DESERT KNOWLEDGE CRC

Buffel grass: both friend and foe

An evaluation of the advantages and disadvantages of buffel grass use, and recommendations for future research

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A report to the Desert Knowledge Cooperative Research Centre on *The dispersal, impact and management of buffel grass* (Cenchrus ciliaris) *in desert Australia*.

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The Desert Knowledge Cooperative Research Centre is an unincorporated joint venture with 27 partners whose mission is to develop and disseminate an understanding of sustainable living in remote desert environments, deliver enduring regional economies and livelihoods based on Desert Knowledge, and create the networks to market this knowledge in other desert lands.

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1. Summary

Buffel grass is an introduced pasture grass that has improved livestock production in many regions of inland Australia. It has brought economic benefits to pastoral communities, particularly in Queensland savannas where tree clearing to enhance pasture production has been widespread. Because buffel grass establishes readily, it has spread beyond areas where it was initially planted and in many cases is considered to be a naturalised species. In some situations this ready establishment has been welcome, but in others, it has not. Buffel grass is now a significant environmental weed of the arid conservation estate and modelling suggests that it has the capacity to expand across a large proportion of northern Australia.

We begin this evaluation with a brief history of buffel grass in Australia, followed by an examination of the advantages and disadvantages of buffel grass to the pastoral industry. We consider other benefits, such as rehabilitation of degraded land and dust control. Negative outcomes in relation to conservation values, non-pastoral industries, Indigenous community values, increased fire hazard and health impacts are outlined. It is clear from benefit-cost analyses, undertaken by others and summarised here, that it is easier to assess the economic benefits and costs of buffel grass to production, than to other land uses, particularly conservation. It is more difficult still to assess environmental, social and cultural benefits and costs. This does not imply that economic benefits of buffel grass to production outweigh other considerations but rather that we lack the tools to adequately assess other aspects.

Our own scoping studies provided useful outputs and directions for future research. Aerial survey was successfully trialled as a means of identifying buffel grass infestations across the entirety of Watarrka National Park, enabling the development of a strategic approach to management. A probability surface model showed that distance to drainage and tracks, followed by ruggedness, hummock grass cover and soil texture were the most important variables in determining the occurrence of buffel grass. Use of genetic markers indicated that hybridisation amongst cultivars is likely to be occurring more than previously thought, so that local adaptation is almost certainly taking place. No significant impacts of buffel grass cover alone were detected on vegetation, bird or ant species composition on rocky hillslopes. Since growing conditions were poor during the study, the results illustrate the difficulties inherent in short-term ecological studies in arid environments rather than provide evidence for or against buffel impacts on biodiversity.

Buffel grass can be both friend and foe. The management of this controversial group of cultivars will only be improved by the combined efforts of production and conservation interests. We recommend a number of research initiatives to develop new insights into sustainable use of buffel grass for both production and conservation outcomes, as well as for maintenance of other values. Research will not be sufficient on its own, but will require political will to ensure implementation and a collaborative approach to sustainable use.

1.1 Recommendations

A strategic management program for sustainable use of buffel grass for production and conservation should be developed and implemented, supported by the following research:

1. Determine whether there are effective grazing regimes – in land systems of different susceptibility to colonisation – for maintaining/containing buffel grass, reducing fuel loads in key locations, and minimising impacts on biodiversity. Are there threshold levels of buffel grass cover below which biodiversity impact is minimised and pastoral production is not compromised?
2. Improve understanding of the relationship between invasion potential of buffel grass and underlying disturbance in order to identify opportunities for mitigating practices
3. Determine the key factors affecting recovery potential for landscapes colonised by buffel grass. Are some land systems more recoverable (assessed in terms of effort invested for biodiversity gains achieved) than others? What is native seed bank survivability under varying buffel regimes? Is recovery potential affected by density or duration of buffel colonisation?
4. Investigate whether there are locally adapted forms of buffel grass emerging through sexual seed production
5. Determine whether, in view of 4, there are varieties (cultivars or locally adapted forms) of buffel grass with distinctive characteristics that can be used to select for:
   (a) pastorally desirable traits, e.g. palatability
   (b) environmentally desirable traits, e.g. low invasiveness
   How does substrate influence palatability vis-à-vis variety?
6. Further develop benefit-cost analysis at local or regional scale, valuing economic, environmental and social/cultural impacts of buffel grass for key land uses, to support priority-setting and trade offs
7. Further develop and implement a risk assessment model to help prioritise areas for management, where the greatest benefit is likely to result from control activities
8. Investigate the potential for buffel grass status to change as a consequence of climate change. For example, will buffel grass become more or less competitive relative to native grasses, are there implications for disease spread or nutrient decline, and what should be the management response?
9. Identify areas of agreement and contention across key stakeholder groups
10. Develop agreed key principles and priority actions as a platform for the development of a national strategy.

