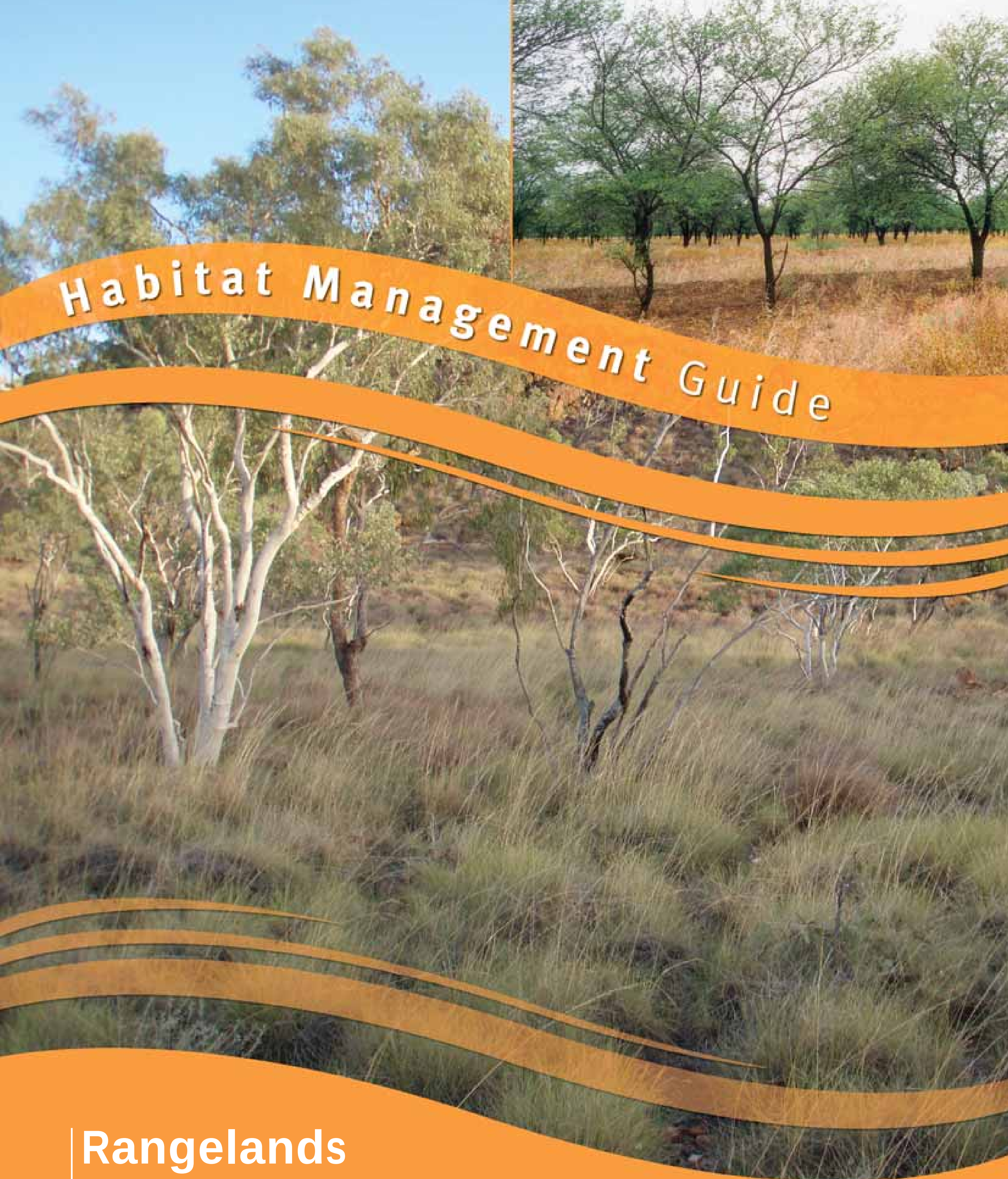
Habitat Management Guide



Rangelands

Ecological principles for the strategic management of weeds in rangeland habitats

CRC Weed management

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Front cover main: Spinifex grassland in north west Queensland.
Front cover inset: Infestation of prickly acacia on Mitchell grass plain in north west Queensland.
Photos: Main: E Vanderduys; Inset: S Campbell, QDPIF

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Contents

Summary

Rangelands occupy about 70 % of the Australian continent. They are diverse, consisting principally of woodlands, shrublands, grasslands and savannas that are used for a variety of purposes. Climate, grazing and fire are major ecological factors. The rangelands as a whole and individual management units have multiple values. While they are essentially occupied by natural or semi-natural vegetation, many non-native species have been introduced to the Australian rangelands. Some of these species are now universally recognised as weeds; others are weeds from particular perspectives. Weed management in rangelands is constrained by the relatively low productivity of rangeland systems and the low density of the human population. These features limit the human and financial resources available for weed detection and management. They, and the large number of weed species involved, highlight the need for habitat-level, rather than just species-level approaches, to weed management. This publication explains the nature of weed invasions in rangelands and how they might be strategically and efficiently managed. Overall, there is a need to minimise the risk that new weeds will be introduced to the rangelands; reduce the probability that weeds already present will spread to other parts of the rangelands; and maximise the capacity of rangelands to resist the proliferation of weeds where they are present.



Rangelands are diverse ecosystems, as evidenced here, from left to right: Saltbush shrubland in far western New South Wales; tropical eucalypt woodland with grassy understorey, north east Queensland; and spinifex grassland in north west Queensland.
Photos: T Grice; J Kemp; and E Vanderduys

Introduction

Australian rangelands are diverse and iconic. They have been subject to over 150 years of European settlement and during most of that period weeds have been an issue of considerable importance to land managers. Large numbers of introduced and native species are amongst those considered problematic.

Between 2001 and 2008, Program 3 (Landscape management) of the Cooperative Research Centre for Australian Weed Management (Weeds CRC) carried out considerable research on weed issues of rangelands. Some of this effort focussed on individual species but substantial emphasis was also directed at the habitat-level. Many managers and researchers recognise that a habitat-level understanding of the issues is important and this approach may provide more efficient ways of dealing with the large number of weed species present in rangelands. Management strategies directed at weeds of rangeland habitats as a whole should augment rather than replace approaches that target particular species. The aims of such strategies would be to help minimise the emergence of new weed species in the rangelands, make those environments more resistant to weed invasions and effectively tackle multiple co-occurring species.

Purpose of this document

This publication takes a habitat-level approach to weeds in rangelands. It aims to provide an understanding of the ecological and anthropogenic forces driving weed invasions in Australian rangelands, and a set of principles for countering those invasions and their impacts. It does not provide detailed information on individual species or ‘operational’ recommendations about how to manage them. Species-level information for many rangeland weeds is available in a series of Weed Management Guides produced by the Weeds CRC.

The habitat-level information, analysis and principles provided here are intended for use by those developing and applying weed management strategies at landscape, catchment and regional scales. This understanding and the principles derived from it are intended to complement approaches that attempt to deal with individual species. Both species-based and habitat-based strategies are important. Although this document is intended mainly for use by developers and managers of such strategies at catchment and regional scales, it should also be of value to operational staff. It describes key aspects of the ecological, economic and social context within which plant invasions of rangelands take place and the ecological processes that are involved. Regardless of whether individual species or rangeland habitats as a whole are being targeted, weed management strategies must consider both context and processes. For those operating more toward the operational end of the activity spectrum, an awareness of the ecological, economic and social context of plant invasions and of the ecological processes involved should encourage more effective feedback to those functioning at the strategic level.

Finally, this document proposes broad principals applicable to the strategic management of weeds of rangeland habitats. These principles are intended to provide a foundation for the eradication, containment and control of weeds. Importantly, they may be applied at various scales from the small property through to the landscape, catchment or region. The term eradication is used in this document to describe the complete removal of all plants of a species, including seeds and other propagules, from a defined area where there is a low probability of reinfestation from outside. Eradication is rarely a practical option at broad spatial scales. This means that most of the weed species currently present will be components of Australian rangeland landscapes indefinitely. The strategic implication of this is that containment and control are the most viable, broad objectives of weed management strategies.

The principles that are proposed are mostly aimed at reducing the impacts of weeds in rangelands by:

- minimising the risk that new weeds will be introduced to the rangelands or Australia as a whole
- reducing the probability that weeds already present will spread to other parts of the rangelands
- maximising the capacity of rangelands to resist the proliferation of weeds even where they are present.

Many of the principles proposed can be applied more generally to non-rangeland habitats.

Glossary of terms

Biological control	The deliberate science-based introduction of a parasitic or herbivorous insect or disease to control a selected (weedy) plant
Containment	The prevention of spread of an invasive species outside a designated area
Control	Reduction of the abundance or impact of an invasive species without necessarily altering its distribution
Delimit	To find the spatial extent
Dispersal	The process whereby seeds or other viable plant parts are moved away from the parent plant
Ecosystem services	Renewable resources such as clean air and water supplies that humans derive from intact ecosystems
Edaphic	Relating to the soil
Eradication	The complete removal of all individuals (including seeds) of an invasive species from a designated area
Fire regime	The frequency, intensity and season of burning over an extended time period
Frugivore	A fruit-eating animal, including many birds, bats and other mammals
Monoculture	Complete dominance of a plant community by one species
Naturalised	Introduced plants that have established self-perpetuating populations in their introduced range
Phylogeny	The evolutionary origin and development of taxonomic groups
Plant functional type	Plant species that perform similar ecosystem functions and share one or more biological characteristics
Potential range	The estimated maximum range that a species could occupy in the absence of effective containment strategies
Prescribed burn	A deliberately lit and managed fire to achieve a particular management objective
Propagule	A seed or other independently viable plant part that could be moved away from its parent plant; a unit of dispersal
Rangelands	Natural or semi-natural plant and animal communities subject to extensive land-uses
Recruitment	Process of establishment of new individuals of a plant species
Refugia	An area that has escaped ecological changes occurring elsewhere and so provides a suitable habitat refuge for plant or animal species
Riparian zone / area	Zones / areas whose characteristics are influenced by their proximity to a river, creek or stream
Sleeper weed	A plant species perceived to have unrealised weed potential
Succession	The process whereby the plant and animal community of an area recovers from disturbance, usually defined as including transitions between very different plant community types
Transformer species	An invasive species that radically alters the composition, structure and / or composition of a native community

1. Rangelands of Australia

Definition and description of the rangeland environment

Rangelands have been very broadly defined. For example, Holechek et al (1989) stated that, "All areas of the world that are not barren deserts, farmed, or covered by solid rock, ice or concrete can be classified as rangelands". Traditionally, rangelands have been closely identified with extensive pastoralism and have been delineated by the types of vegetation that they support and the climates that this vegetation requires. In these terms, rangelands include grasslands, shrublands, woodlands, savannas and at least some types of forests. The roles of herbivores, particularly ungulate herbivores, in the formation and maintenance of rangelands, have been seen as critically important. Much of rangeland science has reflected an ecological emphasis on the function of rangelands as a habitat for herbivores and an economic emphasis on the importance of pastoralism in the rangelands.

In Australia, rangelands occupy around 6 million km^2 or about 70 % of the continent (Foran et al 1990) and occur in all Australian states except Tasmania (Figure 1). Most Australian rangeland areas have low and / or unreliable rainfall and it is climate that most often distinguishes rangelands from non-rangelands in Australia (Young et al 1984). However, there are significant areas of relatively mesic, upland rangelands in the eastern part of the continent.

Figure 1. The distribution of rangelands in Australia.
Credit: Bastin et al 2008

In spite of the emphases on herbivory as a key process and pastoralism as a foundation of human interest in the rangelands, it is also recognised that rangelands are usually multiple-use systems and that many areas of rangelands are not used for pastoralism (Holechek et al 1989). The multiple-use nature of rangelands means that there can be contrasting or conflicting views on what constitutes a weed and whether a particular species is regarded as a weed. This concept of weediness relates more to socio-economic characteristics than it does to biophysical ones. That is, regarding a particular plant species in a rangeland environment as a weed depends on the perspective of the users or other stakeholders in that rangeland.

Diversity and structure of rangeland vegetation

Australian rangelands encompass many vegetation types, vary widely in structure and function and span a broad climatic spectrum. Typically, average annual rainfalls of Australian rangelands vary from 200 mm to 500 mm though those of far northern rangelands, such as those of Cape York Peninsula, may be considerably higher (600 mm to 1200 mm pa). Rainfall tends to be increasingly summer-dominated towards the north of the continent. Soils also vary greatly from sands to loams and heavy cracking clays though typically Australian rangeland soils are relatively low in nutrients, particularly nitrogen and phosphorus. Combinations of climatic and edaphic factors govern the distribution of the main rangeland types in Australia. The distribution and abundance of established weeds of Australian rangelands also reflect the influences of climate and soils, and different rangeland types support characteristic weed species.

Australian rangeland plant communities support at least several thousand native plant species of many different growth forms. In many rangeland types, trees contribute an upperstorey to create savanna or woodland vegetation, but two major rangeland types, the chenopod shrublands and Mitchell grasslands support very few trees. Perennial grasses are prominent in the understoreys of most Australian rangelands and annual grasses and forbs proliferate after suitable rains. These different life-forms exploit the resources that are available at different depths in the soil profile and at various stages in wetting-drying cycles that may be regular or irregular (Westoby 1979 / 1980).

