AN OVERVIEW OF THE CURRENT STATUS OF WEED MANAGEMENT IN AUSTRALIAN RANGELANDS

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Summary Weed management in Australian rangelands encounters a wide variety of ecosystems, a diversity of plant species that are weeds from some perspective, and severe socio-economic constraints. Although this combination of factors suggests that ecology could contribute vitally to the efficiency of weed management, recent published research has emphasised traditional approaches involving herbicides and biological control. However, there seems to be an increased awareness of the need to understand how and why weed invasions occur and to take genuinely strategic approaches.

While several potentially important concepts and principles have emerged, most do not have a firm foundation in Australian rangelands research and there exists the threat that they could be canonized without an empirical basis. Weed management in Australian rangelands is generally decoupled from other aspects of management. Future research should centre not on specific control technologies but on integrative systems that address issues of temporal and spatial variation in weed dynamics and relationships between weed communities and their ecological and economic environment

INTRODUCTION

This paper reviews recent research on the weeds of Australian rangelands and considers how that research has contributed to the management of those weeds. Two key terms used in our title, 'weed' and 'rangelands', are anthropocentric and imprecise so we will begin by briefly describing the nature of Australian rangelands and their weed problems. We will then (i) describe the emphases of recent research, (ii) identify some important management principles, (iii) examine the relationships between the research and the management principles, (iv) describe the nature of current weed management as we see it and (v) suggest where the future of weed management in Australian rangelands should lie.

THE NATURE OF WEED PROBLEMS IN AUSTRALIAN RANGELANDS

'Rangelands' have been defined as lands occupied by native vegetation and used for grazing by domestic livestock and/or game species (Le Houerou 1991). In Australia, most rangelands have arid or semi-arid climates (Harrington *et al.* 1983) but there are also more mesic areas of natural or semi-natural vegetation in which the main land use is pastoralism (Taylor and Whalley 1976). Harrington *et al.* (1983) refer to nine broad Australian rangeland types (semi-arid woodlands, chenopod shrublands, mallee, Mitchell grasslands, tropical and sub-tropical woodlands, arid mulga woodlands, central arid woodlands and temperate rangelands) that together constitute about 6.5 million square kilometres. Young *et al.* (1984) classified about 70% of Australia as 'rangelands' using data on the long term availability of water for plant growth. This definition ignores land use and excludes temperate rangelands of higher elevation in eastern Australia. Under this definition, extensive grazing of livestock is the main human activity on 63% of the rangelands, designated Aboriginal lands occupy 12%, conservation areas occupy less than 3 and 21% of the rangelands are 'vacant' (Foran *et al.* 1989). This review is relevant to areas of native vegetation that are used for pastoralism and to ecologically similar non-pastoral country.

The bioclimatic and socio-economic circumstances of Australian rangelands largely determine the nature of its weed problems. Weeds of a particular area of rangeland may be identified as such by the predominant land user but this is often inadequate because most Australian rangelands are subject to multiple use and there are many interactions between parcels of land that differ in their major land use.

A species may be labelled a weed because of its geographical origin, because of its impact on a particular land use, or because of more encompassing effects on ecosystem structure and function. Thus, from a conservation perspective, a plant may be given weed status because it is not a native plant. From a land use perspective, a native or an exotic species may be labelled a weed because it is toxic to livestock, reduces plant production through competition or interferes with animal husbandry. From an ecological viewpoint a species may be called a weed because it changes the structure of a plant community or the hydrology of the ecosystem. These types of problem are certainly not unique to rangelands but are particularly prevalent there. The same species may be identified in one situation, or by one group of users, as a useful plant and in another as a weed. This is exemplified by the case of introduced pasture species in northern Australia. Of 463 grasses and legumes that were deliberately introduced, 60% have been listed as weeds from

either an agricultural or conservation perspective or both (Lonsdale 1994). Likewise, several exotic grass species are recommended by Agriculture Western Australia for sowing in low rainfall areas even though they are recognised by environmentalists as major environmental weeds.

The weed flora of Australian rangelands is probably more diverse than that of other land use systems. The flora of western New South Wales contains 2027 species. Of these, 407 (about 20%) are exotic (Cunningham *et al.* 1981) and so could be considered weeds from a conservation perspective. At least 126 species (6%) from this flora have been identified as being toxic to livestock (Curran and Grice 1992) and so could be considered as weeds from the pastoralist's perspective. Of the toxic plants, 64 (51%) of the species are native to the region. A full range of growth forms is represented among species that could be regarded as weeds.

Weed management in Australian rangelands thus encounters not only a great diversity of plant species that differ enormously in ecology, but a great variety of ecosystems and widely varying views on what constitutes a weed. Moreover, they occur as components of complex plant and animal communities that are subject to extensive management systems that severely constrain weed management practices. Over the vast majority of Australia's rangelands, socio-economic factors limit resources available for weed management and should be considered in determining research priorities for weeds in Australian rangelands.

