

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

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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 <i>Acacia</i> 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 Phillimore¹, 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. whibleyana* 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 *Acacia* are not currently known to be susceptible to *P. cinnamomi* (Brian Shearer², 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 Keighery³, 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).

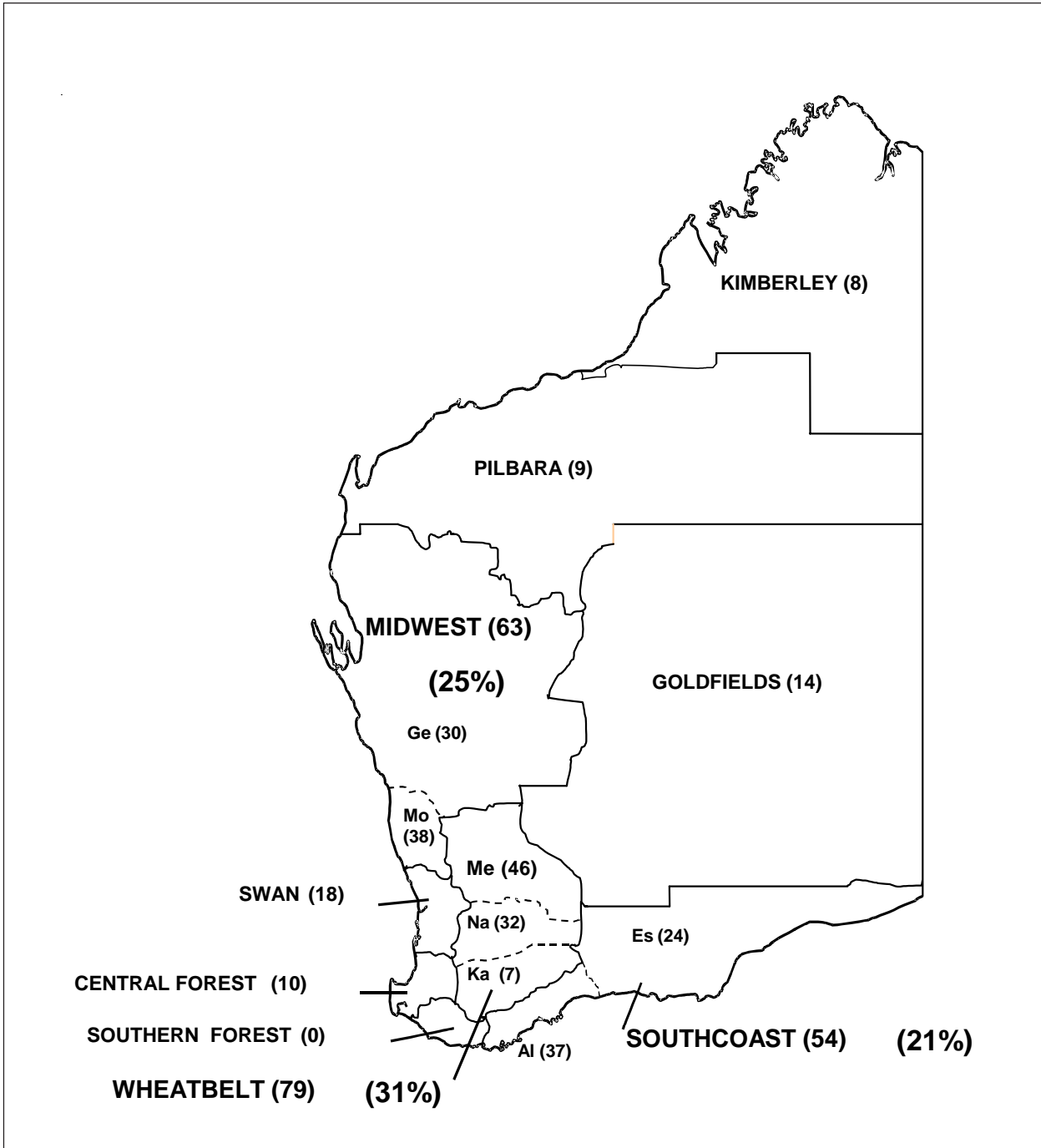


Figure 1. Western Australia showing regions administered by the Department of Conservation and Land Management. The numbers of Rare and Threatened Acacia taxa are identified in these regions of the Kimberley, the Pilbara, the Goldfields, the Midwest, the Wheatbelt and the Southcoast. The regions of the 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 <i>Acacia</i> 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
<i>Acacia</i> plants	29.1	5.4	25.3	2.1	22.2	10.3	0.9	0.3
<i>Acacia</i> 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 verrucula*, 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. verrucula*. *Acacia lobulata* and *A. verrucula* 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. verrucula* 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. verrucula*. 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. verrucula*. 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. verrucula*. Both species were killed by a hot