Native everlasting daisies (*Minuria leptophylla*) near Amata, on the Anangu Pitjantjatjara Lands, north west South Australia.
Photo: S Roper

Harrington et al (1984a) defined nine major types of rangelands in Australia, delineating them mainly on the basis of vegetation structure and composition though each type tends to occur within a particular climatic zone.

These nine major types of rangelands are as follows:

1. semi-arid woodlands

The arid and semi-arid woodlands are spread across a large portion of the south-eastern rangelands in a 150 mm to 500 mm mean annual rainfall zone. The upperstorey of the vegetation is usually dominated by either *Eucalyptus* spp. (eg bimble box (*E. populnea*), mulga (*Acacia aneura*) or a combination of belah (*Casuarina cristata*) and rosewood (bullock bush) (*Alectryon oleifolium)*. There is usually a sparse-dense shrub layer and perennial grasses dominate the ground stratum (Harrington et al 1984b). Proliferation of 'native woody weeds' has long been an issue in this rangeland type.

2. saltbush and bluebush

Saltbush and bluebush rangelands, otherwise known as chenopod shrublands, are largely restricted to semi-arid parts of southern Australia in the 'winter rainfall' zone where the mean annual rainfall is in the range 125 mm to 400 mm. The vegetation is most commonly dominated by low shrubs (<2 m high) of the genera *Atriplex* and *Maireana*. After rain, annual grasses and forbs grow in the spaces between the shrubs (Graetz and Wilson 1984).

3. mallee

This is another rangeland type of southern Australia in the 200 mm to 500 mm average annual rainfall zone, typically on sandy and often calcareous soil. It is characterised by the dominant multi-stemmed *Eucalyptus* spp. Understoreys vary; they may consist of short-lived grasses and forbs, chenopod shrubs or perennial grasses including spinifex (*Triodia* spp.) (Noble 1984).

4. Mitchell grasslands

The virtually treeless Mitchell grasslands occur on alkaline cracking clay soils and are spread across northern Australia in a 250 mm to 500 mm average annual rainfall zone. The vegetation is dominated by perennial tussock grasses, notably of the genus *Astrebla* spp. Annual grasses and forbs are abundant after the rain (Orr and Holmes 1984). The small tree prickly acacia (*Acacia nilotica*), which was introduced to this rangeland type for shade and cattle fodder, is a major weed of Mitchell grasslands and other ecosystems.

5. tropical and subtropical woodlands

These stretch in an arc from south-eastern Queensland to the north of Western Australia in a zone of relatively high rainfall (500 mm to 700 mm average annual rainfall). The summer wet season becomes increasingly distinct as one moves north. The vegetation is a woodland dominated by *Eucalyptus* spp. and other trees with an understorey of perennial grasses (genera include *Themeda*, *Sarga* (=*Sorghum*), *Sehima*, *Chrysopogon* and *Heteropogon*) (Mott and Tothill 1984). Important weed species prevalent in these systems include parthenium (*Parthenium hysterophorus*), giant rats tail grass (*Sporobolus pyramidalis*), bellyache bush (*Jatropha gossypifolia*) and rubber vine (*Cryptostegia grandiflora*).

6. hummock (spinifex) grasslands

Very large areas of arid and semi-arid rangelands, principally in Western Australia, the Northern Territory and South Australia, are occupied by hummock grasslands, which are characterised by the grass genera *Triodia* and *Plechtrachne*. Trees and shrubs tend to be sparse. These communities occur on dunes and sand plains of low nutrient soils under average annual rainfalls of 125 mm to 500 mm (Griffin 1984). The widespread and abundant introduced perennial pasture grass buffel grass (*Cenchrus ciliaris*) has invaded parts of this rangeland type.

7. arid mulga woodlands

While mulga (*A. aneura*) communities also occur elsewhere, Morrisey (1984) describes arid mulga woodlands as a distinct rangeland type found in parts of Western Australia that receive a balance of winter and summer rains. Average annual rainfall in this zone is 200 mm to 275 mm. The understorey is varied but can include a mixture of annual and perennial grasses, forbs and chenopod species. Some areas support spinifex grasses (*Triodia* and *Plechtrachne*) (Morrisey 1984).

An increase of native shrubs has been identified as an issue in this rangeland type.

8. central arid woodlands

The central arid woodlands grow in areas with an average annual rainfall of 155 mm to 360 mm. Many of the soils on which this rangeland type is found are deficient in nitrogen and phosphorus. Vegetation is generally open with the upperstorey dominated by *Eucalyptus* spp., *Acacia* spp. or other trees. There is usually a shrubby midstorey and a ground layer of perennial and annual grasses and forbs (Foran 1984).

9. temperate rangelands

Temperate rangelands are found on the tablelands and slopes of New South Wales in a relatively high rainfall zone (average annual rainfall approximately 650 mm). The native vegetation is mainly grassy woodlands though clearing has been extensive (Lodge et al 1984). The original perennial grass understorey has also been highly modified with many introduced grasses. The invasive Chilean needle grass (*Nassella neesiana*) is a significant emerging weed in these systems.

Land-use and values

Australian rangelands are used by people for a wide variety of purposes. They provide important pastoral resources, lands for Aboriginal people, wildlife habitat, hunting and conservation reserves, catchments for water supplies, timber, minerals and space for recreational pursuits. ACRIS (Australian Collaborative Rangelands Information System) (Bastin et al 2008) delineates Australian rangelands along administrative boundaries (rather than in terms of vegetation, climate, function or land-use) to cover 6.7 million square kilometres. Under this definition 59 % of rangelands are identified as pastoral, and 38 % as conservation reserves and other natural environments (Figure 2). Fifteen per cent are allocated to ‘other’ uses which include areas primarily used for ‘managed resource protection’, cropping and urban development, transport and communications. Aboriginal

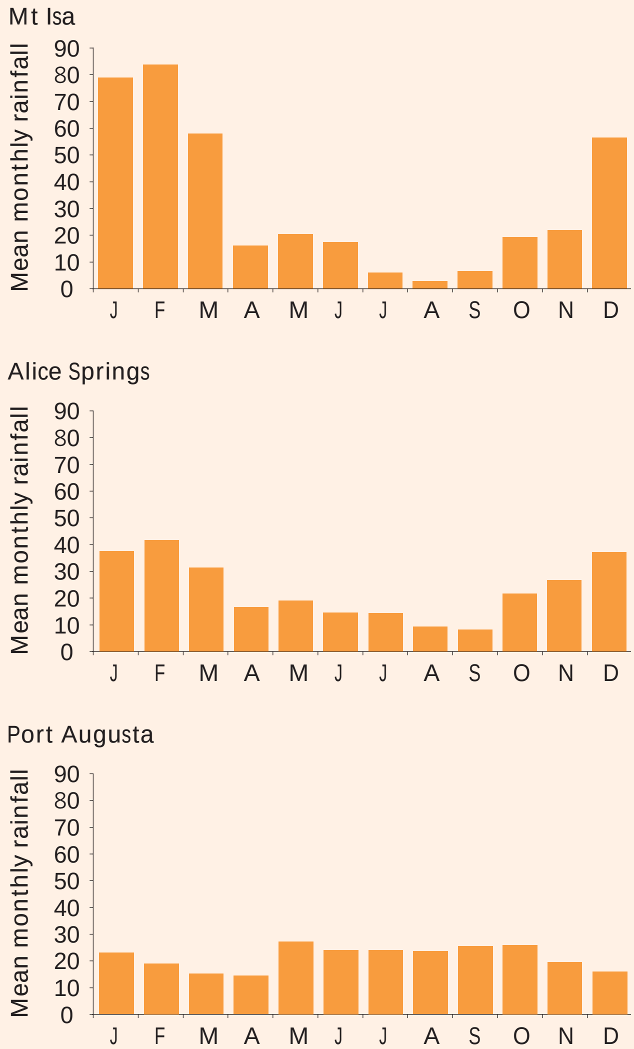
Climatic characteristics of rangelands

Australian rangelands encompass a variety of climates, which can be illustrated by rainfall patterns. Average annual rainfall within rangelands varies from less than 200 mm in parts of South Australia and Western Australia to over 1600 mm in the Top End of the Northern Territory and in northern Cape York Peninsula, Queensland.

There is also a lot of variation between seasons and years:

- rainfall is summer-dominated toward the north of the continent and winter-dominated toward the south
- rainfall in northern Australian rangelands is especially strongly seasonal
- the drier parts of the continent have the highest inter-year variation in rainfall.

All these patterns can be seen in the graphs of average monthly rainfall for Mt Isa (northern rangelands), Alice Springs (central Australia) and Port Augusta (far southern rangelands). Total rainfall, seasonality of rainfall, and inter-year variation in rainfall strongly influence the kinds of weeds that occur and their growth and survival patterns.



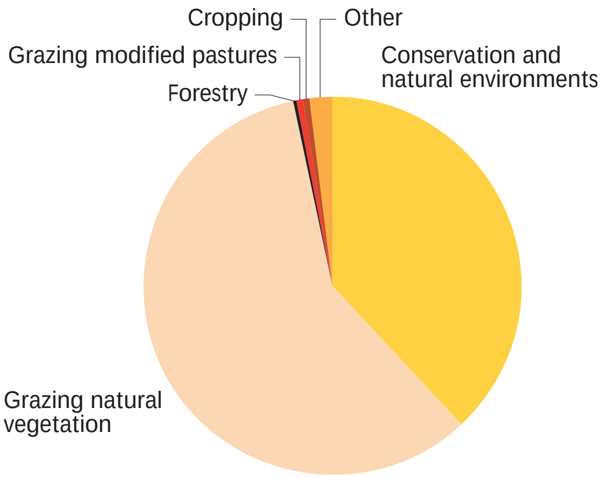


Figure 2: Land-uses of Australian Rangelands (after Bastin et al 2008).

people have some level of responsibility for almost 37 % of Australian rangelands. The ACRIS statistics on uses of rangelands, based as it is on administrative boundaries, incorporates substantial areas that would not be regarded as rangelands defined in terms of land-use. These areas include cropping land (>100,000 km^2) and some estuaries and coastal waters (*ca.* 24,000 km^2).

The allocation of parcels of rangelands to individual uses in this way acknowledges the multiple-use nature of rangelands as a whole. However, rangelands are also multiple-use systems at other scales, including the rangeland type and the individual parcel of land. Very often, a parcel of rangeland will have a primary use but be valued for other reasons as well, by either the primary user or other stakeholders. The multiple-use nature of rangelands at various scales is an important consideration for weed management. Different stakeholders in rangelands as a whole, particular rangeland types, or individual parcels of land, often have different perspectives on whether a particular species of plant is a weed or not and on how any conflicting interests might best be managed (Grice 2006b; 2008).

Pastoralism

Australian rangelands carry about 13 million cattle and 18 million sheep (Australian National Resource Atlas 1999 data: www.anra.gov.au/topics/rangelands/pubs/impact/cattle_sheep.html; accessed 23 September 2008) which is approximately 20 % of Australia's total population of cattle and sheep (Australian Bureau of Statistics: www.yprl.vic.gov.au/cdroms/yearbook2002/; accessed 23 September 2008). Sheep are run mainly in the southern rangelands. Carrying capacities and stocking rates vary greatly with the productivity of the land which is a function of climate and soil type and correlated with vegetation type. Compared with other grazing lands, rangelands are relatively unproductive on a per unit area basis. By definition, rangeland pastoralism depends primarily on natural or semi-natural pastures however pastoral industries have been directly or indirectly responsible for many plant introductions (eg Cook and Dias 2006). Some of these introduced plants have become weeds of rangelands, for either pastoral or other users, whereas others have become very important pasture species (Lonsdale 1994). A significant contention concerns introduced pasture species that are simultaneously valued by pastoral producers and recognised as weeds by other stakeholders, particularly those interested in the conservation of rangeland biodiversity. Another important weed issue for pastoral and sometimes other rangeland users has been the proliferation of native plant species (Noble 1997). Problems associated with this proliferation extend back to the early days of pastoral settlement. This publication focuses most directly on introduced weeds, though at least some of the ecological information and management principles can also be applied to native species, especially those that have spread outside their native ranges, but also to species that are problematic within their native ranges and landscapes.

Conservation

Fifty-three of Australia's 85 Interim Biogeographic Regions (IBRA) include or are constituted entirely of rangelands (www.environment.gov.au/parks/nrs/science/bioregion-framework/ibra/pubs/map9.pdf; accessed 23 September 2008; Martin et al 2006). Australian rangelands support distinctive biotic communities including many endemic plants and animals. In recognition of this around 9 % of the rangelands, as delineated by ACRIS, have been set aside as conservation reserves. Moreover, the environmental and biodiversity values of rangelands that are used primarily for other purposes are also widely recognised. The extent to which the flora, fauna and ecological processes have been impacted by invasive plant species varies considerably between rangeland types and regions.