RECENT RESEARCH EMPHASES

Trends in emphasis in Australian rangeland weed research can be considered in terms of (i) the attention given rangelands relative to other land use systems, (ii) the species that have received attention and (iii) the objectives of the research. We have examined presentations made at the Conferences of the Council of Australian Weed Science Societies (CAWSS) in 1978, 1984, 1987, 1990 and 1993.

The number of presentations dealing with rangelands has increased with successive conferences, but there has been no clear trend in the attention given to rangelands relative to other land use systems. Sixty three presentations specifically deal with weeds of rangelands or rangeland weed issues. (Some additional studies could arguably been included in this list; others could legitimately be omitted.) Overall, this represents approximately 10% of total presentations, ranging from 4.7% (7th CAWSS 1984) to 11.6% (8th CAWSS 1987) at individual conferences. The rangelands are grossly underrepresented relative to the proportion of the continent that they occupy (70%) but probably fairly represented in economic and biodiversity terms.

Rangelands presentations at the five conferences of CAWSS have specifically mentioned 26 species, including trees, shrubs, grasses, forbs and floating aquatic plants representing 15 families. Sixteen of the 26 species are exotic. Most presentations (52 out of 63) related to single species and a very few species accounted for the majority of studies. The five species that received most attention were *Cryptostegia grandiflora* (9 studies), *Mimosa pigra* (6 studies), *Acacia nilotica, Mimosa invisa* and *Xanthium pungens* (2 studies each). Nine presentations dealt with a small group of native woody weeds. Together, these species and limited species groups accounted for 30 of the 63 studies that specifically dealt with rangeland weeds. Recent research has only dealt with a fraction of what could be regarded as the total rangeland weed flora.

To examine the objectives of rangeland weed research, we categorized the 63 titles into ten fields: herbicides, biocontrol, fire, goats, ecology, integrated control, socioeconomics, invasion dynamics, management systems, general. Five papers dealt with more than one major issue and were allocated to more than one category. 'General' presentations usually related to individual species or weed situations. The low numbers of presentations available for this analysis make it difficult to draw conclusions about research emphases or trends but some patterns can be discerned.

The first concerns the overall emphases. Two fields, herbicides and biocontrol, have dominated presentations. Work involving herbicides has made up 30% and biocontrol 13% of all presentations. On the other hand, while numerous presentations have had some ecological content, very few studies have had their primary focus on the ecology of rangeland weeds, whether of individual species or of general aspects of the ecology of weeds in rangelands. Most other fields have been represented by five or fewer presentations. General outlines of individual species have been relatively common. Notably few studies (none?) focused on the effects of weeds in rangelands.

The second concerns apparent trends in emphasis. While work involving herbicides has dominated presentations there may be a trend to less attention being given to this field, though the proportional contribution by biocontrol work has remained relatively constant. Low numbers make it impossible to identify trends in the proportional contribution by presentations dealing with weed ecology, the role of fire and goats in weed management and socio-economic factors. Three fields do, however, appear to have become more prominent at recent conferences, particularly the 1993 conference. These are invasion dynamics, studies of management strategies and management systems, and the integration of different weed control technologies.

These apparent trends should be regarded as somewhat speculative. One cannot be certain if they reflect changing priorities in research and management of weeds in Australian rangelands. Decisions made by conference organizers, the timing of medium to long-term work in relation to conferences, the possibility that studies involving fields that have not received emphasis at Conferences of CAWSS tend to be published elsewhere, and many other factors may have given rise to the patterns we have identified. If they are accepted as genuine, however, what do they mean? We identify four significant points.

i. The need to understand how and why weed invasion or proliferation occur is, perhaps, being more widely recognised. If this is the case, we argue that the process of recognition is still very much in its early stages and should be accelerated.
ii. Any increase in the attention given to invasion, management strategies and integrative approaches to weed control would indicate a trend away from seeking simple solutions to complex problems. They are complex in that they involve large areas, an erratic environment, severe socio-economic constraints and a diversity of weed species.
iii. A need for methods of weed management that are appropriate to extensive rangelands is being recognised. Expensive, labour intensive techniques of weed control, such as many applications using herbicides or mechanical techniques, are not broadly applicable in the rangelands. This is consistent with a decrease in the attention given to herbicides.
iv. The social factor is increasingly being recognised as being vital to sound weed management practices. Presentations on management strategies and systems encompass issues such as the management of weeds on aboriginal lands and community approaches to weed management.