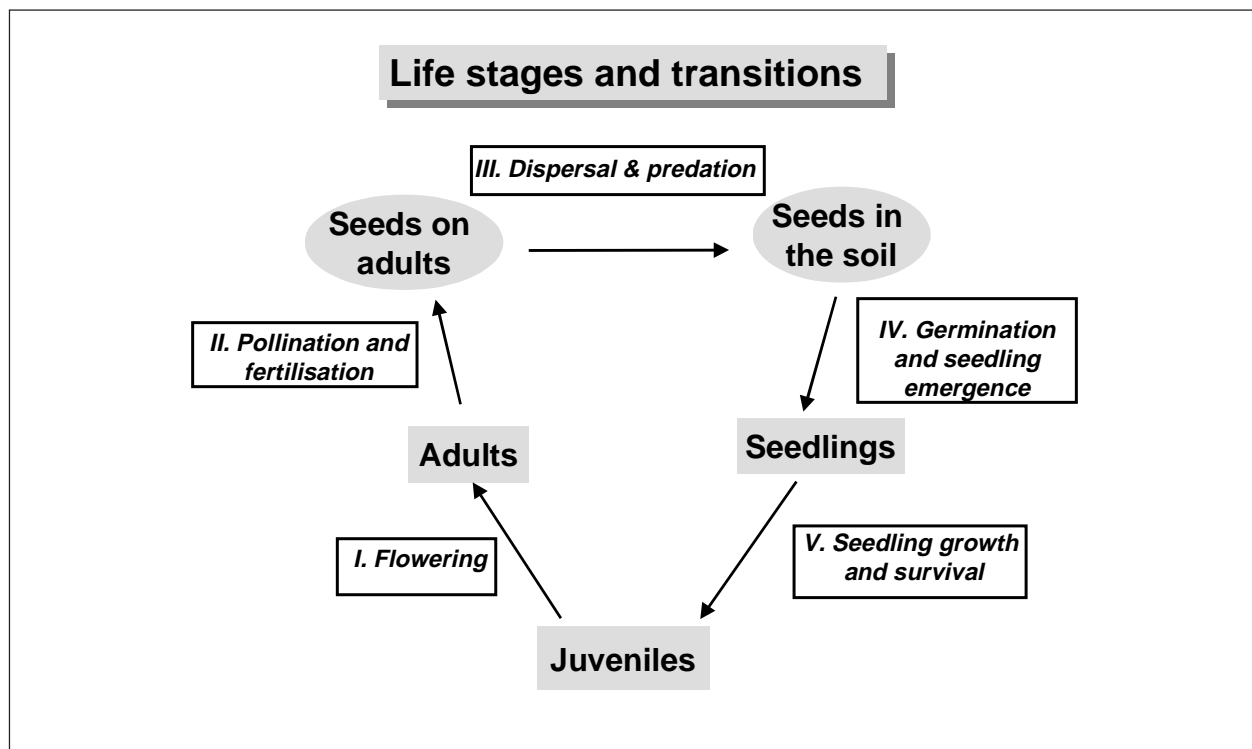


Figure 2. Life stages and transitions of plants

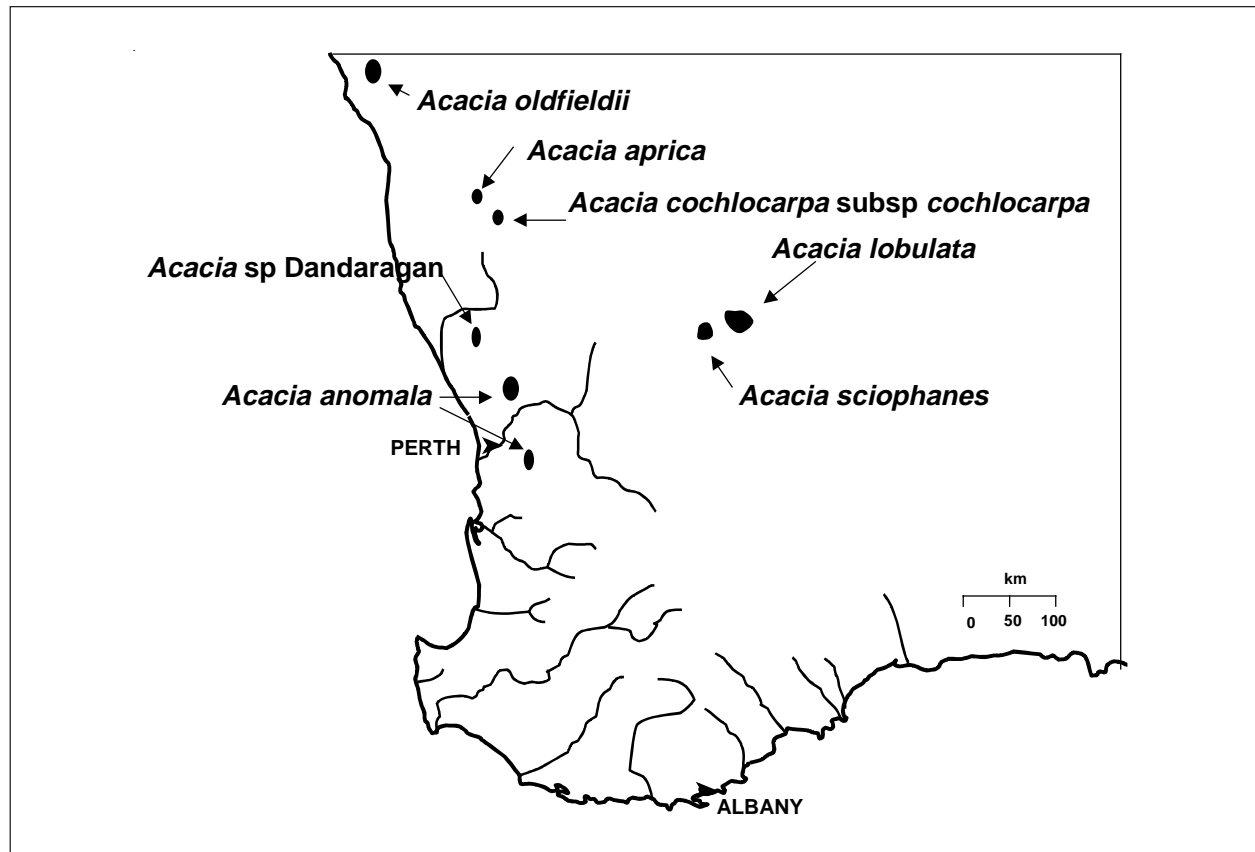


Figure 3. The south-west of Western Australian showing the distribution of Rare and Threatened *Acacia* taxa, referred to in the text.

summer wildfire and similar rates of seedling recruitment were measured, but the common *A. verrucula* 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. verrucula*, 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. verrucula* 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. verrucula* 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. verrucula* 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 bottlenecks than *A. verrucula*. Of particular importance in this respect may be the influence of fire in a variable Mediterranean climate. Both *A. lobulata* and *A. verrucula* 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

