease control. However, with wattle seed a whole set of ***new crop*** questions arise alongside these ***new industry*** issues.

This paper focuses on these new crop issues which, at a fundamental level, resolve to the modelling and testing of crop production systems.

INDUSTRIES, CROPS AND SYSTEMS

Several new perennial crop industries have developed in Australia in recent years, including avocado, blueberry and kiwifruit, but these industries have been established with the benefit of existing cultivation knowledge and experience, recently acquired in the case of kiwifruit, (1900s – New Zealand)(Wood ***et al***. 1994). They were new industries but not new crops and came with well-developed production systems which covered planting layout, establishment, canopy management and harvesting.

Most of our present crops and their production systems have been developed over hundreds or thousands of years by incremental processes of change and interaction in genetics and technology. Perennial tree crops, in particular, tend to have a long history of cultivation. Relatively few tree crops have entered cultivation in the last 200 years and developed into commercial crops: they include pecans in the USA in the 1840s (Smith 1976a) and quinine in the Dutch and British East Indies in the 1850s (van Harten 1976). In Australia, macadamias were first cultivated in the 1860s, though commercial development occurred in Hawaii from the 1930s and the crop was not 'commercially reintroduced' into Australia until the 1950s. (Smith 1976b; Shigeura and Ooka 1984). Examples of Australian crops commercialised in Australia include duboisia in the 1940s (Wood ***et al***. 1994) and tea tree in the 1980s. Currently the quandong, sandalwood and

lemon myrtle, all Australian natives, are in the early stages of commercial cultivation in this country.

Crops new to cultivation require the development and testing of production system models and their components, such as layout and establishment, canopy management and harvesting. In many cases production models readily suggest themselves, either due to the inherent nature of the crop or by analogy with similar crops. A new nut tree crop suggests horticultural production approaches, where long life, canopy management requirements and the relatively high crop value imply intensive management. A new cereal grass suggests a field crop suited to extensive, mechanised production systems. What then is a wattle seed crop?

MANAGEMENT ANALOGIES

The closest crop management analogies to wattle seed production are probably those employed in tree nuts.

In common with tree nut crops, wattles produce edible seeds on a woody perennial plant. Production systems in similar nut crops, such as pecan, almond and macadamia, commonly involve clonal varieties, planting established trees in precise layouts, irrigation, canopy management (basic structural training in macadamia, more intensive annual pruning in almond) and mechanical harvesting (tree shaking and ground pickup in pecan and almond, natural drop and ground pickup in macadamia).

Cereals, usually grasses, also involve the harvest of an edible seed crop, albeit from a structurally very different and short-lived plant. These production systems may commonly involve selected or bred seed, mechanical seed planting, large-scale dryland production, mechanised or no canopy management and one-pass mechanical harvesting.

Hybrid systems and crop exceptions also exist or have been proposed. A notable example is the meadow orchard system, where deciduous fruit tree are grown at ultra high plant densities and harvested (and pruned) biannually by mowing the growing shoots, with the fruit attached. Separation of fruit from vegetative material occurs post harvest.

WATTLE SEED PRODUCTION MODELS

With wattles for food any production model has to account for the harvest of seed from a single or multi-stemmed woody plant that, though perennial, may have a relatively short life in comparison to many tree crops. While wattle seed production models have been proposed and several have been implemented in the field, so far none seems to have been comprehensively tested and evaluated over a full plantation life cycle, nor has comparison of models been undertaken.

To-date, most wattle seed plantings are young and small in scale and tend to have taken a more-or-less horticultural approach to establishment and management. This so particularly in the Riverland of South Australia where the crop is grown under irrigation, using orchard layouts with pruning and trees are trained where necessary to produce single-stemmed trees in anticipation of tree-shaker mechanical harvesting. In some cases the trees have been planted as a crop-producing host plant for quandongs.

There is also interest in growing wattles as a dryland crop to replace shallow-rooted annual crops in currently lands affected by salt (or potentially so) in the Western Australian wheatbelt and the Murray Darling Basin (Maslin ***et al***. 1998; Simpson and Chudleigh 2001). Such a field crop approach implies production system models that aim to contain costs, while perhaps accepting lower yields and quality, compared to a horticultural approach.

As yet, the most efficient or even the ‘best-bet’ model for wattle seed production has not been determined, and it is likely that a range of approaches may prove successful, depending on markets, geographical area, species, complementary and existing farm management practices and specific production targets.