For comparison with the emphases of presentations at conferences of CAWSS, only 16 (5%) of the 310 papers, articles and short communications contained in The Rangeland Journal (formerly The Australian Rangeland Journal) from its inception in 1976 until 1995, focused on weeds. Seventy five per cent of weed papers dealt with native woody weeds, their ecology and general biology, control by fire, goats and mechanical and chemical techniques, and their effects on soil and hydrological processes. The patterns are similar in the presentations made at recent (1990, 1992 and 1994) Conferences of the Australian Rangeland Society. Nine per cent of the total of 295 presentations dealt with weeds. Of the 28 weed presentations, 59% were on native woody weeds, almost one third dealt with specific control measures and another third consisted of general reports on individual weeds or weed communities. Twenty one per cent (compared with 3% for CAWSS) of presentations focused on weed ecology.

PRINCIPLES OF WEED MANAGEMENT IN RANGELANDS

While there is a substantial literature directly related to weeds in Australian rangelands, principles and general concepts of importance to management do not readily emerge from it. Much of the literature tends to be species- or technique-specific and often little conscious attempt is made to draw general principles out of a particular piece of work. There has been no real attempt to synthesize formal principles of weed management for Australian rangelands. Moreover, there has been little effort to link knowledge of rangeland weeds to general principles of rangeland management, and this at a time when many would argue that there has been a major paradigm shift in relation to our understanding of how rangelands function, in particular, of the temporal and spatial patterns of change in rangelands vegetation. However, we identify five concepts and six general principles that are potentially important to weed management. In some cases, the links between concepts/principles and the recent rangeland weed literature are not clear.

Concept 1. Role of dispersal An effective dispersal mechanism will increase the likelihood of a plant becoming a weed. This does not mean that a species can only become a weed if it is capable of dispersing over long distances, but effective long-range dispersal will influence the rate of colonization and the perception of weediness. Managing dispersal can be an important component of an overall control strategy. Brown and McIvor (1993) argued that management of woody weeds should focus on minimizing dispersal and using disturbances, such as fire, that can disadvantage the weed species, rather than rely on competition from herbaceous species.

Concept 2. Competition It has been widely advocated that a dense and vigorous herbaceous stratum is important in deterring the proliferation of woody plants in grasslands and grassy woodlands (Walker *et al.* 1981, Harrington 1991). However, Brown and McIvor (1993) suggest that there is little evidence to support this and that preventing the proliferation of undesired woody plants requires more than maintaining the herbaceous stratum and mechanically or chemically removing established plants. Competition from herbaceous perennials may be important in reducing the growth rates of shrub seedlings. Competition from herbaceous perennials, particularly grasses, is likely to be important in reducing the risk of invasion by herbaceous weeds, but there is little

quantification of this possibility. Circumstances in which competition is important should be more clearly identified.

Concept 3. Disturbance Consistent with the concept that competition minimizes the risk of invasion, is the notion that disturbed communities are more prone to weed invasion. In pastoral rangelands, grazing by livestock is a major form of disturbance and heavy grazing is frequently related to weed invasion or proliferation. However, other types of disturbance have been proposed as counteractive to increases in weeds. A notable example of this is of the relationship between native woody weeds and fire regimes in semi-arid woodlands of southern Australia (Hodgkinson and Harrington 1985). Fire is a prominent factor in many rangeland communities that include a graminaceous understorey, and it plays a role in governing the ratio between woody and herbaceous plants (Lacey *et al.* 1982). The response of weeds to 'disturbance' will depend upon the type of disturbance. It is overstatement to say 'weeds can only invade a plant community that has been disturbed' (Fox 1991). Certainly some exotic species are able to invade natural vegetation without gross levels of exogenous disturbance (McIntyre 1993). The occurrence of weeds is often taken to indicate disturbance.

Concept 4. Invasion patterns Weeds will 'move' through a landscape in different ways, that is, with different spatial patterns. Describing these patterns and understanding their ecological basis can be important in the management of rangeland weeds (Brown and Carter 1996). The principle is applicable at a range of scales. Moody and Mack (1988) discussed the theoretical relationship between the rate of invasion (increase in total area occupied) and the 'initial' distribution of the species. The invasion rate will be higher where there are several dispersed foci of invasion than where there is a single founding colony, even given the same total area of the initial infestations.

Concept 5. Non-equilibrium models of change in rangeland systems Many rangeland ecosystems are widely acknowledged as non-equilibrium systems in which change occurs episodically. Episodes may correspond to management opportunities and can be described in state-and-transition models (Westoby *et al.* 1989). Even though weed invasion constitutes a major type of ecosystem change, weed science has been slow to take up these concepts and apply them to management. Non-equilibrium models could provide a basis for management. In particular, they could help relate management to the erratic nature of weed invasion by explaining and predicting changes in weed populations. They can provide a basis for management strategies that are responsive to the temporal patterns of change. This requires that weed management in rangelands is seen as a component of natural resource management (Brown and MacLeod 1996).