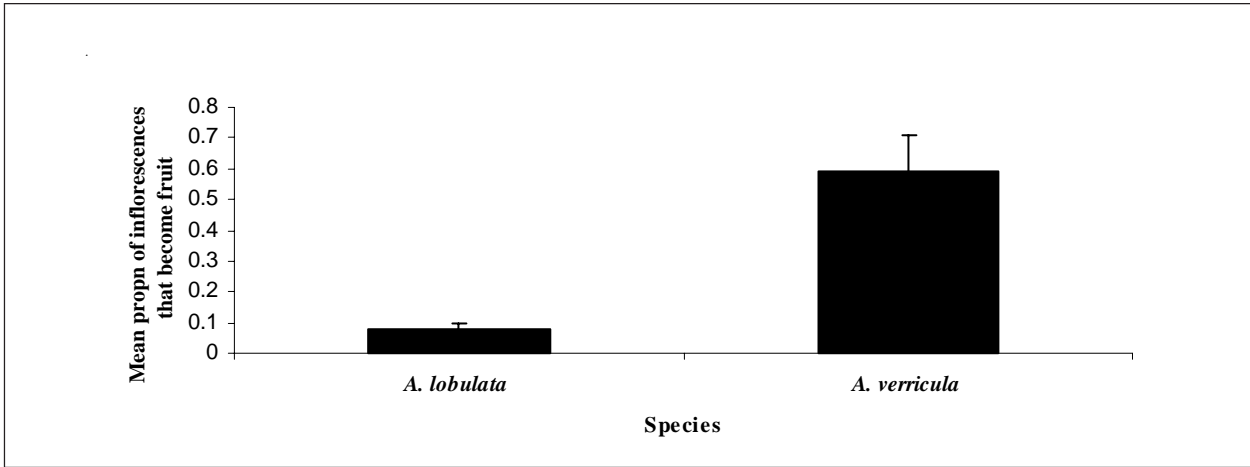


Figure 4a. Mean proportion of *A. lobulata* and *A. verrucula* inflorescences that develop into fruit (from two years' data).

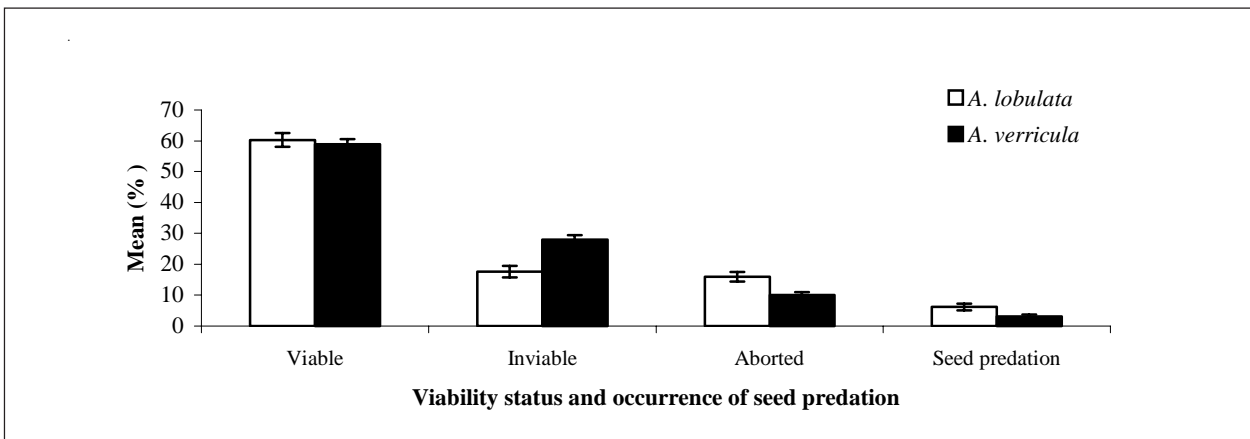


Figure 4b. Mean percentage of *A. lobulata* and *A. verrucula* seeds that are viable, inviable, or aborted and have been affected by predation (from one year's data).