PRODUCTION MODEL COMPONENTS

Production models should incorporate a range of interlinked management components, including species selection, planting layout, canopy management, harvesting and rejuvenation methods.

Harvesting: Because the cost of harvesting is likely to have a large impact on the economic viability of wattle seed production and has fundamental interactions with other management areas, an assessment of likely methods is one of the key decisions for any production model.

Currently, wild harvesting commonly involves spreading tarpaulins or shadecloth beneath trees to catch seed pods, which are dislodged by striking or shaking the limbs with poles.

Given the success of these manual techniques and that many of the main species of interest, including ***A. victoriae***, present their pods on the ends of branches and drop readily, mechanical harvesting or mechanically-aided harvesting appears to be a feasible proposition.

Hand-held petrol-driven limb shakers or pneumatic rakes, similar to those used in small scale olive production, may be options for mechanically-aided harvesting. While relatively slow and labour intensive compared to fully mechanised harvesting, these techniques are likely to handle a range of growth habits, planting densities and layouts.

Tractor-mounted or self-propelled tree shaker-style machines, similar to those used in some nut crops, may also be a feasible option. These harvest systems may utilise shaker integrated catching frames or other catching

technologies for concurrent crop collection, or may drop the crop on the ground for later collection by pickup machines. Shaking and collection machines are likely to require plants with single stems and a raised canopy to work effectively, which implies an interaction with species selection and / or canopy management techniques. Some machines also require significant room to manoeuvre, with resulting implications for planting densities and layouts.

Over-the-row harvesting technologies, similar to those employed in grapes, but which utilise a variety of methods for dislodging crops, are currently undergoing rapid development and may be a potential future technique. These machines may be able to handle multi-stemmed growth habits while requiring specific and well defined planting layouts.

The economic impact of various harvesting techniques in wattles has been recently examined by Simpson and Chudleigh (2001), who used a cost of $3,125 / ha for tree shaker harvesting and $750 / ha for 'finger' mechanical harvesting (equivalent to the 'over-the-row' technology, discussed above). Using these figures they found systems incorporating tree shaking unprofitable, due to the high cost of harvesting. However, these figures and conclusions warrant further analysis, as tree shaker harvesting of almonds in the Riverland of South Australia has been estimated as costing only $526 / ha (Anon. 2001), roughly one-sixth of the figure used by Simpson and Chudleigh, while grape 'over-the-row' harvesting is costed at $1,313 / ha, almost twice that assumed for a similar system in wattles.

A further harvesting technique termed biomass harvesting, which takes a very different approach to crop removal, is also examined by Simpson and Chudleigh. In this technique harvesting occurs once every four years or so by removing the whole tree, back to a stump, and then separating the seed from the leaves and stems. The stump is then allowed to regenerate for harvesting in another four years. This technique is similar in concept to the meadow orchard system proposed for high-density deciduous fruit crops. While overall seed production levels would be low with this system, it is likely to be low-cost and tolerant of a range of growth habits, planting layouts and plant densities. Simpson and Chudleigh have estimated a cost of $500 / ha for this harvesting technique, based on experience in tea tree.

Species, provenance and cultivars: Since ***Acacia victoriae*** seed is the current industry 'standard' for food use and has a relatively well developed market, this species would likely be the first production choice in many situations. However, other species may have potential as an addition to an ***A. victoriae*** main planting or, in certain environments or with particular management systems, as an alternative to ***A. victoriae***. As the production and use of wattle seed expands, growing user experience and sophistication are likely to mean that a number of species are likely to find particular market niches.

While on-farm experimentation with a range of species could provide valuable information and perhaps uncover a useful species, for individuals it also poses a higher degree of production and marketing risk.

Beyond simple species choice, the genetic diversity of Acacias means that the provenance (i.e. geographic source) of planting material may prove important. Among the factors that may be influenced by provenance are growth rate and form, spininess, yield and adaptation to soils and climates. In the longer term, cultivars (i.e. cultivated varieties¾clonally propagated selections) may become the norm for planting material, as is the case in many other crops.

As different species and provenances have different growth habits (such as multi-stemmed versus single stem) the choice made has potential interactions with production factors such as harvesting techniques, canopy management and rejuvenation methods.