Principle 1. Prediction Three types of prediction are potentially important: predicting which plants will become weeds, predicting the Australian range of an actual or potential weed and predicting the patterns of spread of a specific weed. Hobbs (1993) pointed out that there are serious grounds for concern that many more plant species, some of which will inevitably have weed potential, will reach Australia. An ability to predict which plants have weed potential would give an opportunity to reduce risk from exotic species. Some effort has been directed at developing a predictive capacity. Newsome and Noble (1986) considered the eco-physiological characteristics of invading plant species but concluded that 'there is no one suite of eco-physiological characteristics which may allow successful invasion'. Similarly, an attempt to predict the Australian weed status of southern African plants was only able to account for about 40% of the variation in Australian weed status (Scott and Panetta 1993). Prediction of weediness is notoriously difficult especially for plants that may be a problem from a conservation perspective (Hobbs 1993, Lonsdale 1994). This is partly because weediness is as much a function of the interaction between the plant (potential weed) and its environment as a feature of the plant itself.

Bioclimatic analysis, using climatic data from the species' native or current introduced range, has been used to predict the potential range of the species. The reliability of this type of prediction will depend strongly on the extent to which distribution is climatically determined. Other factors such as soil type and hydrology could constrain a species within the region of its climatic potential. Predicting potential range is probably much more reliable than predicting weediness in absolute terms, but range predictions can only be tested by history and have not been rigorously assessed.

On a finer scale, predicting patterns of spread across a heterogeneous landscape would facilitate more efficient targeting of management activity. It would, for instance, identify those parts of a landscape that were most likely to be occupied early in the invasion process and which could function as corridors for the colonization of new sites. Little effort has been put into this type of prediction though, perhaps, it would be the most useful.

Principle 2. Prevention The principle of preventing invasions by exotic weeds can operate at a national scale,

essentially by implementing strict control over plant introductions, or by preventing range expansion by within Australia.

At the national scale, Lonsdale (1994) proposed the precautionary principle that, if it is not possible to decide prior to introduction whether a plant will become a weed, the appropriate response is to tightly regulate introductions. The draft National Weed Strategy recommends that an individual or organization that plans to import a plant species be made responsible for demonstrating low risk of it becoming a weed and for pre-emptively identifying control measures that could be applied in the event of weed potential being realized. In a rangelands context, prevention may not be absolute but could involve accepting some relatively low density of a weed species and managing to avoid transitions to states of weed dominance (see Concept 5, Westoby *et al.* 1989).

Principle 3. Detection To manage a weed one must have an indication of where it occurs. Both prevention at the local and regional scale and, by implication, early intervention, require early detection of both weed potential and the location of infestations. Detection would be facilitated by having a systematic monitoring and recording program.

Principle 4. Early intervention A weed will be more easily managed if control/management measures are undertaken early in the invasion process. Again this can operate at a number of scales: national, regional, catchment/landscape, land use unit (property) and management unit (paddock). Obviously, early intervention depends upon detection.

Hobbs (1993) points to this principle as a means of minimizing the risk of 'new' weeds becoming prominent. Acknowledging that a plant species can be present for an extended period without being recognised as a major problem, he argues that early detection of a change in status will be important, particularly given that many new plant species will inevitably become naturalized.

Principle 5. Integration The concept of integrated management is not new. It involves the integration of a number of control measures into a management package (Noble *et al.* 1992).

Principle 6. Strategic weed management Combining the integration of control measures with a spatial understanding and application is a precursor to a truly strategic approach to weed management. To be genuinely strategic, an approach must at least be applicable at the scale of an ecological unit, for example a large catchment. Many weed situations require a strategy that is relevant at a national level but incorporating elements that are applicable to regional and finer ecological scales. Weed management must also be considered in relation to other aspects of land and animal management. In particular, in rangelands there is a need to manage the whole flora rather than simply individual weed species or populations.

These principles have not been derived from research conducted on the weeds of Australian rangelands though some have closer links than others to rangelands work. Neither have they all been effectively tested through research.

NATURE OF CURRENT WEED MANAGEMENT

How does current management reflect recent research and the concepts and principles we have identified? We address this question by examining some examples, looking at two case studies in particular.

Case study 1. Native 'woody weeds' of the semi-arid woodlands Native shrubs have featured prominently as weeds of rangelands, particularly in the climatically unpredictable semi-arid woodlands of western New South Wales and south-western Queensland. Several species are involved, either singly or in combination, but there has been a long history of grouping them as 'woody weeds' and treating them more or less as a single problem. They vary considerably in their biology.