The central Australian rangelands support a flora that consists of 1758 native plant species, many of which are endemic (Jessop 1981). At least 114 non-native plant species are naturalised in this region constituting 6 % of the flora (Jessop 1981). In the rangelands of western New South Wales 400 non-native species constitute 21 % of the flora of 1917 species (Cunningham et al 1981). It is well established that invasive plant species have deleterious consequences for native plants (Grice 2006a). Resources sequestered by introduced species are, in the short-term at least, unavailable to native plant species. Studies across a wide variety of ecosystems demonstrate that plant species' richness is lower where an invasive species dominates (Grice et al 2004; Scott and Grice 2008).

Rangelands also support a diverse fauna even though species richness of some faunal groups is lower in rangelands than in regions of higher rainfall. Some groups are especially rich in parts of the rangelands (eg mammals in the north of the Northern Territory and reptiles in the hummock grasslands of central Australia (SEAC 1996)). The fauna of the rangelands has been affected by invasive plants though these impacts have not been comprehensively documented. The responses of the fauna of a rangeland community to weeds are likely to be more complex than those of the flora (Grice et al 2004).

Indigenous land-uses

Occupation and control of land by Aboriginal people is a significant feature of Australian rangelands, particularly in Western Australian, the Northern Territory and South Australia. Aboriginal lands include lands returned to traditional owners and lands purchased by or on behalf of indigenous communities. Significant areas of pastoral lease are under the control of Aboriginal communities. These lands are very important for traditional, cultural and societal values as well as for indigenous livelihoods. Whether these Aboriginal lands are used for pastoral or other commercial purposes or not, weeds can significantly impact on them. For example, weeds could deleteriously affect the availability of, or access to, traditional resources (Webber 1996). However, a few introduced species, such as chinee apple (*Ziziphus mauritiana*) have come to have some value as 'bush tucker'.

2. Rangeland weeds and management issues

Significant weeds of rangelands

There are various lists of weeds of rangelands or lists that include important rangeland weeds. Some of these lists bring with them either legislative obligations, funding opportunities or both. Martin et al (2006) listed 622 "non-native naturalised species that are known to occur in [Australian] rangelands". One hundred and sixty of these were considered to be currently threatening rangeland biodiversity. Martin et al (2006) found that regions (Grazing Land Management Zones) vary greatly in the absolute number of weed species that they support and the number of species per unit area. For example the tropical savannas support a large number of species but few species per unit area; the Einasleigh and Desert Uplands and highly modified rangelands support a large number of species in both absolute terms and per unit area; Arnhem Land and Tiwi Islands support few species in absolute terms but a relatively high number of species per unit area.

Weeds of National Significance

In 2000, as a component of Australia's National Weeds Strategy, a list of 71 Weeds of National Significance (WoNS) was compiled. Twenty of these were given priority as warranting long-term, strategically coordinated action at the national level in order to minimise their economic, social and environmental costs. The original list and the prioritised 20 were selected on the basis of their invasiveness, impacts, potential for spread and the socio-economic and environmental consequences of their invasions (Thorp and Lynch 2000). The 20 prioritised species are the ones now recognised as WoNS. Of these 20, 16 either presently occur or have the potential to occur in Australian rangelands. Eight of these are likely to impact on extensive areas of the rangelands if left unchecked (Table 1). Athel pine (*Tamarix aphylla*) is currently problematic only along central Australian river systems. Chilean needle grass occurs in temperate rangelands of north-eastern New South Wales. The other important rangeland weeds are each very widespread.

Table 1. Australia's 20 Weeds of National Significance, grouped according to their relevance to rangelands. Weeds within each category are not ranked.

	Common name	Scientific name
WoNS that are very important in Australian rangelands		
1	Athel pine	*Tamarix aphylla*
2	Chilean needle grass	*Nassella neesiana*
3	Lantana	*Lantana camara*
4	Mesquite	*Prosopis* spp.
5	Parkinsonia	*Parkinsonia aculeata*
6	Parthenium	*Parthenium hysterophorus*
7	Prickly acacia	*Acacia nilotica*
8	Rubber vine	*Cryptostegia grandiflora*
WoNS that occur in rangelands but only in wetlands		
9	Alligator weed	*Alternanthera philoxeroides*
10	Cabomba	*Cabomba caroliniana*
11	Hymenachne	*Hymenachne amplexicaulis*
12	Mimosa	*Mimosa pigra*
13	Pond apple	*Annona glabra*
14	Salvinia	*Salvinia molesta*
WoNS that are of little or no importance to the rangelands		
15	Blackberry	*Rubus fruticosus*
16	Serrated tussock	*Nassella trichotoma*
17	Gorse	*Ulex europaeus*
18	Bitou bush / boneseed	*Chrysanthemoides monilifera* / *C. monilifera* ssp. *monilifera*
19	Willows	*Salix* spp.
20	Bridal creeper	*Asparagus asparagoides*

Sleeper weeds

The term 'sleeper weed' has been coined to describe plants that currently occur in low numbers but have the potential to increase their population size dramatically given the right conditions (Groves 1999). The concept could be applied to a variety of ecological phenomena and its value has been questioned (Grice and Ainsworth 2003; Dwyer 2008). Species may be restricted in abundance or distribution because they are poorly adapted to the local environment; suitable habitat is unavailable; there are limited opportunities to colonise new habitat; population growth rates are intrinsically low (long time to maturity); or because critical mutualists (eg pollinators) are absent. Moreover, some species may be wrongly perceived to be not invasive (Grice and Ainsworth 2003). Nevertheless the 'sleeper weed' concept has been used to identify species that could increase in abundance and range and threaten Australian agricultural industries (Cunningham and Brown 2006).

The Bureau of Rural Sciences has identified 17 sleeper weeds that could have nationally significant impacts on agriculture if allowed to spread. They were selected on the basis that they were thought to occupy less than 100 hectares in total, raising the realistic possibility that they might be contained. If not controlled, a number of them (eg Badhara bush (*Gmelina elliptica*), orange hawkweed (*Hieracium aurantiacum*), panicle jointvetch (*Aeschynomene paniculata*) and snakecotton (*Froelichia floridana*)) could affect Australian rangelands.

National Environmental Alert List

In 2000 the then Commonwealth Department of the Environment and Heritage, in collaboration with the Weeds CRC compiled a list of 28 plant species that are considered to be in the early stages of establishment but have the potential to become a significant threat to biodiversity if they are not managed (Department of the Environment, Water, Heritage and the Arts: www.weeds.gov.au/weeds/lists/alert.html; accessed 25 September 2008). Those of concern to rangeland environments include cutch tree (*Acacia catechu*), Karroo thorn (*Acacia karroo*), barleria (*Barleria prioritis*), kochia (*Bassia scoparia*), Siam weed (*Chromolaena odorata*), Senegal tea plant (*Gymnocoronis spilanthoides*), horsetails (*Equisetum* spp.), leaf cactus (*Pereskia aculeata*), praxelis (*Praxelis clematidea*), cane needle grass (*Nassella hyalina*) and lobed needle grass (*Nassella charruana*). Management guides for each of the 28 alert list species have been produced by the Weeds CRC (www.weedscrc.org.au/publications/weed_man_guides.html; accessed 25 September 2008).

Weed declarations

Pest plants and animals are primarily an issue under state and territory jurisdiction. Each state and territory has enacted legislation that specifies which plant species are most problematic and should become 'declared weeds'. They all recognise several classes of declared weeds, largely based on a weed's current and potential impacts. These classes prescribe the actions required under the legislation to remove or minimise any impacts.

In some cases, there is scope for variation between regions of a state or territory in the class to which a declared species is assigned. Declarations can also be made by local governments.

Life-forms and functional traits

In terms of growth-form, the naturalised plants of the Australian rangelands are almost as diverse as the native flora. The introduced flora of Australian rangelands includes trees, shrubs, vines, succulents, perennial and annual grasses, perennial and annual forbs, and submerged, emergent and floating aquatic plants (Grice and Brown 1996). Of the 94 taxa listed by Martin et al (2006), in their inventory of key weeds that threaten the biodiversity of rangelands, 43 % were shrubs or trees, 26 % perennial grasses, and 10 % perennial forbs. Growth-form and other functional traits help determine the nature and degree of impact that invasive species have on the composition, structure and function of the ecosystems that they invade.

Leguminous species are prominent among the naturalised trees, shrubs and forbs, perhaps because their nitrogen-fixing ability was seen as a desirable attribute for potential forage species for pastoral industries. Leguminous naturalised species include prickly acacia, mesquite (*Prosopis* spp.), parkinsonia (*Parkinsonia aculeata*), mimosa (*Mimosa pigra*) and members of the important genus of tropical forage species *Stylosanthes*.



Weeds on the national Alert List common to rangelands: Karroo thorn, cane needle grass and praxelis.
Photos: P Martin, Weeds CRC; M Imhof, DPI Victoria and C.G. Wilson

Leguminous naturalised species used in the pastoral industry. Left to right: mesquite and mimosa.
Photos: C.G. Wilson

Rubber vine is a serious invader of northern rangeland communities, especially riparian zones.
Photo: C.G. Wilson

Gamba grass can fuel higher intensity fires than native grasses.
Photo: S Lamb

Several vines are serious invaders of rangeland communities, the most prominent being rubber vine which is now widespread in riparian zones and other relatively mesic parts of rangeland landscapes of northern and north-eastern Queensland.

Many species of perennial grass are naturalised in Australian rangelands, most having been deliberately introduced as potential pasture species (Cook and Dias 2006). Some of these have become entrenched as valuable pasture species, the most abundant and widespread, introduced rangeland pasture grass being buffel grass. Many introduced rangeland grasses are perceived to have negative impacts as 'environmental weeds' regardless of whether they also have merit as pasture species. Some 'dryland' perennial grasses produce higher biomass than native perennials and so fuel high-intensity fires that can lead to changes in structure and composition of the vegetation with flow-on effects for native fauna. Species that fall into this category include gamba grass (*Andropogon gayanus*) and perennial mission grass (*Pennisetum polystachion*). Giant rats tail grass was also deliberately introduced as a potential pasture species (Cook and Dias 2006) but it is now widely recognised as a weed of grazing lands and a declared plant in Queensland, the Northern Territory and Western Australia. Another group of invasive grasses that are relevant to the rangelands are the ponded pasture species. Species such as para grass (*Urochloa mutica*) and hymenachne (*Hymenachne amplexicaulis*) are productive pasture species but also environmental weeds. These species are not adapted to the rangelands as a whole but do occur in wetlands and other mesic habitats.

Rangelands as dynamic systems

Rangelands are dynamic systems influenced by many factors, such as climate (including climate change), topography, soil characteristics, grazing and fire regimes, and other disturbance.

Various concepts have been used to help describe and explain spatial patterns and changes over time that occur in rangelands. Under a 'traditional' (climatic climax) view of change in rangelands, grazing disturbs the vegetation away from the climax condition and weeds, which by definition are unproductive, unpalatable or toxic to livestock (Holechek et al 1989), are seen as 'increaser species' that will decline when grazing pressure is reduced (Dyksterhuis 1949). The state-and-transition view of change in rangelands describes transitions that are triggered by natural events or management actions. It incorporates the concept of 'increaser' species in response to grazing, but also allows for other triggers that prompt transitions to plant communities with undesirable (weedy) species (Westoby et al 1989). A third set of concepts proposes a 'trigger-transfer-reserve-pulse framework' that captures something of the 'boom and bust' nature of Australian rangeland ecosystems and prompts discussion of where in a rangeland landscape weeds might colonise and thrive as a result of the timing and distribution of resource availability (Ludwig et al 1997).

Climate is a major driver of rangeland dynamics. At the broadest scale, climate influences the distribution of rangeland types (Harrington et al 1984a). It also governs the coarse scale distribution of weeds (Thorp and Lynch 2000) so that each rangeland is subject to invasion by characteristic weed species (see Diversity and structure of rangeland vegetation). Climate patterns drive the dynamics of weed populations through the processes of growth, reproduction and recruitment.

Climate change has the potential to be a major factor that will influence the distribution and abundance of weeds and the options available for managing them. Temperatures, and the frequency of extreme events such as floods and droughts, are expected to increase (Pearce et al 2007). Rainfall is expected to increase in northern Australia but decrease in southern Australia (McFadyen 2008).

These changes are likely to:

- alter disturbance regimes and expand opportunities for weeds to colonise
- create new habitats for weeds, including species that are not currently a major problem (see Sleeper weeds)
- change the resilience of rangeland ecosystems to weed invasion by increasing the stresses experienced by established plant species (Kriticos et al 2006; McFadyen 2008).

There is likely to be a southward extension of the ranges of tropical weeds; a southward retreat of the ranges of temperate weed species; movement of lowland species to higher altitudes (eg the Atherton Tablelands of north Queensland); and an increase in the ranges of frost sensitive plants such as rubber vine (McFadyen 2008).