Canopy management: Canopy management is likely to be governed largely by harvesting system requirements. Commercial trials in the South Australian Riverland indicate that pruning and training to achieve a single straight stem and raised canopy, suitable for tree shaker-style mechanical harvesting, appears to be a feasible practice for the normally multi-stemmed species, ***A. victoriae.*** However, the technique requires more than a simple once-only removal of multiple stems and considerable detailed hand pruning is required to progressively reduce and remove shoots, so as to suppress the plant's normal multi-stemmed habit.

The need for canopy management in multi-stemmed species could be reduced or removed completely with different harvesting techniques, such as over-the-row or biomass harvesting. Single-stemmed species or varieties are also likely to be more amenable to a number of harvesting techniques, without the need for significant modification to tree architecture.

Rejuvenation: Because Acacias may be relatively short lived, methods to rejuvenate plantings may be an important aspect of commercial production. Coppicing (cutting trees back almost to ground level to stimulate further growth from dormant trunk buds – although this may also result in multiple stem development), pollarding (cutting trees back to a point some distance above ground level, to stimulate growth and particularly the development of a bushy crown) and / or shallow ripping to induce regrowth through suckering, have been proposed, although these methods have yet to be trialed and perfected.

Input management: The management of inputs, such as water and fertilisers, is likely to have an impact on tree growth rates, yields and plantation longevity, as well as interacting with other practices, such as canopy management. Optimum programs and strategies have yet to be determined.

Other considerations: As in any crop, the wattle seed production unit has to mesh with other on-farm systems, in areas such as labour requirements and operation timing, machinery and input usage. Any system also must be able to meet desired production targets, which may be more than simple seed yields or returns per hectare in the case of a potentially multi-use crop such as acacia. For example, production targets may encompass the performance of other crop or livestock systems, as when acacias are used as a host plant for root-parasitic quandongs or sandalwoods or when acacias provide a fodder source, or may encompass often hard to measure environmental benefits.

CONCLUSION

Probably the biggest issue for an expanded wattle seed industry is the development of suitable production systems, which integrate harvesting, species, canopy management and rejuvenation approaches, among others. Testing and comparison of current and proposed production system models should be a priority, and it is likely that several systems may prove suitable, depending on markets, geographical area, species, complementary and existing farm management practices and specific production targets.

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Broadscale production of wattle seed to address salinity: potential and constraints

GRAEME OLSEN[1]

[1] Olsen & Vickery, PO Box 357, Waroona, Western Australia 6215
Email: golsen@iinet.net.au

SUMMARY

Edible *Acacia* seed, or 'wattle seed', is a potential commercial crop that could provide land management benefits in low- to medium-rainfall agricultural areas in southern Australia. A review of wattle seed on behalf of the Joint Venture Agroforestry Program found that large markets for food ingredients are out of reach for existing wattle seed production systems, due to the high harvesting cost. Lowering the cost to a level competitive with other large-scale food crops will require development of a new production system that integrates crop layout, harvesting method and species selection. An efficient harvester is likely to have many features in common with modern cereal crop headers: light weight, continuously moving, straddling the crop, and a wide intake to maximise the tonnage harvested per operating hour. Species best suited to such a harvesting system would be short, compact and erect, bear their seeds near the top of the plant, have a high ratio of seed production to vegetative growth, and be suited to growing at high density. A plant with these characteristics would be very different from the tall, spreading shrubs currently used for edible seed production. A first step towards building a large-scale wattle seed industry would be to explore the abundant genetic resource of this genus for species with desirable characteristics for low-cost production.

INTRODUCTION

The water use of annual crops and pastures in the low- and medium-rainfall agricultural zones of southern Australia is out of balance with rainfall, resulting in a slow filling of soil profiles with excess water and, in many areas, a remobilisation of salt stored in the soil. As a result, large areas of the southern agricultural landscape are at risk of developing dryland salinity. The area likely to be affected in south-west Western Australia is estimated to be up to 30% (State Salinity Council 2000).

Of the many potential solutions to this problem, a key one is to reduce the leakage of rainfall past the shallow root zone of agricultural systems based on annual plants, by increasing the area of deeper-rooted perennial plants on farms (Hatton and Nulsen 1999). The extent to which perennial plants might be deployed in agriculture depends on the goal. Options include:

- slowing the rate of spread of salinity and delaying the onset of symptoms (least ambitious),
- halting the spread of salinity,
- reclaiming saline land (most ambitious).