When the region was settled for sheep pastoralism in the 1850s, the country was generally an open woodland with a mid-storey of scattered shrubs, localized shrub patches and an herbaceous stratum of perennial grasses. The shrubs began to proliferate soon after settlement and the problem was sufficiently severe by the turn of the century for the issue to be a major focus of a New South Wales Royal Commission into the state of the western lands (Anon. 1901). An Inter-departmental Committee was formed in the late 1960s to examine the problem of 'scrub and timber regrowth in the Cobar-Byrock district and in other areas of the Western Division of New South Wales' (Anon. 1969). Scientific research began in the 1960s followed by more extensive work in the 1970s and 1980s. This focused on what were seen as key aspects of the ecology of the main species, especially responses to fire, because fire was identified as an environmental factor that could be used as a broad scale management tool. As well as seeking appropriate management practices, these studies sought to explain the transition from grassy woodland to shrubland. As a result of this research, a case for fire being the main broadacre tool for shrub management was advanced (Hodgkinson and Harrington 1985). Significantly, fire had also been seen as a key factor by the Royal Commission (Anon. 1901) and the

Inter-departmental Committee (Anon. 1969). Other work has tested herbicides and application technologies and compared mechanical control methods. The potential for using goats to control the more palatable shrub species has also been explored (Harrington 1979, Muir 1993).

In spite of this activity and attention, there is no evidence that western New South Wales has fewer woody weeds or less area covered by woody weeds than it did, say in the 1950s. A monitoring project using satellite imagery to detect changes in woody plant cover across large areas of western New South Wales over the last 10–20 years suggests that, during this period there have been large increases in woody plant cover in many areas of the region (David Gardiner personal communication).

The emphasis in the field has been on mechanical and chemical control techniques. Using mechanical methods to remove shrubs has been either associated with development for cropping or part of agency-assisted programs. The use of fire has not been at all prominent in spite of its promotion by researchers and agency advisers. There are several reasons for this. There has been a long history of fire suppression in western New South Wales and this may have ingrained a social opposition to its use. There is a cost in terms of lost production before and after burning. There is a risk in the use of fire in that the user could be liable to damage to other properties. There is a perceived threat that burning promotes germination of shrubs. Low and erratic rainfall limits fuel production and opportunities for burning. Thus, this most prominent output of 30 years research has not been applied effectively. The principles of detection, early intervention and prevention at the local scale have been advocated but it is not clear that they have been widely accepted and put into practice by managers. There is no clear indication that ecological concepts of competition, disturbance, and spatial and temporal patterns of invasion are being widely used at a management level. The integration of control technologies remains at the level of research (Noble *et al.* 1992).

Notably, integration at an ecosystem/whole property management level is not practiced effectively. Managers view woody weeds as an isolated problem and this may partly explain the apparent preference for mechanical and chemical control techniques. In particular, grazing management is not being linked to woody weed management and without this link being recognised, the chances of effective uptake of fire as a management tool is greatly reduced. Greater attention is being given to the management of 'total grazing pressure' (Ken Hodgkinson personal communication), but this attention must find interpretation as reduced grazing pressure if there is to be a flow through to improved management of woody weeds.

It is recognised by many that there has been a communication gap between researchers and land managers and this may have been partly responsible for the poor uptake of research results into weed management. A Woody Weed Task Force formed in 1988 was intended to facilitate the development of woody weed management programs, in particular by aiding communication. The group includes representatives of pastoral industry bodies, State Government agencies and the CSIRO but it has not yet lead to real progress.

In New South Wales, native 'woody weeds' have been recognised in legislation such that the key species have been named under legalisation and some regulations put in place to facilitate woody weed control. Clearing of native vegetation on the leasehold lands of the Western Division of New South Wales is controlled by legislation and lease conditions but attempts have been made to legislatively separate clearing for woody weed control from clearing for other purposes. Under legislation, clearing includes burning so that permits are required before prescribed fires can be carried out. More recent legislation imposes more strict controls on activities that affect native flora and fauna and there is a perception that this will place further constraints on the management of native woody weeds (Russell Harland personal communication).

Case study 2. Exotic 'woody weeds' of northern Australia The situation with *Cryptostegia grandiflora* (Roxb.) R.Br. (rubbervine) provides an informative comparison with that of native shrubs in southern rangelands. *C. grandiflora* was identified as a problem plant in the early 1900s (Parsons and Cuthbertson 1992). It is now a major problem in tropical rangelands of northern Australia. *C. grandiflora* is an exotic shrub-vine, introduced late in the nineteenth century and widely planted as an ornamental. It became naturalized and has spread widely in northern and eastern Queensland. Its current distribution covers an estimated 350 000 square kilometres and bioclimatic analysis suggests there a potential for it to extend its range into the Northern Territory and Western Australia to perhaps 20% of the continent (Tomley 1995).

As for native shrubs in western New South Wales there has been a strong research emphasis placed on mechanical and chemical control. Additionally, a biological control program in operation since 1985 has identified, tested and released two agents, a moth and a rust fungus. A recent publication (Vitelli 1995) refers to some of the principles we have outlined. Prevention and early intervention at the scale of the land use unit are highlighted as important but other principles are not explicitly invoked, particularly those that relate management of the species

to its ecology and that of the communities in which it occurs.