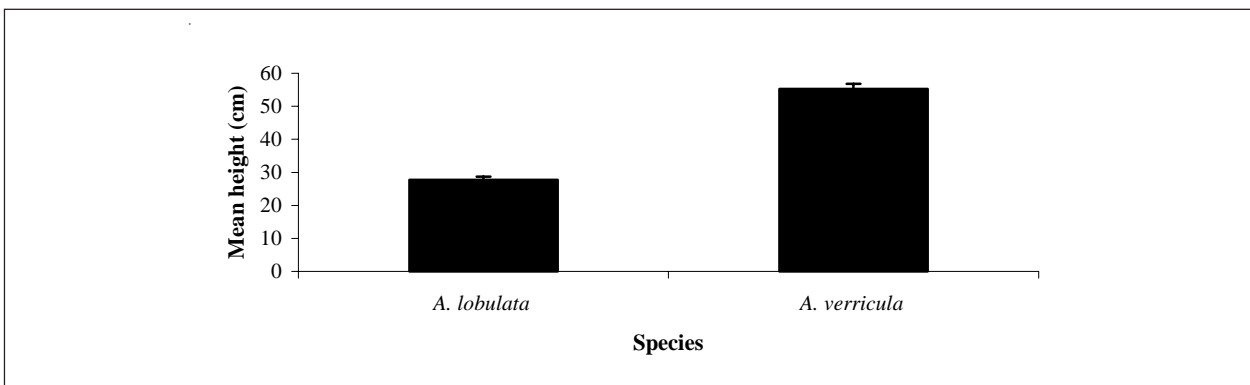


Figure 4c. Mean height of burn-recruited seedlings of *A. lobulata* and *A. verrucula*, two years after fire. Of 279 *A. verrucula* seedlings sampled, 9 were reproductive (3%). No *A. lobulata* seedlings were reproductive.

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

In conclusion, phylogenetic and ecological studies of the rare *A. lobulata* and common *A. verrucula* 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. verrucula*, 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 Wundwinlin *A. sciophanes* population ($t_m = 0.61$) was significantly lower than outcrossing rates for two *A. anfractuosa* populations ($t_m = 0.86, 0.85$) and that the correlated paternity (probability that siblings shared the same father) in the *A. sciophanes* population ($r_p = 0.61$) was higher than in either of the two *A. anfractuosa* populations ($r_p = 0.44, 0.36$). 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).

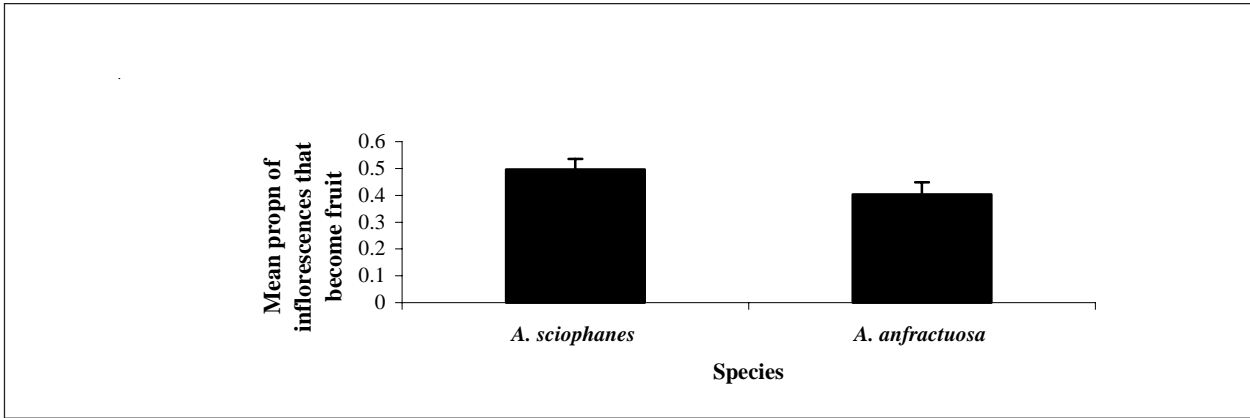


Figure 5a. Mean proportion of *A. sciophanes* and *A. anfractuosa* inflorescences that develop into fruit (from two years' data).