The scale on which perennial plants are needed in order to control recharge also varies from place to place, due to hydrological variability and complexity. Where landscape relief is low, or soils have low permeability, lateral movement of groundwater is slow compared to the rate at which soil profiles are filling with excess rainfall. This leads to the conclusions that strategic placement of small areas of perennial vegetation would usually be ineffective in controlling salinity, and that a high proportion of the agricultural landscape (in some areas as much as 80%) would have to be revegetated to achieve that aim (George *et al.* 1999; Hatton and Salama 1999).

The National Land and Water Resources Audit (2001) gives a broad estimate of the likely need for perennial vegetation in agricultural areas: '. . . for effective reduction in recharge there may need to be 30–50% reforestation in a catchment (and even more if trees are to be harvested).' Based on this estimate, between 15 and 25 million hectares of perennial plants could be needed in southern agricultural regions. Such large-scale use of perennial plants in agricultural systems is likely only if the bulk of those plants have a commercial use (Bartle 2001) and produce financial returns similar to existing agricultural crops.

Acacias are strong candidates for development into new perennial agricultural crops, as they have potential to produce a wide range of commercial products, including edible seeds. Their favourable attributes include:

- large number of species,
- adaptation to Australian conditions,
- wide variability between and within species, enhancing the prospects for selecting suitable germplasm for commercial development, and
- potential to enhance nature conservation goals if appropriate species are planted in suitable locations.

The biological attributes of *Acacia* that favour their

development as crop plants and the range of potential commercial uses for *Acacia* are discussed elsewhere in this proceedings (Bartle *et al.*).

Edible *Acacia* seed, or 'wattle seed', is a potential commercial crop that could provide part of the perennial plant component of a new Australian agriculture. It has many attractive elements as a commercial crop:

- it has a long history of use by indigenous Australians as food (Devitt 1992, cited in Harwood 1994),
- a small commercial wattle seed industry is already in operation (Maslin *et al.* 1998),
- grains and seeds are high-value products that lose only a moderate percentage of their value in transport costs when transported long distances to markets,
- grain production and export is a familiar industry for Australian farmers, and
- an Australian grain handling infrastructure is well developed.

Maslin *et al.* (1998) reviewed the potential of Australian *Acacia* species for wattle seed production. Based on plant features that would suit commercial production and reports of their utilisation by Aborigines, they listed 47 species considered suitable for cultivation in the semi-arid agricultural region of southern Australia.The 18 species considered to have the best prospects were grouped into three categories:

Most promising species: *A. murrayana*, *A. victoriae*

Other promising species: *A. jennerae*, *A. microbotrya*, *A. pycnantha*, *A. retinodes*, *A. rivalis*, *A. saligna*

Lesser-known species: *A. anthochaera*, *A. blakelyi*, *A. scirpifolia*, *A. brumalis*, *A. calamifolia*, *A. confluens*, *A. hakeoides*, *A. hemiteles*, *A. prainii*, *A. subrigida*.

WATTLE SEED REPORT – BY AGTRANS RESEARCH

The Joint Venture Agroforestry Program[1] commissioned Agtrans Research[2] to assess the technical, commercial and economic basis for developing a large-scale wattle seed industry in Australia. A report on this project, *Wattle Seed Production in Low Rainfall Areas* (Simpson and Chudleigh 2001) is available from the Rural Industries Research and Development Corporation, publication number 01/08.

A brief summary of the findings of this study is presented below.

Potential markets

The high-value bush food market has potential for significant growth but is unlikely to reach a size that would require broadscale dryland production of wattle seed. To achieve that goal, with its accompanying land management benefits, would require expansion into larger, lower-value markets such as specialty flours for use in bread, biscuits, cakes and pasta. To expand further, to become a large-scale industry comparable to other mainstream cereal crops, would require expansion into large, price-competitive markets for generic food ingredients such as starches, vegetable protein and vegetable oils.

Nutritional value

There is limited information available on the nutritional value of wattle seed. The results of analyses of whole seeds (including seed coats) of a small number of species indicate that wattle seed has a protein content of about 20%, a fat content of about 5% (mostly unsaturated), a carbohydrate content of about 40% (mostly starches), and a dietary fibre content of approximately 30%. These attributes may make wattle seed an attractive source of food ingredients but further work is needed to investigate their nutritional constituents in more detail, test the nutritional value of a wider range of species, and quantify the variation within species.