With rubbervine, the plant's dispersal ability must be addressed in developing management options. With other exotic shrub weeds of northern Australia, the potential to do something about dispersal *per se* has been identified at research and extension levels. The proposal to establish an extensive buffer zone to minimize the westward spread of rubbervine is a potentially useful strategic development (Fuller 1993b), pertinent in that it involves collaboration across state boundaries. Three important species, *Acacia nilotica* (Benth.) Brenan (prickly acacia), *Prosopis* spp. (mesquite) and *Ziziphus mauritiana* Lam. (chinee apple) are cattle-dispersed and the risks of colonization of new areas by these weeds may be minimized by controlling stock movements (Jeffrey 1995, Grice 1996). It is not apparent that this is occurring.

As with the management of native shrubs in the semi-arid rangelands, at the level of application, management of rubbervine is generally decoupled from other aspects of land management. The species is treated more or less in isolation from other weed ecological problems. Fully integrative strategies that address the problem at management unit, land use unit, catchment, region and national scales are not yet effectively implemented.

Other examples Overall, for most rangeland weeds, we are well short of having effectively implemented, comprehensive strategies that incorporate a broad array of general principles. In some cases the principles we have outlined are being incorporated. The principle of early intervention is being applied to *Tamarix aphylla* (athel pine), insofar as control measures are being applied while its Australian distribution is still very limited relative to its potential (Fuller 1993a) and to *Chromolaena odorata* (siam weed) and *Alternanthera philoxeroides* (alligator weed) in Queensland.

Probably the most comprehensive development of a strategic approach that adopts general rangeland weed management principles has been for the management of *Mimosa pigra*. For this species, research has covered the species' ecology and population dynamics, and chemical, mechanical and biological control. Guidelines to the management of the species have considered predictions of potential range (Lonsdale 1992), dispersal, prevention of spread and the need for early intervention (Benyasut and Pitt 1992), monitoring to detect infestations (Pitt and Napompeth 1992), the role of competition and disturbance (Benyasut and Pitt 1992) and temporal patterns of invasion (Lonsdale 1992). These ideas have been incorporated into recommendations for integrated management (Miller *et al.* 1992) but the long term outcome of this work is uncertain. A catchment approach is critical to the effective management of *M. pigra*. This has been most easily achieved where catchments fall within single management units, such as Kakadu National Park or the Oenpelli flood plain. Where it is necessary to transcend management units, co-ordination is essential. Groups such as the Mary River Landcare Group have successfully co-ordinated efforts at a catchment level, but on other river systems, where this co-ordination is absent, management tends to be *ad hoc*. This is particularly true where individual pastoral leases cover only part of a catchment (Grant Farrell personal communication).

These examples suggest that in spite of major effort, and some apparently desirable trends, progress has been limited. Limits to progress could be that research has been inappropriately targeted, research results have not been adequately translated into management recommendations, or that managers have been unable or unwilling to take them up. All three seem likely but to different degrees in different situations. A further probability is that the slow progress reflects the episodic nature of vegetation change in rangelands. This may, for instance, have had a part to play in the poor uptake of fire in the management of native woody weeds in the semi-arid woodlands, because opportunities for fire come, on average, only once in ten years (Walker 1981). This points to the need for a more effective combination of research, education/technology transfer and legislative/regulatory functions.

RESEARCH FOR MORE EFFECTIVE MANAGEMENT

The attention given to weeds of rangelands has remained steady relative to the overall amount of weed research carried out. A small number of high profile exotic and native woody weeds have received the bulk of this attention. Work on herbaceous species has been depauperate, there being a long list of plants that could be regarded as weeds particularly from a conservation perspective, but few of these have received attention (Tiver 1992). There has, for example, been little effort put into annual Mediterranean weeds of the southern rangelands or prospective pasture species that are or could become weeds in the north.

Most research on weed management has focused on specific control methods and technologies. The results of such studies are useful but there is a need to incorporate them into integrative systems that are appropriate to various situations. Further, in the rangelands more than anywhere, weeds research should take an ecosystem approach. The key management question then becomes not 'How do we most effectively kill this weed?' but 'How do we most effectively manage this system so that the

problem of weeds is minimized?'. To do this, weed research for rangelands should more comprehensively address issues of spatial and temporal variation in weed population dynamics and relationships between weed and environment. Weed populations are made up of numerous interacting subpopulations that can be defined at various scales. Understanding these interactions will help identify appropriate objectives and achieve them by applying suitable treatments and combinations of treatments. Perhaps even more important, however, is identifying which subpopulations should be the focus of management for the most effective use of limited weed management resources. This will depend upon understanding how the ecology of a species, and in particular demographic characteristics, vary across the landscape and between climatic zones. Applying the outcomes of this research will also require better systems for monitoring change in weed populations, again at several scales: management unit (property), catchment, region, national.