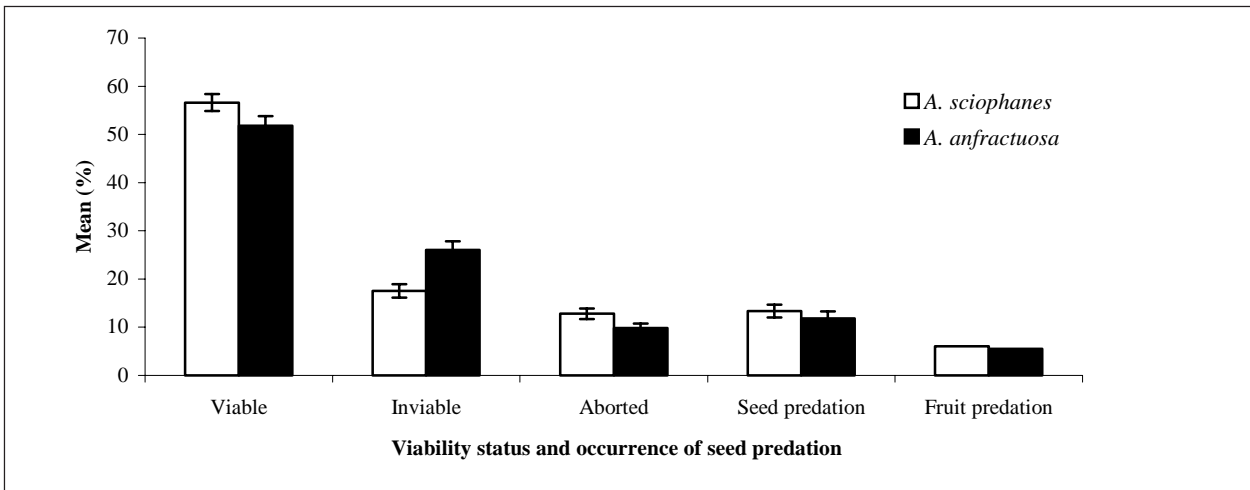


Figure 5b. Mean percentage of *A. sciophanes* and *A. anfractuosa* seeds that are viable, inviable, or aborted and have been affected by predation (from one year's data).

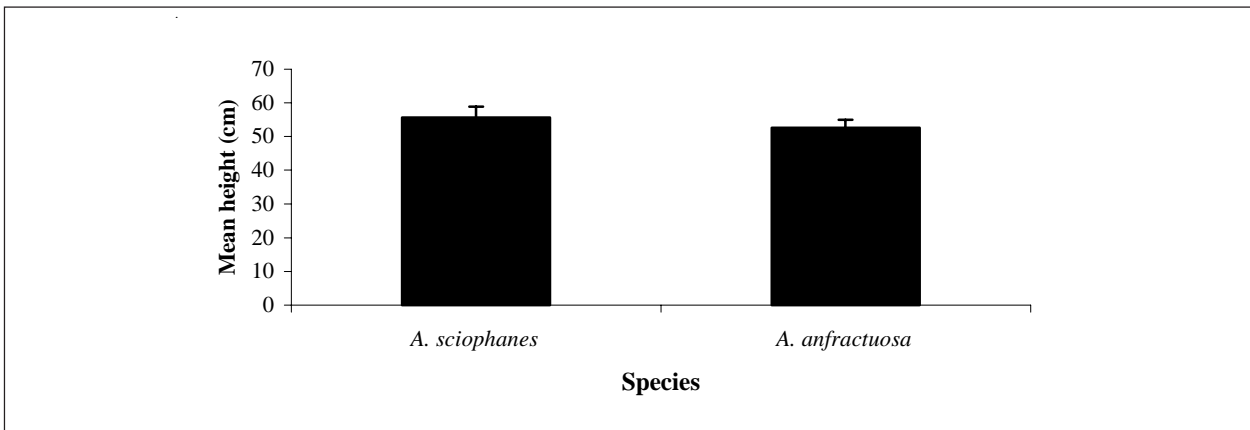


Figure 5c. Mean height of one-year-old, *A. sciophanes* and *A. anfractuosa* seedlings transplanted into the burnt habitat of *A. anfractuosa*.