Harvesting

Harvesting is the largest impediment to lowering the cost of producing wattle seed. Three methods were assessed– butt shaking, finger stripping, and whole biomass harvesting. Calculations of the cost per harvested tonne assume an average annual seed production of 1.25 tonnes per hectare:

Butt shaking involves mechanically shaking each tree to dislodge pods and seeds into collecting trays. Harvest cost of this method is estimated to be $3,125 per hectare, or $2,500 per tonne of seed. This method suffers the disadvantage of being a stop-start operation, limiting the scope for reducing its cost by further development. It also requires single-stemmed tree architecture, and may not be effective at dislodging lightweight pods at the extremities of tall, flexible *Acacia* trees or shrubs.

Finger stripping involves combing pods from the outer foliage of plants. This is a much cheaper harvesting option, at an estimated cost of $750 per hectare, or $600 per tonne of seed, because it could be incorporated into a machine that moved continuously along rows of trees. This method would be suitable for species that carried most of their seed pods on the outer edges of the canopy.

Whole biomass harvesting, followed by separation of the pods and seed, is estimated to cost $500 per hectare, or $471 per tonne of seed (assuming a harvest yield every four years of 85% of 1.25 tonnes per hectare).

These cost estimates are speculative, as considerable development work would be needed to optimise harvest

[1] The Joint Venture Agroforestry Progam (JVAP) is coordinated and supported with funding by three Australian government research and development corporations (RDCs) – Rural Industries (RIRDC), Land and Water Australia (LWA), and Forest and Wood Products (FWPRDC).

[2] Agtrans Research is a private research consultancy, PO Box 385, Toowong, Queensland 4066. Email: agtrans@powerup.com.au.

machinery for particular species, or groups of species, layouts and silvicultural methods.

Species selection criteria

For commercial seed production *Acacia* species would have to be selected and developed to maximise harvesting efficiency. Critical factors include suitable plant architecture (which depends on the harvest method), high seed yield, regular seed production and a long harvest window.

In addition, suitable species would have to be non-toxic, have desirable nutritional characteristics, be adapted to a range of climates and landscapes, be easy to propagate and manage, grow well in an agricultural setting and, if possible, produce valuable co-products.

Although it is likely that any *Acacia* species would improve the water balance if grown as a crop in place of annual crops or pastures, there may be substantial differences between species. Therefore, root architecture and water usage may also be used as selection criteria to maximise the land management benefits from any new crop.

Economics

The report includes an economic analysis of a production system with 625 trees per hectare in a plantation layout, under each of the three harvesting systems described above.

Assumptions used include:

- discount rate = 10%
- duration of project = 12 years
- seed production = 1.25 tonnes per hectare (625 trees x 2 kg per tree)
- seed production starting in year three and reaching a maximum in year five; for the 'whole biomass harvesting' option, harvesting is carried out every four years, when seed production is 85% of its maximum
- establishment cost = $380 per hectare
- annual management cost = nil
- market price for seed = $1,000 per tonne (at farm gate)
- harvesting costs as above: $3,125 per hectare for butt shaking, $750 per hectare for moving fingers, and $500 per hectare for whole biomass harvesting.

Under these assumptions, a seed production enterprise based on butt shaking was very unprofitable, while enterprises using finger stripping or whole biomass harvesting produced positive returns, comparable with returns from growing wheat.

The sensitivity of these results to some of the assumptions used in the economic analysis were tested. It was found that the profitability of wattle seed production is influenced strongly by seed yield, harvesting cost and market price. Break-even values for each of these factors are given in Table 1.

For all three factors, break-even values for the butt shaking method of harvesting are well outside those assumed in the economic analysis, by a factor of approximately three, while for both finger stripping and whole biomass harvesting, break-even values are inside the range needed for profitability.

TABLE 1
Break-even values for seed yield, harvest cost and market price (at farm gate) for wattle seed.

	HARVEST METHOD		
	BUTT SHAKING	FINGER STRIPPING	WHOLE BIOMASS
Min. yield per tree (kg/year)	5.7	1.4	1.0
Max. harvest cost ($/kg)	1070	1070	1027
Min. market price ($/t)	2870	710	500

Note that this analysis assumed a farm gate price of $1,000 per tonne for wattle seed, a price that may be sustainable in a small-scale industry but not in large markets in competition with other large-scale crops.