In rangelands, weed management should be integrative and strategic, based on an understanding of invasion patterns, the importance of dispersal, the roles of disturbance and competition, and of non-equilibrium models of vegetation change. It must address the need for prediction, detection and prevention. Some progress has been made toward these ends but there is still a long way to go. A weed management strategy should encompass the potential range of a weed species and contain components that are operable at a full range of scales from the management unit (paddock) to the national level. An integrative approach should not be confused with a strategic approach. The building block of most strategies should be applicable to the land use unit (pastoral property, national park) and to clusters of such units, ideally amalgamated by catchments. Action by managers of such units and clusters of units is most important, with the roles of state government agencies being education and facilitation rather than actual weed management.

Finally, the objectives of a weed management strategy should be clearly established. Eradication is rarely a realistic objective. It will only be realistic in the very early stages of an invasion. When eradication is not realistic, suitable alternative objectives must be devised and this will entail identifying levels of infestation that are tolerable and devising management schemes that can achieve those tolerable levels. This requires some knowledge of weed impacts. Where large areas of rangelands are already subject to heavy infestations of a weed, containment of those heavy infestations should be the objective. Containment can be implemented at a range of scales because even within infested land use units, catchments or districts, there are areas that have low weed densities or are weed free. Thus, the development of weed management objectives should also involve a strong spatial element. As part of the process of developing objectives, it is necessary to identify responsibilities and means of ensuring that responsibilities are met.

Future work relevant to rangelands should focus on (i) developing approaches for managing weed systems not individual weeds, (ii) devising and testing strategies that can be applied by the managers of land use units working in collaboration with one another, (iii) describing and explaining weed invasion processes at a range of scales, (iv) identifying appropriate objectives for different weed situations.

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REFERENCES

Anon. (1901). Royal Commission in Inquire into the Condition of Crown Tenants. Western Division of New South Wales. (NSW Government Printer, Sydney).

Anon. (1969). Report of the Inter-departmental Committee on scrub and timber regrowth in the Cobar-Byrock district and other areas of the Western Division of New South Wales. (NSW Government Printer, Sydney).

Benyasut, P. and Pitt, J.L. (1992). Preventing the introduction and spread of *Mimosa pigra*. *In* 'A Guide to the Management of *Mimosa pigra*,' ed. K.L.S. Harley, pp. 107-8. (CSIRO, Canberra).

Brown, J.R. and MacLeod, N.D. (In press). Integrating ecology into natural resource management policy. *Environmental Management* 20.

Brown, J.R. and McIvor, J.G. (1993). Ecology of woody weed invasion in the tropical woodlands of north-eastern Australia: implications for management. Proceedings of the 10th Australian and 14th Asian-Pacific Weed Conference, pp. 471-4.

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

Curran, G. and Grice, T. (1992). Poisoning caused by plants. *In* 'Rangeland Management in Western NSW', pp. 102-13. (NSW Agriculture, Orange).

Foran, B.D., Friedel, M.H., MacLeod, N.D., Stafford Smith, D.M. and Wilson, A.D. (1989). 'The Future of Australia's Rangelands'. (CSIRO, Canberra).

Fox, M.D. (1991). Developing control strategies for environmental weeds. *Plant Protection Quarterly* 6, 109-10.

Fuller, M.R. (1993a). The invasion and control of *Tamarix aphylla* on the Finke River, central Australia. Proceedings of the 10th Australian and 14th Asian-Pacific Weed Conference, pp. 44-6.

Fuller, M.R. (1993b). Proposal to establish a national buffer zone to prevent the westward movement of rubber vine (*Cryptostegia grandiflora*) in Australia. Proceedings of the 10th Australian and 14th Asian-Pacific Weed Conference, p. 132.

Grice, A.C. (In press). Seed production, dispersal and germination ecology of *Cryptostegia grandiflora* and *Ziziphus mauritiana*, invasive shrubs in tropical woodlands of northern Australia. *Australian Journal of Ecology.*

Harrington, G.N. (1979). The effects of feral goats and sheep on the shrub populations in a semi-arid woodland. *Australian Rangeland Journal* 1, 334-45.

Harrington, G.N. (1991). Effects of soil moisture on shrub seedling survival in a semi-arid grassland. *Ecology* 72, 1138-49.

Harrington, G.N., Wilson, A.D. and Young, M.D. (1983). 'Management of Australia's Rangelands'. (CSIRO, Melbourne).

Hobbs, R.J. (1993). Dynamics of weed invasion: implications for control. Proceedings of the 10th Australian and 14th Asian-Pacific Weed Conference, pp. 461-5.

Hodgkinson, K.C. and Harrington, G.N. (1985). The case for prescribed burning to control shrubs in eastern semi-arid woodlands. *Australian Rangeland Journal* 7, 64-74.