Disturbance is any relatively discrete event or occurrence that removes organisms or otherwise disrupts an ecological community and so alters the physical environment or the availability of space or resources (Begon et al 1996). Some forms of disturbance are natural features of all ecosystems, including rangeland ecosystems. Disturbances can vary in cause, type, spatial extent and frequency and inevitably result in changes in the availability of resources for both the flora and fauna. Disturbances can kill or reduce the biomass of individual plants, often affecting species differentially. Furthermore, different plant species exhibit different capacities to respond to disturbances of different types, extents or frequencies. Disturbance has often been portrayed as a prerequisite for plant invasions (Fox 1991). The kinds of disturbance that occur in a rangeland will influence which non-native species do well. Some species may be disadvantaged by particular disturbance regimes.

Grazing can significantly disturb rangeland ecosystems by reducing plant biomass. When considering the role of grazing in rangelands in general or in relation to weeds in particular, it is important to account for total grazing pressure. This is the sum of the effects of domestic, native and feral herbivores (Fisher et al 2005). Selective grazing can directly lead to changes in species composition by removing or reducing the size of plants that belong to more palatable species. Grazing can indirectly lead to compositional change by creating gaps in which recruitment can take place. Some species may be adapted to more effectively exploit particular gaps because either more of their propagules reach these gaps or they are better adapted to the conditions there. High stocking rates over extended periods are likely to create opportunities for weeds that are unpalatable and / or require the removal or reduction of competition in order to establish. The effects of grazing may be exacerbated during and after drought (Ash et al 2002; Bray et al 1999; Grice and Campbell 2000; Kernot et al 2000; McKeon et al 2004; Navie et al 1998a; Partridge 1999) and following burning. Unpalatable, annual weed species, such as parthenium, are especially responsive to disturbances that remove large amounts of plant biomass.

Fire also disturbs rangeland vegetation. Its influence on composition, structure and function of the vegetation depends upon the intensity, frequency, season and type of fire (Grice and Slatter 1996). Fire regimes vary between rangeland types and across climate zones. Large parts of the tropical woodlands in the north of the Northern Territory are burned annually (Walker 1981), whereas large sections of the semi-arid woodlands will carry fires only following exceptionally

Fire prone weed species include rubber vine.
Photo: QDPIF

wet years (Noble 1997). In contrast to the situation in forest and heath communities, in most rangeland types the greatest contribution to fuel comes from perennial grasses. Fire and grazing herbivores can be seen as competitors for herbaceous material so there is a strong negative correlation between grazing intensity and fire frequency and intensity. The characteristics of fire determine how much and which components of the vegetation (live and dead) are removed by burning and on what time schedule.

Fire regimes of Australian rangelands have changed significantly since European settlement. Plant species vary in their responses to fire and a high proportion of individuals of some species, including some weed species, are killed by fire. These must recover from fire by either propagules protected from the fire (eg by burial in the soil) or recolonisation through dispersal from unburned areas. Other species are resilient to fire; even though their shoots may be damaged or destroyed, they recover by sprouting from growing points that have been protected from the fire (Gill 1981). Targeted prescribed burning may be used to help manage some weed species. Relatively fire-prone weed species include rubber vine (Bebawi and Campbell 2002a; Grice 1997a;b), mesquite (*Prosopis pallida*) (Campbell and Setter 2002) and bellyache bush (Bebawi and Campbell 2002c). Fire-resilient species include chinee apple (Grice 1997b) and *Prosopis* spp. other than mesquite (van Klinken and Campbell 2001). High biomass perennial tussock grasses, such as gamba grass and perennial mission grass, tend to increase fire intensity and frequency (Rossiter et al 2003).

Weeds in rangelands—patterns and processes

To be problematic in a particular environment, an introduced species must find suitable habitat. It must be able to sequester significant resources relative to other plant species that occur in that habitat. It must be able to recruit new individuals, grow and reproduce and disperse viable propagules to suitable habitat. The more effectively it carries out each of these processes, the more likely it is that it will dominate native and other introduced plants. If such a plant possesses traits that make it undesirable to some land-users or stakeholders, it will be regarded as a weed. Its weed status may or may not be recognised in legislation.

Recruitment

'Recruitment' describes the process whereby new individuals are added to a population. In arid and semi-arid rangeland environments rainfall is a critical driver of population events including recruitment. Rainfall dictates the timing of germination and emergence of seedlings. Some weed species of Australian rangelands build and maintain sizeable seedbanks; examples include parthenium (Navie et al 1998b) and noogoora burr (*Xanthium occidentale*) (Hocking and Liddle 1995). Rubber vine is an example of a species with a short-lived seedbank, most seeds germinating within 12 months of being shed from the parent plant (Grice 1996). The existence of persistent seedbanks can exacerbate the difficulties of control of a weed infestation as it provides an immediate source of new plants to replace those removed during control operations.

Growth and reproduction

An important parameter influencing rates of expansion of weed populations is age at first reproduction, that is, the time between emergence of seedlings from the soil and first production of seeds (Campbell and Grice 2000). This varies considerably among weed species. Annual species, such as parthenium, produce seeds within a year of having germinated. Other weeds of Australian rangelands can take several years before they produce any seed and many more before they reach maximum seed output. Generally, the larger an individual the more seeds it will produce. The time to first reproduction is of great practical importance. Controlling a new infestation before it reproduces can prevent the establishment of a persistent seedbank, minimise the effort needed on follow-up control operations and reduce the likelihood of secondary infestations arising.

Another important parameter relating to plant reproduction is the number of seeds produced during an individual reproductive episode. It is common for highly invasive species to have a high reproductive output. Even relatively small rubber vine plants may produce 9000 seeds in a single season and large chinee apple trees can produce 5000 seeds in a single season (Grice 1996).

Prickly acacia seed pods.
Photo: C.G. Wilson

Rubber vine seeds are adapted for wind dispersal.
Photo: F Bebawi

Dispersal

Dispersal is the process whereby seeds or other propagules are moved away from the parent plant. Different weed species are dispersed by different mechanisms. In general terms, the dispersal of rangeland plants can involve the action of wind, water and animals, including humans. Many weeds are dispersed by more than one mechanism.

Several rangeland weeds have traits that adapt them for wind-dispersal. Rubber vine and calotrope (*Calotropis procera*) are examples. Their seeds have a tuft of fine hairs attached to one end so that they parachute slowly to the ground and are moved horizontally by the wind. The distance that they are moved is a function of the strength of the wind and height from which they are released. Because rubber vine plants can grow up over the canopies of large trees, seeds can be released from a considerable height (up to 20 m) so at least a small proportion will be carried tens or hundreds of metres or even more. The dispersal units of some invasive grasses, for example gamba grass and buffel grass, can also be spread by wind, aided by awns and other structures that increase their surface areas.

Seeds of weeds growing near water may be spread downstream in the current whether or not they have specific adaptations to facilitate this. This is probably a significant dispersal mechanism for parkinsonia which grows most prolifically on creek and river banks and on flood-out areas. Species, such as the stoloniferous grass hymenachne, that can propagate vegetatively can also be moved downstream when stem sections are broken off from the parent plant.

A large number of rangeland weeds are dispersed by animals (Table 2). Seeds of the leguminous species mesquite and prickly acacia are consumed by livestock and feral pigs and a proportion of the seeds are passed intact and viable (Radford et al 2001). In the case of prickly acacia, cattle are more effective dispersal agents than sheep. Cattle are major dispersal agents of leguminous and fleshy-fruited weed species because of the large numbers of fruits that they consume per head and large herd sizes. Chinee apple is spread by a variety of mammals including cattle, wallabies and pigs (Grice 2002). These different animals will result in different seed dispersal patterns and their relative importance will vary with their abundance, digestive physiology and factors which govern their movement around the landscape (see ‘Seed shadows and dispersal curves’, in the companion Habitat management guide *Rainforests: Ecological principles for the strategic management of weeds in rainforest habitats*).

Species with fleshy fruits or edible pods are spread by being consumed by animals. Here a mesquite seedling (left) is growing in cow manure, wallaby manure (centre), and chinee apple seed (right) is found in feral pig manure.
Photos: QDPIF

Birds are important dispersal agents of a number of rangeland weeds though they are not as significant there as they are in rainforests where a high proportion of native and introduced plant species are fleshy-fruited (see 'Frugivore dispersal', in the companion Habitat management guide *Rainforests: Ecological principles for the strategic management of weeds in rainforest habitats*). Fleshy-fruited rangeland weeds include chinee apple and lantana. Birds such as figbirds, pied currawongs, channel-billed cuckoos and emus are avian frugivores of the rangelands. The male great bower bird (*Chlamydera nuchalis*) decorates its bower with fruits of bellyache bush and, in doing so, disperses the seeds. Some species such as red-tailed black cockatoo (*Calyptorhynchus banksii*) are probably more important as seed predators than dispersal agents, for example of chinee apple (Grice 2002).

Invertebrates are sometimes involved in local dispersal. Meat ants (*Iridomyrmex* spp.), for example, consume and disseminate up to 12,000 seeds / midden / year of bellyache bush in riparian areas (Bebawi and Campbell 2002b; 2004; Bebawi et al 2007).

Some species, such as red-tailed black cockatoos, are probably more important as seed predators than dispersal agents.
Photo: S Roper

Humans deliberately or inadvertently disperse seeds of many rangeland weeds. Most species that are now serious rangeland weeds were deliberately introduced to Australia (eg Cook and Dias 2006). Subsequently they have been dispersed locally or over long distances by human activity. People move weed seeds on motor vehicles and farm machinery and in transported livestock, fodder, soil and other produce. Contaminated pasture seed is another means whereby weed seeds are spread.

Some of the issues associated with human-aided dispersal in the rangelands include:

- transport of seeds as contaminants of livestock, pasture seed, other goods or vehicles, between blocks owned by the same manager, and often at a distance from one another
- transporting fodder that is contaminated with seed of species such as giant rats tail grass—this threat is especially prevalent during drought years (Vogler and Bahnisch 2006)
- moving livestock for agistment or other reasons without imposing a suitable holding period

A great bower bird's collection, including fruits, used to decorate its bower.
Photo: F Bebawi QDPIF

Vehicle wash down helps prevent weed spread.
Photo: QDPIF

- failing to wash-down agricultural machinery or road trains—this has been a major means of long distance spread of parthenium
- failing to wash-down vehicles used for servicing of power and water infrastructure
- construction of roads or other infrastructure and the transport of soil or gravel.

Seed movement into Kakadu National Park

A study conducted over two months (1989) in Kakadu National Park, Northern Territory, collected a total of 1511 seeds from 222 tourist vehicles that were entering the park (Lonsdale and Lane 1991). These seeds represented 84 species, many alien to the region. About 70 % of vehicles were carrying seeds.

The timing of dispersal is important. Flowering and fruiting are strongly seasonal in many species (Table 3) so that seed dispersal usually occurs in brief episodes during a plant's annual growth cycle. Some species, for example, rubber vine, bellyache bush, yellow oleander (*Cascabela thevetia*), giant rats tail grass and mimosa, can fruit nearly all year round, though even in these cases there are peaks of seed production and release.

Seasonal patterns of dispersal are important

Knowledge of seasonal patterns of weed seed dispersal is critical to their management. Plants that disperse their seeds in summer should be controlled in autumn, winter or spring before they release their seeds into the environment. For those that disperse their seeds in winter, control should occur in spring, summer or autumn. With summer and winter seed-dispersing weeds, land mangers have time to organise control operations. However, weeds that have an indefinite dispersal season require immediate control because seed is constantly being released into the environment. Weeds that have an indefinite dispersal season include bellyache bush, yellow oleander and mimosa (Bebawi et al 2005; Bebawi et al 2007; Vitelli et al 2006).

Left: rubber vine flower; Right: mimosa flower.
Photos: C.G. Wilson; and S Vidler, Weeds CRC

Table 2. Animal dispersers of some weeds of Australian rangelands.

Weed species	Dispersal agents							
	Cattle	Sheep / goat	Horse	Feral pig	Camel	Donkey	Macropods	Birds	Ants
Bellyache bush				X				X	X
Chinee apple	X	X	X	X	X	X	X	X	
Giant rats tail grass	X								
Grader grass	X							X	X
Lantana								X	
Mesquite	X	X	X	X	X	X	X	X	
Parkinsonia	X		X						
Parthenium		X						X	
Pond apple				X			X	X	
Prickly acacia	X		X						
Rubber vine								X	
Yellow oleander								X	

Table 3. The timing of seed dispersal for some common rangeland weeds.