Research and development needs

Four key strands of research and development required for the development of a large-scale wattle seed industry were identified:

- food production and nutritional characteristics–determining the nutritional composition and behaviour of wattle seed, their pre-processing requirements, and their performance in industrial food processing
- market research–to improve understanding of potential volumes and prices of different market sectors, and the strengths and weaknesses of competing products
- economic analyses–refinement of the assumptions used in this report, and extension of economic analyses to other production systems
- seed production, harvesting and sustainability–exploration of technical issues ranging from species selection and establishment through growing systems to harvesting and sustainability issues.

Summary of conclusions

1. Bush food markets are growing, but will always be a niche opportunity, providing only limited land management benefits.
2. Large markets for food ingredients may be accessible to wattle seed and could stimulate large areas of dryland *Acacia* cropping, but current production systems are not competitive due to their high cost, harvesting cost being the main impediment. To compete in large-scale markets, production costs would have to be well below $1000 per tonne, perhaps as low as $200. Production costs in this range are possible only if low-cost harvesting systems are developed. Finger harvesting and whole biomass harvesting have the most potential.

3. Yield, harvest cost and market price are the three critical issues affecting profitability.
4. Too little is known at this stage to allow a reliable assessment of the potential of wattle seed in low rainfall areas. The critical research and development required to establish this industry's potential were identified in the study (listed above).

DEVELOPMENT OF A LARGE-SCALE INDUSTRY

The Agtrans Research report summarised above provides a starting point for further exploration of the issues that confront the development of a large-scale wattle seed industry. Some of these issues–food safety, market price and low-cost production systems–are discussed briefly below. Other important issues such as nutritional properties of wattle seed, their suitability for various uses and marketing issues are not dealt with here, although all are critical to the development of a large wattle seed industry.

Food safety

New crops developed for human consumption require a cautious approach, to ensure that new foods present no unacceptable health risks. Seed of some species of *Acacia* were eaten by Australian Aborigines as part of their traditional diet (Maslin *et al.* 1998), and are generally regarded as safe, especially if heated to denature anti-nutritional factors (Simpson and Chudleigh 2001).

Hegarty *et al.* (2001) reported that most widely-used bush foods are likely to be safe if consumed in modest quantities as part of a mixed diet, and if handled and prepared in ways that avoid or destroy any toxic contaminants or constituents, where applicable. However, where a minor food plant becomes used in much greater amounts in the diet, or a native plant not previously used for food is added to the diet, then food safety must be assessed more closely. This could be the situation if some wattle species became more widely eaten, or if others were newly developed as seed crops.

Natural variability in newly cultivated species and the wide range of individual human tolerance to different chemical compounds may result in isolated cases of illness, even in crops that are safe for most of the population (Hegarty *et al.* 2001). For a new food crop, these issues should diminish in time, as the crop becomes more uniform through plant breeding, and as susceptible sections of the population become aware of their susceptibility to the new food and avoid it.

Increasing the scale of wattle seed production

The current edible wattle seed industry is very small. Annual commercial production is between 12 and 20 tonnes, and the price paid to producers is in the range $12,000–$25,000 per tonne for clean seed (Simpson and Chudleigh 2001). Production costs are high, most seed being harvested manually from natural stands of *Acacia victoriae*. A few private growers harvest seed from small plantations, some using manual methods and some developing and testing various mechanised systems.

What changes would be required for wattle seed to expand from its current position as a boutique industry into an industry of sufficient size to produce significant land management benefits? A brief look at existing large-scale grain crops is useful.

Wheat is at the opposite end of the spectrum to wattle seed. It is the dominant crop in southern Australia and is grown on large areas at low production cost. About 20 million tonnes of wheat are harvested in Australia each year (about 3% of global production), of which 70–80% is exported (ABARE 2001). Growers receive about $160 per tonne at the farm gate (ABARE 2000). The wheat industry has benefited from sustained, high levels of investment in research and development, and operates in highly mechanised production systems.

Other large-scale crops have features similar to wheat. Table 2 contains details of all Australian dryland crops with annual production over one million tonnes. With the exception of oats, over half of Australia's production of these crops is exported. Average export prices (1995–2000) were approximately $200 per tonne, apart from canola at $386 per tonne.

TABLE 2
Statistics for large-scale Australian dryland crops (FAO 2002). Data are averages for 1995-2000 inclusive.