Jeffrey, P.L. (1995). Prickly acacia. *In* 'Exotic Woody Weeds and their Control in North West Queensland', pp. 3-9. (Queensland Department of Lands, Brisbane).

Lacey, C.J., Walker, J. and Noble, I.R. (1982). Fire in Australian tropical savannas. *In* 'Ecology of Tropical Savannas,' eds. B.J. Huntley and B.H. Walker, pp. 246-72. (Springer-Verlag, Berlin).

Le Houerou, H.N. (1991). Rangeland and rural space management: a challenge for development and environment. Abstracts of the 4th International Rangeland Congress, Montpellier, France.

Lonsdale, W.M. (1992). The biology of *Mimosa pigra*. *In* 'A Guide to the Management of *Mimosa pigra*', ed. K.L.S. Harley, pp. 8-32. (CSIRO, Canberra).

Lonsdale, W.M. (1994). Inviting trouble: introduced pasture species in northern Australia. *Australian Journal of Ecology* 19, 345-54.

McIntyre, S. (1993). The nature of exotic invasions in herbaceous vegetation of high and low species richness: implications for conservation and management. Proceedings of the 10th Australian and 14th Asian-Pacific Weed Conference, pp. 466-70.

Miller, I.L., Napompeth, B., Forno, I.W. and Siriworakul, M. (1992). Strategies for the integrated management of *Mimosa pigra*. *In* 'A Guide to the Management of *Mimosa pigra*', ed. K.L.S. Harley, pp. 110-4. (CSIRO, Canberra).

Moody, M.E. and Mack, R.N. (1988). Controlling the spread of plant invasions: the importance of nascent foci. *Journal of Applied Ecology* 25, 1009-21.

Muir, S. (1993). Integrated control of woody weeds in western New South Wales. *In* 'Pests of Pastures: Weed, Invertebrate and Disease Pests of Australian Sheep Pastures', ed. E.D. Delfosse, pp. 390-4. (CSIRO, Melbourne).

Newsome, A.E. and Noble, I.R. (1986). Ecological and physiological characters of invading species. *In* 'Ecology of Biological Invasions: An Australian Perspective', eds. R.H. Groves and J.J. Burdon, pp. 1-20. (Australian Academy of Science, Canberra).

Noble, J.C., Grice, A.C., MacLeod, N.D. and Müller, W.J. (1992). Integration of prescribed fire and sub-lethal chemical defoliation for controlling shrub populations in Australian semi-arid woodlands. Proceedings of the First International Weed Control Congress 2, 362-3.

Parsons, W.T. and Cuthbertson, E.G. (1992). 'Noxious Weeds of Australia'. (Inkata Press, Melbourne).

Pitt, J.L. and Napometh, B. (1992). Survey techniques for *Mimosa pigra*. *In* 'A Guide to the Management of *Mimosa pigra*', ed. K.L.S. Harley, pp. 33-6. (CSIRO, Canberra).

Scott, J.K. and Panetta, F.D. (1993). Predicting the Australian weed status of southern African plants. *Journal of Biogeography* 20, 87-93.

Taylor, J.A. and Whalley, R.D.B. (1976). The philosophy of range management research in Australia. *The Journal of the Australian Institute of Agricultural Science* 42, 181-6.

Tiver, F. (1992). Herbaceous weed invasion in the north-eastern pastoral districts of South Australia. Australian Rangeland Society 7th Biennial Conference, pp. 235-6.

Tomley, A.J. (1995). The Biology of Australian Weeds 26. *Cryptostegia grandiflora* R.Br. *Plant Protection Quarterly* 10, 122-30.

Vitelli, J.S. (1995). Rubber vine. *In* 'Exotic Woody Weeds and their Control in North West Queensland', pp. 14-7. (Queensland Department of Lands, Brisbane).

Walker, J. (1981). Fuel dynamics in Australian vegetation. *In* 'Fire and the Australian Biota', eds.

A.M. Gill, R.H. Groves and I.R. Noble, pp. 101-27. (Australian Academy of Science, Canberra).

Walker, B. (1993). Rangeland ecology: understanding and managing change. *Ambio* 22, 80-7.

Walker, B.H., Ludwig, D., Holling, C.S. and Peterman, R.M. (1981). Stability of semi-arid savanna grazing systems. *Journal of Ecology* 69, 473-98.

Westoby, M., Walker, B. and Noy-Meir, I. (1989). Opportunistic management for rangelands not at equilibrium. *Journal of Range Management* 42, 266-74.

Young, M.D., Walker, P.A. and Cocks, K.D. (1983). Distribution of influences on rangeland management. *In* 'Management of Australia's Rangelands', eds. G.N. Harrington, A.D. Wilson and M.D. Young, pp. 333-6. (CSIRO, Melbourne).