Species	Seed dispersal time											
	Spring			Summer			Autumn			Winter		
	S	O	N	D	J	F	M	A	M	J	J	A
Bellyache bush	X	X	X	X	X	X	X	X	X	X		
Calotropis			X	X	X	X						
Chinee apple	X									X	X	X
Gamba grass								X	X	X	X	X
Giant rats tail grass	X	X	X	X	X	X	X	X	X	X	X	X
Grader grass						X	X	X	X	X		
Hymenachne								X	X	X		
Lantana	X	X	X	X	X	X	X	X				
Mesquite								X	X	X	X	X
Mimosa	X	X	X	X	X	X	X	X	X	X	X	X
Parkinsonia				X	X	X	X					
Parthenium	X	X	X	X	X	X	X	X	X			
Pond apple				X	X	X	X	X				
Prickly acacia			X	X	X	X						
Rubber vine	X	X	X	X	X	X	X	X	X	X	X	X
Yellow oleander	X	X	X	X	X	X	X	X	X	X	X	X

Regional and landscape processes

Even though many rangelands can appear relatively homogeneous across very large areas, weeds of rangelands are not evenly spread. They are patchily distributed at continental, regional and landscape scales. This is due to a combination of habitat and management factors and invasion history. The abundance of prickly acacia in Queensland's Mitchell grasslands (see Diversity and structure of rangeland vegetation—4. Mitchell grasslands) is largely due to it having been planted as a shade and fodder tree in that vegetation type. It has spread to other vegetation types at a number of locations further east, probably by being moved along transport (rail and road) corridors in freighted live cattle (Mackey 1998). The current distribution of chinee apple also reflects its history of introduction. Chinee apple is distributed in relatively discrete pockets located in the vicinity of early settlements in Queensland, the Northern Territory and Western Australia. Most of these infestations probably represent independently naturalised populations that have radiated out from trees planted by settlers in the late 1800s and early 1900s (Grice 2008).

Bioclimatic modelling has been used to predict the potential ranges of weeds at the continental scale (Thorp and Lynch 2000). Even in the cases of species that are already regarded as very serious weeds of rangelands, potential ranges have not yet been realised. This is illustrated by the case of rubber

Infestation of prickly acacia.
Photo: QDPIF

Infestation of rubber vine.
Photo: J Vitelli, QDPIF

vine in northern Australia. This species has been on the continent for over 100 years and its potential range is estimated to cover around 20 % of the Australian continent. This is a broad zone stretching through eastern and northern Queensland and across the north of the Northern Territory and Western Australia. However, the species is only prevalent in Queensland with only small infestations (targeted for eradication) having been found in the Northern Territory and the Kimberley region of Western Australia (Tomley 1998).

The unevenness of distribution and abundance of weeds can be exploited by managers. For example, the discrepancy between potential and actual ranges is incorporated into the national strategy for managing rubber vine by establishing containment lines to prevent westward spread and focusing control operations on the periphery of the species' actual range (NRME 2004). At a finer scale, areas of less suitable habitat where abundance is lower may be used to protect areas that are more prone to invasion. Similarly, managers could target populations that are located in parts of a region, catchment or landscape that are more likely than other populations to give rise to new infestations.

Social aspects of weed invasion

Human interactions with rangeland environments and perspectives on different plant species determine what is or is not a weed. Both native and introduced plants are regarded as weeds by different stakeholders in the rangelands. Most of the introduced species were brought to Australia deliberately for ornamental, forestry, agricultural or pastoral purposes. Urban centres and even small settlements are potential sources of weeds for the surrounding landscape. They are often points of introduction and foci of disturbance that may facilitate the spread of some types of weeds. Perhaps 70 % of plant species currently recognised as weeds in Australia were introduced as garden plants whether or not they were also introduced for other purposes. The gardens of rangeland urban centres and even remote pastoral homesteads can be a source of species that invade surrounding rangelands. Barker et al (2006) identified 800 species of garden plants currently in Australia that could present a risk to Australian grazing industries. Two hundred and sixty one of these species were assessed as posing a serious threat and a proportion of these are potential rangeland weeds.

Weeds are unevenly spread across regions and catchments

In general terms, weeds tend to be more abundant and diverse in:

- regions that are more intensively settled
- climatic zones that have higher and more reliable rainfall
- landscape units that receive run-on or are relatively fertile (Grice 2000).

The distributions of weeds in the upper Burdekin catchment of north-east Queensland reflects historical and habitat factors. The most serious infestations of rubber vine and chinee apple are found relatively close to the principal town of the region, Charters Towers. This is likely to have been an epicentre of weed introduction, naturalisation and spread. Sub-catchments that are more remote from this or other epicentres have fewer weed species. Many weeds are more abundant in riparian zones than in adjacent upland areas, reflecting the effects of water and nutrient availability (Grice et al 2000).

Prickly acacia in a town environment.
Photo: QDPIF

Rubber vine: an escaped garden plant

Rubber vine (*Cryptostegia grandiflora*) was first introduced to Australia as an ornamental plant. It was suitable for tropical environments and produced large showy flowers. During World War II it was cultivated as a possible source of rubber though it was never productive for this purpose in spite of the quality of the rubber that could be produced from its sap. It naturalised from the combination of ornamental and experimental plantings and spread to occupy a range covering around 350,000 square kilometres by 1998 (Tomley 1998). In 2000, rubber vine was declared a Weed of National Significance (Thorp and Lynch 2000) and has been the target of a national management program ever since (NRME 2004).

The various users of Australian rangelands view some naturalised plant species from quite different perspectives. A species that one user regards as a weed could be considered by another to be a valuable plant. This gives rise to contentions over whether and how such a species should be managed. Contentions exist in relation to the occurrence of a species on particular areas of land, as well as where a species has spread, or could spread, from sites where it is valued to adjacent sites where it is considered a weed. Perhaps the most common manifestation of these conflicting interests involve species considered by pastoral interests to be useful forage plants but considered by conservation interests to be deleterious from a biodiversity point of view (van Klinken et al 2006). A high-profile example of such a species is buffel grass which is probably the most important pasture grass in Australian rangelands. Other contentious species are listed in Table 4.

The strategic management options in these contentious cases are:

(i) prohibit cultivation

(ii) permit cultivation but compensate those who are negatively affected (eg by funding research or subsidising weed control)

(iii) permit cultivation but have cultivators voluntarily or obligatorily take action to counter off-site naturalisation, spread or negative impacts (Grice et al 2008).

The challenge for policy makers in such situations is to decide whether to intervene legislatively and, if so, how. The challenge for land managers is to determine whether and how it may be possible to contain the species or manage negative impacts in cases where cultivation is permitted. For two of the species listed in Table 4, at least some jurisdictions have elected to take option (i) above and prohibit cultivation. Hymenachne is now a WoNS species and declared in all Australian states and gamba grass is declared in Western Australia and Queensland.

Buffel grass (left) and gamba grass (right) are examples of species for which there are conflicting interests between pastoral and environmental interests.
Photos: R Davies; and B Waterhouse, AQIS

The introduced flora of Australia and its weed status

Invasion is considered to be the least likely outcome of a multistage process that begins when organisms arrive outside their native range (Mack et al 2000). Williamson and Fitter's (1996) 'tens rule' holds that just one in ten of those species transported to a new location will appear in the wild (ie, become casual invaders); only one in ten of those casual invaders will become naturalised (manage to sustain a population over the short term); and one in ten of those naturalised will spread and establish invasive populations.

Many exotic species exist in very small numbers, for example in gardens and botanic gardens, and never become invasive. Determining why some species become invasive and others do not has long occupied researchers without many conclusive results. However, one of the most useful ways to determine if a species is likely to become invasive is its reputation elsewhere. The Weeds CRC recently published *The introduced flora of Australia and its weed status*. Every introduced plant species in Australia, past and present, is listed in this publication along with if, and where, it is 'weedy' elsewhere in the world. The publication aims to inform gardeners about potentially weedy plants that should be avoided.

The logistics of weed management in rangelands

Defining characteristics of rangelands are low human population density and low intensity of land-use. These traits create major challenges for weed managers. In many instances, such as grazing enterprises, there are often only a few individuals responsible for managing large parcels of land. Weed management is just one of a multitude of activities that have to be prioritised on a daily basis and it will often not be considered until more routine matters are addressed.

The low density of human population means that it can also be difficult to detect and delimit weed infestations. This problem can be exacerbated by inadequate weed identification skills (as it can in other environments). The relatively open nature of many rangeland types means that it may be possible to use either satellite or aerial remote sensing to detect weeds and attempts have and are being made to develop such technologies. However, they are likely to require species-specific modification and it seems unlikely such approaches can be used to detect small, isolated infestations in an efficient manner. Delimitation of known infestations may be a more realistic possibility.

Siam weed.
Photo: C.G. Wilson

The other major practical challenge relates to the scale of many rangeland weed infestations. The current distributions of many rangeland weeds and areas within those distributions that are actually occupied cover many thousands of square kilometres and can go across property, region, catchment and state / territory boundaries. Moreover, cost-effective, broad-scale techniques (see section 3. Weed management techniques for rangelands) are not always available. Decisions must be made between three broad strategic options: eradication, containment and control. Complete eradication at the continental scale is rarely an option, in rangelands or elsewhere (Groves and Panetta 2002). It is usually only achievable when the targeted weed species has a very limited distribution. Seven species are currently targets of national eradication campaigns. Only one of these, Siam weed, is regarded as a rangeland weed; the rest target weeds of the wet tropics (see 'National eradication programs in the tropics', in the companion Habitat management guide *Rainforests: Ecological principles for the strategic management of weeds in rainforest habitats*).

Eradication of kochia from Australia

Kochia (*Kochia scoparia*) was introduced to Western Australia in 1990 and tested for its potential as a forage species for salt-affected lands. It was soon realised that it was highly invasive and targeted for eradication under a state government program. In spite of the fact that the locations to which the species was introduced were known it took 10 years to complete the program (Dodd and Randall 2002).

Table 4. Some common naturalised plants of Australia that are commercially cultivated and have weed potential (extracted from Grice et al 2008).

Scientific name (Family)	Common name	Growth form	Use	Weed impacts
Desmodium spp. Desv. (Fabaceae)	Desmodium	forb	pasture	environmental: northern woodlands
Cenchrus ciliaris L. (Poaceae)	buffel grass	grass	pasture	environmental: tropical and warm temperate rangelands
Andropogon gayanus Kunth (Poaceae)	gamba grass	grass	pasture	environmental: tropical savannas
Hymenachne amplexicaulis Nees (Poaceae)	hymenachne	grass	pasture	environmental: northern coastal wetlands sugar cane crops
Urochloa mutica (Forssk.) T.Q. Nguyen (Poaceae)	para grass	grass	pasture	environmental: northern coastal wetlands
Stylosanthes spp. Sw. (Fabaceae)	Stylos	shrub	forage	environmental: northern woodlands
Leucaena leucocephala (Lam.) de Wit (Fabaceae)	Leucaena	shrub / tree	forage	environmental: northern woodlands
Azadirachta indica A. Juss. (Meliaceae)	Neem	tree	ornamental horticulture	environmental: northern riparian zones

An important logistical consideration when addressing rangeland weeds concerns the fact that many sites, catchments and habitats are invaded by more than one weed species. Weed species co-occur at very fine scales. This means that attempts to tackle single species may be thwarted by weed-species interactions. If only one weed species at a site or in a district is targeted, co-occurring weed species, rather than more desirable plants, may replace it. Consequently, the overall benefit of the weed control program may be negligible.

3. Weed management techniques for rangelands

This guide is focused on management of weeds at the habitat level, rather than on how to manage individual weed species. Techniques for treating weed infestations are usually species- or growth-form specific. The synopsis in this section briefly describes the techniques that are available for managing rangeland weeds. These techniques are tools that are used to apply strategies built on the principles presented in section 4. Principles for the strategic management of weeds in rangelands.

Weed management techniques suitable for use in rangelands include chemical spraying, burning, grazing and browsing, mechanical methods and biological control (Table 5). Virtually always, a single application of any of these techniques does not 'fix' a weed problem. Rather, effective weed management requires on-going action, usually involving the integration of a variety of techniques.

Chemical methods

Whether, where and when herbicides should be used to control rangeland weeds depends upon the types of weeds present, the habitat in which the weeds are growing, accessibility of the site(s), the density and extent of the infestations and the estimated cost:benefit ratio of the situation. These factors also influence which chemicals should be used and how they can be most effectively applied. Herbicides may be applied to the foliage, stems or soil. Soil applications are common for woody species. Treatment of individuals (eg cut stump and basal bark method) are more applicable to low density populations. Ground based equipment (eg use of boom-sprays) is most useful for populations of medium density while aerial application is more appropriate for large scale, dense populations.

Fire is an integral part of rangeland management, including weed control as seen here with mesquite.
Photo: QDPIF

A critical consideration is off-target effects, including short-, medium- and long-term environmental effects.

Burning

Fire is an integral part of rangeland management particularly in northern Australia (Partridge 1999). It is a prominent feature of many rangeland types, especially those with a grassy understorey (Grice and Brown 1996). It is used for a variety of purposes including management of native woody plants, to stimulate herbage growth for livestock, to reduce wildfire hazard and to manipulate the composition of plant communities for conservation purposes (Hodgkinson et al 1984). It is also useful in weed management but it is not universally effective against all weed species. Fire is useful against rubber vine, mesquite, bellyache bush and parkinsonia but not effective against gamba grass, chinee apple and other *Prosopis* spp. The use of fire must be supported by an understanding of life histories, especially fire survival strategies, fire-stimulated germination, and time to recover reproductive capacity (Hodgkinson et al 1984). Fire may release nutrients that can be rapidly sequestered by certain types of weeds.