CROP	YIELD (t/ha)	PRODUCTION (Mt)	EXPORT (Mt)	EXPORT PRICE (A$)
Wheat	1.8	21.7	15.2	227
Barley	1.8	5.9	3.2	198
Oats	1.6	1.6	0.2	183
Lupin	1.1	1.5	0.8	221
Canola	1.3	1.3	0.8	386

It is likely that wattle seed would have to conform to a similar pattern if it were to become a large industry. Most of its production would have to be exported and its price would reflect its competitive position relative to other commodity crops. Features that give wattle seed an advantage in small markets (novelty, unique flavour, and special dietary features) would be of little or no value in commodity grain markets, where uniformity, cost, nutritional content and performance in food processing are more important criteria.

The task of marketing large tonnages of wattle seed would be challenging. If *Acacia* seed crops provided only a modest percentage of the total area of perennial plants needed to control salinity (say 10%, or 2 million hectares), then the annual production of seed would be about 2.5 million tonnes, based on an estimated production rate of 1.25 tonnes per hectare (Maslin *et al.* 1998). A harvest tonnage of this size would make the wattle seed industry larger than Australia's canola industry, half the size of the

barley industry and about one eighth the size of the wheat industry.

The development of a wattle seed industry on this scale (or larger) would be a major undertaking and would be achievable only if wattle seed could overcome a number of commercial hurdles, including:

- acceptance into large-scale markets for food ingredients, both domestic and export
- better quality or lower price than competing products
- an attractive return to growers.

Reducing the cost of production

The remainder of this paper deals with one of the commercial hurdles listed above – the need to reduce the cost of production of wattle seed.

Production costs for existing large-scale, broad-acre Australian crops provide useful guidance. These crops are grown over large areas, benefit from economies of scale, and are produced by low-cost methods that include direct seeding, continuous harvesting by wide, high-speed, light-weight machinery, and bulk handling of harvested seed. Using wheat production in Western Australia as an example, the cost of production using these methods is about $130 per hectare to grow the crop, and a further $30 per hectare to harvest it, based on contract prices plus materials, but excluding overheads and GST (drawn from a variety of unpublished sources). Therefore, for a crop yield of 1.7 tonnes per hectare (the average wheat yield for Western Australia from 1996 to 2000; ABARE 2001), the on-farm cash cost to produce each tonne of wheat is about $75 for growing and $20 for harvesting.

If wattle seed were to be grown and sold in large quantities it would have to be competitive with other large-scale commodity crops, and be produced in similarly low-cost farming systems. Some elements of low-cost production are easily achievable. For example, direct seeding acacias should be relatively straightforward. For most species of interest, the seeds are large enough to be handled efficiently by conventional seeding equipment, and the seeds germinate easily and reliably after pre-treatment. Similarly, bulk handling of wattle seeds should be possible using the grain industries' existing infrastructure, with little or no modification.

Harvesting is more problematic. None of the harvesting methods assessed by Simpson and Chudleigh (2001) for use on rows of tall shrubby acacias is likely to match the harvesting cost of headers used in cereal cropping, regardless of how much development effort is applied, because of the difference in their fundamental principles of operation. Therefore, further refinement of existing horticultural approaches to wattle seed production are unlikely to lead to the development of a farming system that can produce millions of tonnes of wattle seed at prices competitive with those of other commodity crops.

To lower the cost of wattle seed production to a competitive level is likely to require the development of a new, efficient production system. Three integrated elements of efficient systems are:

- crop layout
- harvesting method
- species selection.

Each of these elements is dependent on the choices made for the others. They are discussed briefly below.

Crop layout

Conventional long-term plantations are unsuited to perennial crops in medium- to low-rainfall agricultural areas because of the likelihood of reduced productivity due to competition for water, and the risk of death from drought. Instead, dispersed layouts have been proposed for new perennial crops in this rainfall zone. They include:

- alley farming, with one or more rows of trees in long belts, separated by wide alleys of annual crops or pastures (Stirzaker and Lefroy 1997);
- phase farming, in which a whole paddock is planted with a crop of close-spaced perennial plants (Harper *et al.* 2000). The perennial plants are removed after a number of years and replaced with a phase of annual crops and pastures. The duration of the perennial phase would depend on many factors, including the product(s) being produced, plant growth rate, water use, management requirements, plant longevity, site factors such as annual rainfall and soil water storage, and economic factors such as optimisation of crop returns within the perennial phase, and optimisation of the profitability of the entire farming system.

Both of these layout types could be used for low-cost wattle seed production, but with some provisos. In both cases, the species used would have to be short-statured to allow the crop to be straddled by a harvester and be suited to growing at high density. For alley farming, the *Acacia* belts would have to be at least one harvester width wide, to enable the harvester to collect a high tonnage of seed per operating hour. If wider than a single harvester width, belt width should be a multiple of harvester width to maximise harvesting efficiency.