2. Introduction

Four outcomes were originally proposed for the Desert Knowledge CRC scoping project *The dispersal, impact and management of buffel grass (*Cenchrus ciliaris*) in desert Australia* and were revised in November 2004 in the light of experience gained up to that time. They were:

Outcome 1. Improved efficiency in the detection and mapping of buffel grass incursions into conservation areas. Monitoring programs based on an understanding of dispersal patterns and using cost-effective survey techniques have lower operating costs, and earlier detection will reduce the costs of remediation.

Outcome 2. Improved understanding of buffel grass dispersal. Understanding the patterns of distribution of buffel grass varieties across the landscape will allow better targeting of management actions. Identifying dispersal mechanisms, e.g. via roads and waterways, will allow inexpensive modification of routine practices, e.g. in road reserve management, to reduce rate of spread beyond areas of beneficial use and subsequent costs of control actions or direct impacts. The potential to control buffel grass spread within conservation areas will similarly be enhanced, e.g. by improved park design and access control, reducing remediation costs. As a result of 1 and 2, conservation area managers will be better equipped to prioritise areas for control action, e.g. by identifying the most vulnerable areas, or areas likely to serve as sources for continued spread.

Outcome 3. Improved understanding of biodiversity impacts. A small number of studies have indicated negative impacts of buffel grass on various species of native plant and animal. An improved documentation and understanding of these impacts for native species in central Australia will help to prioritise areas for control and survey as well as assist in the assessment of buffel benefit versus detriment.

Outcome 4. Evaluation of advantages and disadvantages of buffel grass use (and of particular varieties) and recommendations for future research. A literature review, combined with a discussion of the above outcomes, will form the basis of a qualitative assessment of the benefits and detriments of buffel grass use. This evaluation will be applicable to established activities, such as pastoralism and ecotourism, and to opportunities for new or developing activities, such as bush produce. Directions for future research will be identified, based on project outcomes and wider issues of buffel grass management.

This report is intended to meet the requirements of Outcome 4.

In addition, three papers have been submitted or are in preparation:

- Puckey *et al.* (submitted), regarding the use of aerial survey, predictive modeling and GIS for landscape scale management of buffel grass
- Smyth *et al.* (in preparation), regarding biodiversity impacts
- Waycott *et al.* (in preparation), addressing the implications of genetic diversity of buffel grass varieties for dispersal pathways and adaptation.

3. Buffel grass in Australia

Buffel grass was introduced to north-western Australia and central Australia, and probably elsewhere, in the 1870s by Afghan cameleers. The cameleers restuffed worn harnesses and saddle packs, discarding the original buffel grass stuffing brought from their homelands, and also hand spread it as they travelled (Humphreys 1967, Walter Smith, cited in Kimber 1986, Winkworth 2000). Much later, it was deliberately introduced to improve pasture production in the rangelands. It occurs naturally in northern Africa, the Middle East and across to India, and in Indonesia (Whyte *et al.* 1959, cited in Humphreys 1967).