The effectiveness of burning depends on the characteristics of the fire used (see Rangelands as dynamic systems—Fire). It should be noted that fire is not a 'free' tool. Prescribed burning imposes costs in terms of fire management and the opportunity costs associated, for example, with the need to acquire and consume grass fuel that is then no longer available as forage for livestock. It may be necessary to destock pastoral lands in order to allow vegetation to recover following burning.

Mechanical methods

Mechanical techniques can be used against woody species. Various methods are available (eg bulldozing, chaining,

Bulldozing chinee apple.
Photo: QDPIF

Table 5. An overview of weed management techniques suitable for use in Australian rangelands (Hodgkinson et al 1984; Gardener et al 1996; Noble 1984; Palmer 1996; Webber 1996; Wilson 1996; Wilson et al 1984).

Control method	Uses	Strengths	Weaknesses	Issues
Chemical	Woody weeds Small infestations of herbaceous weeds	Can achieve high mortality if undertaken correctly Can be selective (spot spraying) Works while you sleep	Operator variability Some application methods give variable results Requires plant / weed knowledge Labour intensive Can be non-selective (monocot:dicot) ie broadacre spraying Follow up required Relatively expensive	OH&S hazards Off-target risks
Fire	Broad-scale application Good for large areas of open (grassy) woodland In Mitchell grasslands, stimulates tussocks Native woody weed control	Low cost Promoted by researchers and advisors Powerful tool to a manager who can promote the vegetation most desired Ecologically sustainable with patch burning (leaves wildlife refuge)	'How' and 'when' to burn requires planning 6 months to 12 months in advance Requires land to be de-stocked Can require a permit or licence Fuel load and burn opportunities are reliant on previous rainfall and are often the limiting factor in 'when to burn' Optimal environmental conditions required (rainfall) Leaves the soil exposed—susceptible to wind and water erosion, can be favourable to recruitment of new plants Not always appropriate for riparian areas Effectiveness can be dependent on the right temperature and particular growth stage Loss of productivity may occur if post-burn seasonal conditions (uncontrollable) are not favourable Not target specific—creates a cost of lost production Benefits may not be visible for many years	Potential for damage to fences, houses, stock and surrounding properties Social perceptions of post-burn results
Mechanical	In preparation for cropping Preferred option for woody weed / shrub control	Increases water penetration and aeration of the soil Natural—no chemicals Can provide an opportunity to plant (grass seed) simultaneously (eg blade ploughing)	Time consuming over large areas (labour intensive) Requires large machinery High impact, especially to soil Non-selective (chaining)—removes desirable natives including non-target trees (mulga) Doesn't work while you sleep Has potential to stimulate soil seedbank, increasing weed presence	May require a licence / permit in particular states and territories
Grazing / browsing	Consuming the foliage of weeds and preventing them from setting seed	Can be effective if sufficient animals are available (eg goats on *Acacia* spp.)	Must be acceptable to grazing animals—herbaceous species generally most preferred Dynamic interaction between herbivore, plants and soil Pressure can negatively effect the land and increase weed populations Fencing an additional cost	Tolerance level to weeds varies between individuals Native plants could also be impacted on
Biological	For introduced and native weeds In combination with other methods Has potential to target woody weeds	Good for heavy infestations Host specific Good for land managers as they don't pay Mostly low impact with minimal disturbance (soil) Long term and sustainable Has potential for mycoherbicides and biotechnology options	Damage caused before agent is released Success is variable and depends on many variables like rainfall Close phylogenetic relationships between introduced and native species (ie *Acacia*)	Expensive during the trial phase Takes many years to fruition, release then management

blade-ploughing, stick-raking) depending on the types of weeds present, the habitat type, the extent and density of infestations and the expected cost:benefit ratios of the situation. The most effective are generally those that can sever the root system of plants below ground (eg blade-ploughs and cutter bars). Mechanical methods tend to cause extreme soil disturbance which may stimulate germination of weeds (or other species) and provide ideal opportunities for the same or different weeds to establish (see Rangelands as dynamic systems—Disturbance). Follow-up to initial applications of mechanical techniques is especially important.

Grazing and browsing

Grazing and browsing animals can be used to manage weeds. There are two ways in which this might happen. First, a manager may be able to choose those types of herbivores that preferentially graze plant species that the manager wishes to control. Camels and goats have been used in this way, particularly to target woody species. Second, grazing management in general can be used to maximise the resilience of the vegetation. Maintenance of the herbaceous perennial component of the vegetation by sound grazing management promotes moisture penetration, maintains fertility of the soil, suppresses shrub seedlings and reduces weed establishment in general (Harrington et al 1984c; Ash et al 2002; Kernot et al 2000; McKeon et al 2004). Seasonal spelling from livestock grazing promotes higher grass biomass and ground cover. Spelling for short periods of time can also reduce the presence of annual weeds such as grader grass (*Themeda quadrivalvis*), as demonstrated by a study where spelling for two years reduced the biomass of grader grass from 70 % to less than 20 % (W. Vogler pers comm.).

The value of patch burning

Managers of conservation areas are now recognising that patchiness in vegetation created by certain fire regimes and mosaic burning promotes diversity of habitat (Hodgkinson et al 1984). Infrequently burnt areas, such as some areas of semi-arid mallee ecosystems, provide refugia and genetic reservoirs for local fauna and flora (Noble 1984). Many native animals prefer areas in a late successional stage, for shelter and nesting, adjacent to recently burnt patches that provide fresh growth and a different range of food reserves (Griffin 1984).

Biological control

Biological control of weeds is a scientific approach to identifying, introducing, testing, releasing and evaluating pests and pathogens that specifically target particular weed species. For introduced species this generally involves searching the species' native range for organisms. The technique rests on the notion that 'left behind' pests and pathogens that helped regulate the weed's population in the native range could perform a similar role if introduced. In ecological terms, a biological control agent will help by interfering with the weed's capacity to acquire, allocate and retain resources (Grice and Campbell 2000). Rangeland weeds for which biological control programs have been conducted include bellyache bush, mesquite, mimosa, parkinsonia, parthenium, prickly acacia and rubber vine. Success of biological control in general is mixed. One of the more effective in the rangelands is that for rubber vine. The rust *Maravalia cryptostegiae* was introduced from Madagascar (the native range of rubber vine) and is now widespread within its range in north Queensland. It results in periodic defoliation and reduced seed output by rubber vine (Tomley 1998).

Goats being used to manage prickly acacia.
Photo: QDPIF

Rust fungus, introduced as a biological control agent for rubber vine.
Photo: QDPIF

4. Principles for the strategic management of weeds in rangelands

Resources will never be sufficient to eliminate weed problems in the rangelands (or any other habitat type, ecosystem or land use system). This makes it all the more important to direct the resources that are available to maximum benefit—weed management must be as efficient as possible. This requires a strategic approach and strategic weed management can be defined as the choice of measures and application of resources at times and places that gain the greatest benefit for the resources available (Grice 2000).

This section presents some broad principles for strategic weed management in rangelands. Their application is intended to:

1. minimise the risk of new incursions into rangelands
2. manage current weed problems to minimise their impact
3. manage rangelands to minimise their susceptibility to current or potential weeds.

These broad aims require understanding of rangeland systems, individual weed species, interactions between weed species and the tools available to manage them. Spatial patterns and processes are especially important here because weed invasions are themselves essentially spatial in nature.

Managing single species, multiple species, landscapes and regions

Even though many species of weeds of Australian rangelands are currently or potentially very widespread, each rangeland type is characterised by particular species. This is also true at finer (landscape) scales. Any one rangeland region may currently or potentially support a variety of weed species. To some degree, each species will require individual attention. This is because different species are prone to different control measures and exhibit different patterns of distribution and abundance because of different histories or habitat preferences. On the other hand, a multi-species approach to weed management is also required. This is demanded partly because of need and partly because of opportunity. The need relates to the scale of rangeland weed problems—number of species, spatial extent—and to the interactive nature of weed problems—one weed may benefit when control action is taken against another. The opportunity relates to commonalities between weed species that can be exploited by managers. These commonalities have been expressed in the notion of functional types in reference to weeds (Díaz et al 2002). There is a need, then, to find the most effective balance between managing individual weed species and managing a suite of weed species in a particular rangeland type or region. One cannot be neglected at the expense of the other.

Preventing new incursions

Prevention is a broad principle of weed management. Its most general application involves preventing new species of weeds from entering an area. Australian Commonwealth regulations require that any plant species not already present in the country must be subject to a formal Weed Risk Assessment process (WRA) before it can be imported into Australia.

This process allocates species to one of three categories:

1. importation permitted
2. importation prohibited
3. further assessment required because insufficient information is available (Pheloung et al 1999).

This system cannot, by itself, completely prevent the introduction to Australia of species that subsequently become problematic because predicting weediness is not an exact science. However, this measure is likely to retard the rate of new incursions through the deliberate introductions that have been, by far, the major source of weeds in Australia.

The principle of prevention can also be applied at sub-continental scales. A large number of plant species already in Australia have the potential to become problematic. Some have not yet naturalised but could do so. Others are naturalised but have very restricted distributions. Precluding potentially problematic plants from cultivation in the rangelands would be one helpful measure. A general precautionary approach to this issue could operate at the habitat level though, in practice, decisions would be required on a species-by-species basis. Prevention at sub-continental scales would also require resolution of conflicting interests that arise as a result of the multiple-use nature of rangelands.

Managing dispersal

Management of dispersal should be conducted in conjunction with attempts to prevent new weed problems at the sub-continental scale. Rangeland weeds are dispersed by a wide variety of dispersal mechanisms (see Weeds in rangelands—patterns and processes: Dispersal) and the management of dispersal requires consideration of inter-specific differences in dispersal mechanisms. However, there is also a strong basis for the management of dispersal at the habitat level because there are important dispersal syndromes in rangelands. It is not generally feasible to manage dispersal of wind- or water-dispersed species. (In these cases effort would be more effectively directed at reducing seed production or targeting new infestations that arise from dispersed seeds). However, it is feasible to target clusters of species that are spread

Feral animals, such as these camles on Anangu Pitjantjatjara Lands in north-west South Australia, can spread weed seeds and cause disturbance that facilitates weed estabilshment.
Photo: S Roper

either by domestic or feral animals or by vehicles, equipment or goods that are transported in them.

Controlling the movement of domestic stock is an essential part of sound property management. Considering their role as dispersers of weeds it is a sound principle for containing spread of weeds both within and between pastoral properties and the transport corridors along which they are moved. As far as movement between paddocks is concerned, effective fences are barriers to the spread of weeds provided the movement of livestock between paddocks is thoughtfully conducted. The timing of movement in relation to the fruiting periods of livestock-dispersed plants and withholding periods (at least seven days) for livestock that are likely to be carrying seeds are both practical means for limiting livestock-dispersed weeds.

Feral animals are rarely constrained by standard fences. Managing dispersal of weeds by feral animals requires control of their populations. Reduced dispersal of weeds by feral animals is one of the benefits of effective feral animal control programs. There is likely to be value in co-ordinated control of weed and feral animal populations on a regional basis.

Vehicle and equipment hygiene will reduce the spread of weeds that are moved by these means. It may be possible to avoid taking vehicles into small infestations of weeds when they are seeding. Otherwise, it is necessary to adequately wash-down vehicles and equipment prior to moving them to weed-free paddocks or properties. Service and construction vehicles as well as farm vehicles and machinery, and the goods they carry, must be considered as potential dispersers of weed seeds and subject to hygiene measures. Education of land managers, transport agents, service providers and tourists has an important role to play here.

Early intervention

Delay in dealing with weed infestations increases the chances that their populations will increase, expand and give rise to other infestations. Persistent seedbanks are more likely to be an issue where infestations have been in place for a long time without having been treated. They will greatly extend the time for which initial treatments require follow-up actions. Early intervention requires early detection and identification of weed problems. Awareness of species that could become a problem (‘emerging weeds’) is an important step in detecting their infestations. There must then be a capacity for rapid response. It is important to recognise that rapid response is not the same as a ‘quick fix’. Rather it is beginning what could be a lengthy or even perpetual process of reducing expansion and impact of weed problems.

It is particularly pertinent to identify areas within the landscape where new weeds are likely to establish initially and then remain vigilant through regular surveillance and prompt control of any plants that may be found. Generally, susceptible areas will be closely aligned to dispersal mechanisms and include road corridors, areas where livestock are fed, transported stock feed and riparian areas and floodplains.

Setting priorities between weed infestations

Habitat factors and the history of weed invasions ensure that weed populations are not evenly spread across rangeland landscapes. Weeds will not reach all parts of a region at the same time, they may spread in some directions (eg down wind or down stream) faster than others and do better in some parts of the landscape than others. Some weed infestations are more likely than others to undergo rapid expansion and to give rise to new infestations. An important part of developing a weed management strategy is to identify those infestations that should be given priority for control. Priorities should be decided on the basis of the risks presented and the benefits to be gained.

Priority should be given to:

- Out-lying infestations. These have been shown to contribute disproportionately to range expansion (Moody and Mack 1988). An infestation may be regarded as out-lying at any scale from continental to local.
- Infestations that are located so that there is a high probability that they will spread rapidly or give rise to new infestations. Populations of water-dispersed weeds that are located in the upper reaches of a catchment pose a threat to downstream areas. Infestations in high quality habitat are likely to produce large quantities of seed.