Harvesting method

To maximise the rate of collection of seed from low yielding crops (1.25 tonnes per hectare), a wattle seed harvester would be likely to have many design principles in common with modern cereal crop headers, including high ground speed and manoeuvrability, and a wide front. It is likely that the machine would:

- straddle the crop, to minimise the required ground speed while maximising the number of plants that could be harvested simultaneously,

- move continuously, to maximise the amount of seed collected per operating hour, and
- remove only pods and seed, to minimise the machine's weight, harvesting effort required, and the amount of superfluous material harvested.

Species selection

The harvesting principles described above would require a very different plant architecture from the types of acacias currently considered suitable for edible seed production. From a harvesting perspective, features that would enhance the suitability of an *Acacia* species for large-scale, low-cost wattle seed production include:

- uniform height and shape
- short, erect stature
- pods located at or near the top of the plant
- large seeds
- high seed production per hectare (not necessarily per plant)
- uniform ripening
- inhibited pod shattering
- high ratio of seed production to vegetative growth

In addition, there are many other criteria for selecting new crop species that are unrelated to harvesting. They include onset of seeding at a young age (essential for phase farming), resistance to pests and diseases, tolerance of environmental stress, suitable root architecture to maximise exploitation of soil water, desirable nutritional and food processing characteristics, plus many factors related to management in a farming system, including palatability to stock, toxicity to stock, weed risk, nitrogen fixing ability, and tolerance of herbicides and insecticides.

Combined biomass and seed crops

The possibility of developing new *Acacia* crops that produce both edible seed and biomass for industrial uses appears attractive. However, the requirements for harvesting biomass and those for harvesting seed are very different, and it would be difficult to design a harvester that performed both tasks efficiently (Richard Giles, pers. comm.). In addition, the feedstock requirements of most biomass industries would demand year-round harvesting, not just at seeding time. A more likely scenario is that some *Acacia* species may be developed as large-scale crops for industrial uses. If these species also produced edible seeds, then some seed would be collected opportunistically by dedicated biomass harvesting machines during harvesting operations at seeding time, and could be separated and sold as a by-product of biomass harvesting.

Suggested way forward

The preceding discussion leads to the conclusion that the development path to be followed for an edible wattle seed industry depends on the target size for the industry. If it is to grow from its present niche status into an industry supplying small or medium-sized markets at prices in excess of $500 per tonne, then a suitable approach may be to refine existing growing and harvesting techniques, and select and breed new cultivars from within the species already identified as having potential for edible seed production.

However, if a more ambitious goal is set–to develop a large wattle seed industry that is competitive in global commodity markets–then a different development pathway is needed, in order to achieve the low cost of production that is essential for success in those markets.

Critical steps in developing a large wattle seed industry would be to:

- search the *Acacia* flora of Australia for species that have desirable characteristics for large-scale, low-cost cropping systems,
- explore their potential for improvement by careful selection and breeding,
- integrate species selection, farming system development, and harvester development, to optimise all three simultaneously.

The great diversity within the *Acacia* genus (and within many of its species) offers hope that this development pathway could succeed. However, an exploration of the *Acacia* flora is only the first step. New crop development requires substantial investment of time, money and expertise to produce a pool of genetic material with desirable characteristics.

Before such a plant breeding program is started, an understanding is needed of genetic diversity within the target species. There are likely to be differences in genetic variation between species. For example, Moran *et al.* (1992, cited in Ahmed and Johnson 2000) found distinct genetic variation in *Acacia holosericea* (three isozyme races) with corresponding differences in morphology and growth, but no variation between 15 populations of *A. cowleana*.

Plant breeding work on Australian native crop plants such as *Acacia* is insignificant in comparison with a crop such as wheat (Ahmed and Johnson 2000). All major agricultural crops have undergone unconscious selection, leading to their domestication, long periods of informal development since first domesticated (Diamond 1998), and formal plant breeding in more recent times, to produce crops that are easy and reliable to establish and grow, easy to harvest, have high yields, and produce high quality uniform products. The domestication of wild *Acacia* species would require many of the same steps, but could take advantage of modern techniques for genetic investigation and plant breeding to hasten the process. Perhaps as little as a decade would be needed to transform a representative of one of Australia's best known genera into a potential new food crop of global significance.

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