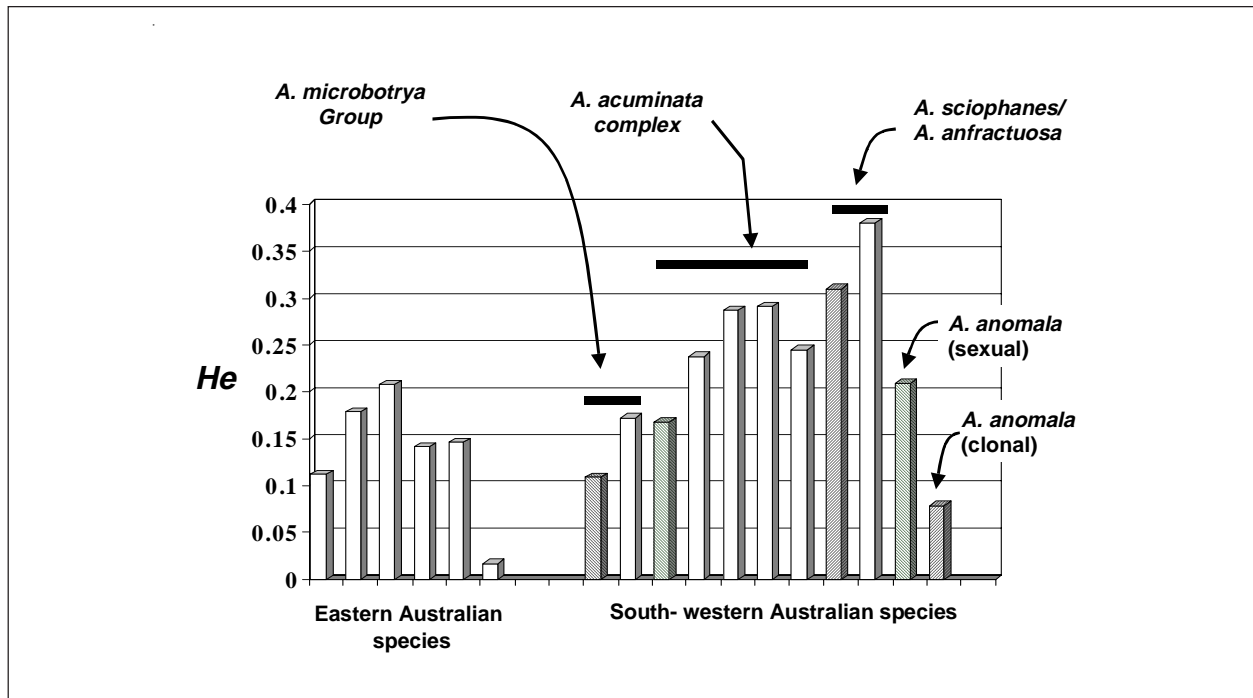


Figure 6. Population based estimates of genetic diversity (H_e) in eastern Australian and south-western Australian Acacia species. The eastern Australian species are from left to right *A. aulacocarpa* (McGranahan et al. 1997), *A. mearnsii* (Searle et al. 2000), *A. melanoxyton* (Playford et al. 1993), *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. anomala* (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 ($N_e = c. 25\ 000$). 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 many 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 *Acacia* 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 *Acacia* 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
<i>A. lobulata</i>	Geographically rare and locally abundant (+ one roadside pop.), narrow habitat preference, ancient evolutionary lineage.	Changed fire regimes (as for <i>A. aprica</i> and <i>A. cochlocarpa</i> ssp. <i>cochlocarpa</i> for roadside population).	Reproductive output?; fire response, post-fire growth and reproductivity; available habitat?; age of taxon
<i>A. sciophanes</i>	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.
<i>A. sp.</i> '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.
<i>A. anomala</i>	Geographically rare and locally abundant, narrow habitat preference ancient evolutionary lineage.		Age of taxon; reproductive attributes.
<i>A. aprica</i> and <i>A. cochlocarpa</i> subsp. <i>cochlocarpa</i>	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 *Acacia* 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 *Acacia* 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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