Prickly acacia growing along drainage lines.
Photo: QDPIF

- Infestations that threaten areas of high value. These may be areas of high pastoral production, habitat for particular native species or drought refuges for wildlife.
- Small infestations that can be completely eliminated relatively easily.

Resolving conflicting interests

It is important to work toward resolution of conflicting interests surrounding 'weeds' in rangelands. This is not an easy task. An important step toward resolution is mutual acknowledgement of the validity of different points of view. There will rarely, if ever, be 'win-win' solutions to problems of conflicting interests. In some cases, prohibition of a particular species will be the most appropriate response. In others, a way forward may be found in a compromise that provides some relief to those who experience the negative consequences from a plant while those who favour the species bear some of the costs (Grice et al 2008). In some situations, the introduction of codes of practice for contentious species has been a practical approach to allow their continual use in a manner that reduces their weediness.

Developing long-term but flexible strategies with realistic goals

Weed management in rangelands requires a perpetual commitment. Even under the most effective of programs, weeds will remain in rangeland landscapes and impact on their multitude of values. Few rangeland weeds can be eradicated, except perhaps over very localised areas, and even then it will always be necessary to monitor in order to detect new out-breaks of the same or other species. Such a situation requires long-term strategies. Strategies may be developed at national, regional and local scales, each designed in the context of plans for each of these scales.

Strategies must also be flexible so that they can respond to new weeds, new outbreaks of existing weeds, climatic circumstances and new control technologies.

Strategies must also have realistic goals. Most broadly these may be expressed in terms of prevention, eradication, containment and control (see Purpose of this document, and The logistics of weed management in rangelands). Realistic goals may be defined in terms of acceptable densities of weeds and degrees of impacts on particular rangeland assets.

Committing resources for the long-term

A long-term strategy without a long-term commitment of resources cannot be effective. It is important that weed management is seen as a continuing need of good rangeland management rather than an isolated activity designed to 'fix' a problem. Effective weed management will minimise both the impacts that weeds have and the resources subsequently required. While there may be great value in a massive initial effort to tackle a weed problem, resources will be wasted if initial efforts are not followed up. A long-term commitment of resources is required to prevent new weed problems, detect weed infestations, treat those infestations using appropriate technologies, provide follow-up treatment as long as there are residual populations or risks of reinfestation, and research weed problems to develop and refine approaches to weed management. All of this requires co-ordination across jurisdictions and between individuals, and decisions about areas of responsibility and how those responsibilities can be met.

Managing weeds in a whole-of-system context

Invasive plant species are only one of the issues facing managers of rangelands. Invasive (feral) animals, grazing, fire and water management, variable climates including extreme events such as droughts and floods, fluctuating prices for rangeland products, increasing prices of key inputs into rangeland industries (eg fuel, labour), and broad-scale threats to rangeland biodiversity are some of the other issues with which managers of rangelands must contend. Weeds must be managed in the context of this complexity of issues even though many aspects of rangelands are largely out of the control of individual land managers. Perhaps especially important are the integration of grazing, fire and weed management and, in at least some cases, the coordinated management of invasive plants and feral animals. Rangelands that are in good condition are more likely to be relatively resistant to weed incursions. In most instances this will require the maintenance of a healthy understorey that can actively compete with any invasive plants for available resources and reduce the likelihood of them establishing persistent infestations.

The variability of rainfall in many rangeland environments also needs to be considered in the context of weed management and can be used to advantage. Traditionally, range expansion for many weeds has been associated with infrequent but prolonged periods of favourable rainfall (often two or more above average years in a row). Conversely, implementation of control activities following periods of below average rainfall can be beneficial, particularly if plants have had limited opportunity to reproduce and replenish soil seed reserves.

Conclusion

Weeds are a major threat to rangeland environments and the industries and people that depend on them. While species-specific approaches will remain important, it is necessary to consider the problem of weeds at regional, catchment and landscape scales addressing multiple species in a strategic way. Perhaps more so than in other land-use systems, there is a need to consider the fact that rangelands are subject to multiple human uses. There is an important issue of contentious plants, whereby different stakeholders in the rangelands prefer different outcomes, and 'win-win' solutions may often not be possible. Weeds must be managed in a whole-of-system context requiring long-term, strategic commitments, and an understanding of how weeds function in rangeland environments.

Desert oaks on the Anangu Pitjantjatjara Lands, north west South Australia.
Photo: S Roper

References

Ash, A.J., Corfield, J.P. and Ksiksi, T. (2002). *The ecograze project: Developing guidelines to better manage grazing country.* CSIRO Sustainable Ecosystems, Townsville.

Barker, J., Randall, R. and Grice, A.C. (2006). *Weeds of the future? Threats to Australia's grazing industries by garden plants.* Meat & Livestock Australia, Sydney.

Bastin, G. and ACRIS Management Committee (2008). *Rangelands 2008—Taking the Pulse.* National Land and Water Resources Audit, Canberra.

Bebawi, F.F. and Campbell, S.D. (2002a). Impact of early and late dry-season fires on plant mortality and seedbanks within riparian and subriparian infestations of rubber vine (*Cryptostegia grandiflora*). *Australian Journal of Experimental Agriculture* **42**:43–48.

Bebawi, F.F. and Campbell, S.D. (2002b). Seed dispersal of a myrmecochorous weed, bellyache bush (*Jatropha gossypiifolia*) in riparian landscapes of northern Queensland. *In:* A.J. Franks, J. Playford and A. Shapcott (eds). *Proceedings of the Royal Society of Queensland, landscape health in Queensland symposium.* The Royal Society of Queensland, Brisbane, pp. 98–102.

Bebawi, F.F. and Campbell, S.D. (2002c). Impact of fire on bellyache bush (*Jatropha gossypiifolia*) plant mortality and seedling recruitment. *Tropical Grasslands* **36**:129–137.

Bebawi, F.F. and Campbell, S.D. (2004). Interactions between meat ants (*Iridomyrmex spadius*) and bellyache bush (*Jatropha gossypiifolia*). *Australian Journal of Experimental Agriculture* **44**:1157–1164.

Bebawi, F.F., Mayer, R.J. and Campbell, S.D. (2005). Phenology of bellyache bush (*Jatropha gossypiifolia* L.) in northern Queensland. *Plant Protection Quarterly* **20**:46–51.

Bebawi, F.F., Vitelli, J.S., Campbell, S.D., Vogler, W.D., Lockett, C.J., Grace, B.S., Lukitsch, B. and Heard, T.A. (2007). The biology of Australian weeds 47. *Jatropha gossypiifolia* L. *Plant Protection Quarterly* **22**:42–58.

Begon, M., Harper, J.L. and Townsend, C.R. (1996). *Ecology: individuals, populations and communities.* Blackwell Science, Oxford.

Bray, S., Yee, M., Paton, C., Silcock, R. and Bahnisch, L. (1999). The role of humans in the invasion of pastures by giant rats tail grass (*Sporobolus pyramidalis*). *In:* D. Eldridge and D. Freudenberger (eds). *People and rangelands: Building the future. Proceedings of the VI International Rangeland Congress.* Townsville, Australia, pp. 593–594.

Campbell, S.D. and Grice, A.C. (2000). Weed biology: a foundation for weed management. *Tropical Grasslands* **34**:271–279.

Campbell, S.D. and Setter, C.L. (2002). Mortality of *Prosopis pallida* (mesquite) following burning. *Australian Journal of Experimental Agriculture* **42**:581–586.

Cook, G.D. and Dias, L. (2006). It was no accident: deliberate plant introductions by Australian government agencies during the twentieth century. *Australian Journal of Botany* **54**:601–625.

Cunningham, D. and Brown, L. (2006). *Some priority agricultural sleeper weeds for eradication.* Bureau of Rural Sciences, Canberra.

Cunningham, G.M., Mulham, W.E., Milthorpe, P.L. and Leigh, J.H. (1981). *Plants of Western New South Wales.* NSW Government Printer, Sydney.

Díaz, S., Briske, D. and McIntyre, S. (2002). Range management and plant function types. *In:* A.C. Grice and K.C. Hodgkinson (eds). *Global Rangelands Progress and Prospects.* CABI Publishing, Wallingford, UK, pp. 81–100.

Dodd, J. and Randall, R.P. (2002). Eradication of kochia (*Bassia scoparia* (L.) A.J. Scott, Chenopodiaceae) in Western Australia. *In:* H. Spafford-Jacob, J. Dodd and J.H. Moore (eds). *Proceedings of the 13th Australian Weeds Conference.* Council of Australian Weed Science Societies, Perth, pp. 300–303.

Dwyer, J. (2008). 'Sleeper weed': caution, use only as directed. *In:* R.D. van Klinken, V.A. Osten, F.D. Panetta and J.C. Scanlan (eds). *Proceedings of the 16th Australian Weeds Conference.* Queensland Weed Society, Brisbane, pp. 57–59.

Dyksterhuis, E.J. (1949). Condition and management of rangeland based on quantitative ecology. *Journal of Range Management* **2**:104–115.

Fisher, A., Hunt, L., James, C., Landsberg, J., Phelps, D., Smyth, A. and Watson, I. (2005). *Management of total grazing pressure.* Commonwealth of Australia, Canberra.

Foran, B.D. (1984). Central arid woodlands. *In:* G.N. Harrington, A.D. Wilson and M.D. Young (eds). *Management of Australia's Rangelands.* Division of Wildlife and Rangelands Research CSIRO, East Melbourne, pp. 299–315.

Foran, B.D., Friedel, M.H., MacLeod, N.D., Stafford Smith, M. and Wilson, A.D. (1990). *A policy for the future management of Australia's rangelands.* CSIRO, Canberra, Australia.

Fox, M.D. (1991). Developing control strategies for environmental weeds. *Plant Protection Quarterly* **6**:109–110.

Gardener, M.R., Whalley, R.D.B. and Sindell, B.M. (1996). The failure of management technology for reproductively efficient grassy weeds: The Chilean needle grass example. *Proceedings of the 11th Australian Weeds Conference.* University of Melbourne, Melbourne, pp. 243–246.

Gill, A.M. (1981). Adaptive responses of Australian vascular plant species to fires. *In:* A.M. Gill, R.H. Groves and I.R. Noble (eds). *Fire and the Australian Biota.* Australian Academy of Science, Canberra.

Graetz, R.D. and Wilson, A.D. (1984). Saltbush and bluebush. *In:* G.N. Harrington, A.D. Wilson and M.D. Young (eds). *Management of Australia's Rangelands.* Division of Wildlife and Rangelands Research CSIRO, East Melbourne, pp. 209–222.

Grice, A.C. (1996). Seed production, dispersal and germination in *Cryptostegia grandiflora* and *Ziziphus mauritiana*, two invasive shrubs in tropical woodlands of northern Australia. *Australian Journal of Ecology* **21**: 324–331.

Grice, A.C. (1997a). Fire for the strategic management of rubbervine *Cryptostegia grandiflora*, an invasive shrub. *In:* B.J. McKaige, R.J. Williams and W.M. Waggitt (compilers). *Bushfire '97 Proceedings, Australian Bushfire Conference.* CSIRO Tropical Ecosystems Research Centre, Darwin, pp. 239–244.

Grice, A.C. (1997b). Post-fire regrowth and survival of the invasive tropical shrubs *Cryptostegia grandiflora* and *Ziziphus mauritiana*. *Australian Journal of Ecology* **22**:49–55.

Grice, A.C. (2000). Weed management in Australian rangelands. *In:* B.M. Sindel (ed). *Australian Weed Management Systems.* R.G. and F.J. Richardson, Melbourne, pp. 429–458.

Grice, A.C. (2002). The biology of Australian weeds 39. *Ziziphus mauritiana* Lam. *Plant Protection Quarterly* **17**:2–11.

Grice, A.C. (2006a). The impacts of invasive plant species on the biodiversity of Australian rangelands. *The Rangeland Journal* **28**:27–35.

Grice, A.C. (2006b). Commercially valuable weeds: can we have our cake without choking on it? *Ecological Management and Restoration* **7**:40–44.

Grice, A.C. (2008). *Ziziphus mauritiana* Lam. *In:* F.D. Panetta (ed). *The Biology of Australian Weeds. Volume 3.* R.G. and F.J. Richardson, Melbourne, pp. 295–310.

Grice, A.C. and Ainsworth, N. (2003). Sleeper weeds—a useful concept? *Plant Protection Quarterly* **18**:35–39.

Grice, A.C. and Brown, J.R. (1996). An overview of the current status of weed management in Australian rangelands. *Proceedings of the 11th Australian Weeds Conference.* University of Melbourne, Melbourne, pp. 195–204.

Grice, A.C. and Campbell, S.D. (2000). Weeds in pasture ecosystems—symptom or disease? *Tropical Grasslands* **34**:264–270.

Grice, A.C. and Slatter, S.M. (1996). *Fire in the management of northern Australian pastoral lands.* Tropical Grassland Society of Australia, Occasional Publication No. 8, St Lucia, Queensland, Australia.

Grice, A.C., Clarkson, J. and Spafford, H. (2008). Commercial weeds: roles, responsibilities and innovations. *Plant Protection Quarterly* **23**:58–64.

Grice, A.C., Lawes, R.A., Abbott, B.A., Nicholas, D.M. and Whiteman, L.V. (2004). How abundant and widespread are riparian weeds in the dry tropics of north-east Queensland? *In:* B.M. Sindel and S.B. Johnson (eds). *Proceedings of the 14th Australian Weeds Conference.* Weed Society of New South Wales, Sydney, pp. 173–175.

Grice, A.C., Radford. I.J. and Abbott, B.N. (2000). Regional- and landscape-scale patterns of shrub invasion in tropical savannas. *Biological Invasions* **2**:187–205.

Griffin, G.F. (1984). Hummock grasslands. *In:* G.N. Harrington, A.D. Wilson and M.D. Young. *Management of Australia's Rangelands.* Division of Wildlife and Rangelands Research CSIRO, East Melbourne, pp. 271–284.

Groves, R. (1999). Sleeper weeds. *In:* A. Bishop, M. Boersma and C. Barnes (eds). *Proceedings of the 12th Australian Weeds Conference.* Tasmania Weed Society, Hobart, pp. 632–636.

Groves, R.H. and Panetta, F.D. (2002). Some general principles for weed eradication programs. *In:* H. Spafford-Jacob, J. Dodd and J.H. Moore (eds). *Proceedings of the 13th Australian Weeds Conference.* Plant Protection Society of Western Australia, Perth, pp. 307–310.

Harrington, G.N., Wilson, A.D. and Young, M.D. (1984a). *Management of Australia's Rangelands.* Division of Wildlife and Rangelands Research CSIRO, East Melbourne,

Harrington, G.N., Mills, D.M.D., Pressland, A.J. and Hodgkinson, K.C. (1984b). Semi-arid woodlands. *In:* G.N. Harrington, A.D. Wilson and M.D. Young (eds). *Management of Australia's Rangelands.* Division of Wildlife and Rangelands Research CSIRO, East Melbourne, pp. 189–207.

Harrington, G.N., Friedel, M.H., Hodgkinson, K.C. and Noble, J.C. (1984c). Vegetation ecology and management. *In:* G.N. Harrington, A.D. Wilson and M.D. Young (eds). *Management of Australia's Rangelands.* Division of Wildlife and Rangelands Research CSIRO, East Melbourne, pp. 41–61.

Hocking, P.J. and Liddle, M.J. (1995). *Xanthium occidentale* Betol. Complex and *X. spinosum* L. *In:* R.H. Groves, R.C.H. Shepherd and R.G. Richardson (eds). *The biology of Australian Weeds. Volume 1.* R.G. and F.J. Richardson, Melbourne, pp. 241–302.

Hodgkinson, K.C., Harrington, G.N., Griffin, G.F., Noble, J.C. and Young, M.D. (1984). Management of vegetation with fire. *In:* G.N. Harrington, A.D. Wilson and M.D. Young (eds). *Management of Australia's Rangelands.* Division of Wildlife and Rangelands Research CSIRO, East Melbourne, pp. 141–156.

Holechek, J.L., Pieper, R.D. and Herbel, C.H. (1989). *Range Management Principles and Practices.* Prentice Hall, New Jersey.

Jessop, J. (1981). *Flora of Central Australia.* Reed Books, Sydney.

Kernot, J., Bethell, J. and Shaw, K. (2000). Seasonal pasture spelling demonstration 'Huonfels' Station. *Proceedings of the Northern Grassy Landscapes Conference.* Tropical Savannas CRC, Katherine, p. 150.

Kriticos, D.J., Alexander, N.S. and Kolomeitz, S.M. (2006). Predicting the potential geographic distribution of weeds in 2080. *In:* C. Preston, J.H. Watts and N.D. Crossman (eds.). *Proceedings of the 15th Australian Weeds Conference.* Weed Management Society of South Australia, Adelaide, pp. 27–34.

Lodge, G.M., Whalley, R.D.B. and Robinson, G.G. (1984). Temperate rangelands. *In:* G.N. Harrington, A.D. Wilson and M.D. Young (eds). *Management of Australia's Rangelands.* Division of Wildlife and Rangelands Research CSIRO, East Melbourne, pp. 317–329.

Lonsdale, W.M. (1994). Inviting trouble: introduced pasture species in northern Australia. *Australian Journal of Ecology* **19**:345–354.

Lonsdale, W.M. and Lane, A.M. (1991). Vehicles as vectors of weed seeds in Kakadu National Park. *Plant invasions—The incidence of environmental weeds in Australia.* Australian National Parks and Wildlife Service Publication, Canberra, pp. 167–169.

Ludwig, J., Tongway, D., Freudenberger, D., Noble, J. and Hodgkinson, K. (1997). *Landscape Ecology, Function and Management: Principles from Australia's Rangelands.* CSIRO, Melbourne.

Mack, R.N., Simberloff, D., Lonsdale, W.M., Evans, H., Clout, M. and Bazzaz, F.A. (2000). Biotic invasions: causes, epidemiology, global consequences and control. *Ecological Applications* **10**:689–710.

Mackey, A.P. (1998). *Acacia nilotica* ssp. *indica* (Benth.) Brenan. *In:* F.D. Panetta, R.H. Groves and R.C.H. Shepherd (eds). *The biology of Australian weeds.* R.G. and F.J. Richardson, Melbourne, pp. 1-18.

Martin, T.G., Campbell, S. and Grounds, S. (2006). Weeds of Australian rangelands. *The Rangeland Journal* **28**:3–26.

McFadyen, R. (2008). *Briefing note: Invasive plants and climate change.* Cooperative Research Centre for Australian Weed Management, Adelaide. www.weedscrc.org.au/documents/bn_climate_change_2007.pdf; accessed 23 July 2008.

McKeon, G.M., Hall, W.B., Henry, B.K., Stone, G.S. and Watson, I.W. (2004). *Pasture degradation and recovery in Australia's rangelands: Learning from history.* Queensland Department of Natural Resources, Mines and Energy.

Moody, M.E. and Mack, R.N. (1988). Controlling the spread of plant invasions: the importance of nascent foci. *Journal of Applied Ecology* **25**:1009–1021.

Morrisey, J.G. (1984). Arid mulga woodlands. *In:* G.N. Harrington, A.D. Wilson and M.D. Young (eds). *Management of Australia's Rangelands.* Division of Wildlife and Rangelands Research CSIRO, East Melbourne, pp. 285–298.

Mott, J.J. and Tothill, J.C. (1984). Tropical and subtropical woodlands. *In:* G.N. Harrington, A.D. Wilson and M.D. Young (eds). *Management of Australia's Rangelands.* Division of Wildlife and Rangelands Research CSIRO, East Melbourne, pp. 255–269.

Navie, S.C., McFadyen, R.E., Panetta, F.D. and Adkins, S.W. (1998a). *Parthenium hysterophorus* L. *In:* F.D. Panetta, R.H. Groves and R.C.H. Shepherd (eds). *The Biology of Australian Weeds.* R.G. and F.J. Richardson, Melbourne, Vol 2, pp. 157–176.

Navie, S.C., Panetta, F.D., McFadyen, R.E. and Adkins, S.W. (1998b). Behaviour of buried and surface-sown seeds of *Parthenium hysterophorus* L. *Weed Research* **38**:335–341.

Noble, J.C. (1984). Mallee. *In:* G.N. Harrington, A.D. Wilson and M.D. Young (eds). *Management of Australia's Rangelands.* Division of Wildlife and Rangelands Research CSIRO, East Melbourne, pp. 223–240.

Noble, J.C. (1997). *The delicate and noxious scrub: CSIRO studies on native tree and shrub proliferation in the semi-arid woodlands of eastern Australia.* CSIRO, Canberra.

Natural Resources, Mines and Energy (NRME) (2004). *Rubber vine management.* Department of Natural Resources, Mines and Energy, Queensland, Brisbane.

Orr, D.M. and Holmes, W.E. (1984). Mitchell grasslands. *In:* G.N. Harrington, A.D. Wilson and M.D. Young (eds). *Management of Australia's Rangelands.* Division of Wildlife and Rangelands Research CSIRO, East Melbourne, pp. 241–254.

Palmer, W.A. (1996). Biological control of prickly acacia in Australia. *Proceedings of the 11th Australian Weeds Conference.* University of Melbourne, Melbourne, pp. 239–241.

Partridge, I. (1999). *Managing grazing in northern Australia: A grazier's guide.* Department of Primary Industries, Queensland.

Pearce, K., Holper, P., Hopkins, M., Bouma, W., Whetton, P., Hennessey, K. and Power, S. (eds) (2007). *Climate Change in Australia.* Technical Report 2007. CSIRO and Bureau of Meteorology, Australia.

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

Radford, I.J., Nicholas, D.M., Brown, J.R. and Kriticos, D.J. (2001). Paddock-scale patterns of seed production and dispersal in the invasive shrub *Acacia nilotica* (Mimosaceae) in northern Australian rangelands. *Austral Ecology* **26**:338–348.

Rossiter, N.A, Setterfield, S.A., Douglas, M.M. and Hutley, L.B. (2003). Testing the grass-fire cycle: alien grass invasion in the tropical savannas of northern Australia. *Diversity and Distributions* **9**:169–176.

Scott, J.K. and Grice, A.C. (2008). Research on the environmental impact of weeds in Australia. *In:* R.D. van Klinken, V.A. Osten, F.D. Panetta and J.C. Scanlan (eds). *Proceedings of the 16th Australian Weeds Conference.* Queensland Weeds Society, Brisbane, pp. 36–38.

State of the Environment Advisory Council (SEAC) (1996). *Australia State of the Environment 1996.* CSIRO, Collingwood, Australia.

Thorp, J.R. and Lynch, R. (2000). *The determination of Weeds of National Significance.* National Weeds Strategy Executive Committee, Launceston.

Tomley, A.J. (1998). *Cryptostegia grandiflora* Roxb. ex R.Br. *In:* F.D. Panetta, R.H. Groves and R.C.H. Shepherd (eds). *The biology of Australian weeds.* R.G. and F.J. Richardson, Melbourne, pp. 63–76.

van Klinken, R.D. and Campbell, S.D. (2001). The biology of Australian weeds 37. *Prosopis* L. species. *Plant Protection Quarterly* **16**(**1**):2–20.

van Klinken, R.D., Friedel, M. and Grice, T. (2006). Perennial pasture conflicts: is there a way through? *In:* C. Preston, J.H. Watts and N.D. Crossman (eds). *Proceedings of the 15th Australian Weeds Conference.* Weed Management Society of South Australia, Adelaide, pp. 687–690.

Vitelli, J.S., Madigan, B.A. and Worsley, K.J. (2006). *Mimosa pigra* in Queensland. *In:* C. Preston, J.H. Watts and N.D. Crossman (eds). *Proceedings of the 15th Australian Weeds Conference.* Weed Management Society of South Australia, Adelaide, pp. 251–254.

Vogler, W.D. and Bahnisch, L.M. (2006). Effect of growing site, moisture stress and seed size on viability and dormancy of *Sporobolus pyramidalis* (giant rats tail grass) seed. *Australian Journal of Experimental Agriculture* **46**:1473–1479.

Walker, J. (1981). Fuel dynamics in Australian vegetation. *In:* A.M. Gill, R.H. Groves and I.R. Noble (eds). *Fire and the Australian Biota.* Australian Academy of Science, Canberra, pp. 101–127.

Webber, L. (1996). Managers' perspectives of weed management within rangelands management systems. *Proceedings of the 11th Australian Weeds Conference.* University of Melbourne, pp. 214–222.

Westoby, M. (1979 / 1980). Elements of a theory of vegetation dynamics in arid rangelands. *Israel Journal of Botany* **28**:169–194.

Westoby, M., Walker, B. and Noy-Meir, I. (1989). Opportunistic management for rangelands not in equilibrium. *Journal of Range Management* **42**:266–274.

Williamson, M. and Fitter, A. (1996). The varying success of invaders. *Ecology* **77**:1661—1666.

Wilson, B.J. (1996). Technical aspects of weed management in Australian rangelands. *Proceedings of the 11th Australian Weeds Conference.* University of Melbourne, Melbourne, pp. 205–214.

Wilson, A.D., Tongway, D.J., Graetz, R.D. and Young, M.D. (1984). Range inventory and monitoring. *In:* G.N. Harrington, A.D. Wilson and M.D. Young (eds). *Management of Australia's Rangelands.* Division of Wildlife and Rangelands Research CSIRO, East Melbourne, pp. 113–127.

Young, M.D., Gibbs, M., Holmes, W.E. and Mills, D.M.D. (1984). Socio-economic influences on pastoral management. *In:* G.N. Harrington, A.D. Wilson and M.D. Young (eds). *Management of Australia's Rangelands.* Division of Wildlife and Rangelands Research CSIRO, East Melbourne, pp. 79–93.

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