Buffel grass spread slowly after its initial introduction. In central Australia for example it took about a century before rapid expansion occurred. Rex Hall (13/2/1985, in discussion with R.G. Kimber) said that cameleers introduced buffel grass to Ti-Tree Well shortly after the overland telegraph line was completed (in 1872). When he first came to central Australia, around 1929, Ti-Tree Well was the only place he saw it, but Jim Wickham used to visit and have his 'gins' dig it up, and he took it out to the Lander River and planted it. The first herbarium specimen in Alice Springs was recorded in 1930 by Government Botanist C.T. White (Humphreys 1967). During the 1950s, government agencies began trial plantings and pastoralists began spreading the seed on their own initiative (Des Nelson, pers. comm.). Sowing became widespread in central Australia following a prolonged drought from 1958 to 1965, and successful establishment brought relief from severe dust storms and erosion (Keetch 1981). Buffel grass remained limited in its distribution until a sequence of high rainfall events during the mid-1970s when its range expanded rapidly (Griffin 1993). Government agencies planted it extensively for revegetation and erosion control on parks and reserves until the mid-1970s (Albrecht and Pitts 1997) and on pastoral lands until the mid-1980s (C. Stanton, pers. comm., 23 June 2000). By the 1990s, it had been recognised as a significant environmental weed e.g. Griffin (1993), while it continued to be planted as a valuable pasture grass by many pastoral landholders into the 2000s. High rainfall events again in 2000–2002 led to another episode of rapid expansion.

Presently it covers extensive areas in the semi-arid and arid environments of Western Australia, Northern Territory, South Australia, Queensland and New South Wales. Hannah and Thurgate (2001) estimated that by 2000 buffel grass had naturalised between 30 and 50 million hectares in Queensland alone. Hall (2000) on the other hand suggested that the potential area of buffel in Queensland was some 22 m ha, with another 15 m ha marginally suited, on the basis of soils and climate. Chudleigh and Bramwell (1996), on the basis of ABS pasture areas, estimated the area of buffel grass in all of northern Australia to be 4.8 m ha in 1993 and 5.3 m ha in 1995, of which approximately half had established naturally. According to Hall (2000) there are no statistics available on areas of sown or naturalised buffel grass in Australia. Clearly, estimates vary wildly, depending amongst other things on the resolution of the data and how one defines areas of natural spread. A recent modelling study estimated that, at a coarse continental scale, over 60% of mainland Australia was potentially suitable for buffel grass establishment based on edaphic and climatic requirements (Lawson *et al.* 2004). Australia's Virtual Herbarium (2005) records show that in 2005 buffel grass occurred in all states except Tasmania.

Experience in other parts of the world has been similar. Buffel grass was introduced into Texas and northern Mexico in the 1930s and 1940s (Cox *et al*. 1988) and is now spreading 'exponentially' (Arriaga *et al.* 2004). Modelling based on rainfall, soils and elevation suggests the grass could cover up to 53% of the Mexican state of Sonora. It is widespread and expanding in places such as Arizona, where it has been declared a noxious weed (Piggott 1995, cited in Franks 2002). It has also become dominant in parts of the Hawaiian islands (Daehler and Carino 1998) and regions of Africa where it is not native (D'Antonio and Vitousek 1992).

Buffel grass is suited to areas with an annual rainfall of 300 – 1200 mm (Cameron 2004) but will do well with lower rainfall where soils receive run-on. In Australia, it occurs largely in the north, where summer rainfall predominates, and it does not tolerate flooding or waterlogging. Soil nutrients have more influence than soil texture on the ability of buffel grass to establish and grow. It is favoured by medium to high phosphorus levels as well as high nitrogen and a neutral to alkaline pH (Hall 2000), while it can do well on textures ranging from sands and loams to heavy cracking clays.

Buffel grass is not a simple entity. The most common species in Australia is *Cenchrus ciliaris*, which has given rise to diverse cultivars. Two others, *C. pennisetiformis* (Cloncurry buffel) and *C. setiger* (formerly *setigerus*, Birdwood grass) occur less commonly. According to Hall (2000) there have been 580 direct official introductions from some 35 countries of *Cenchrus* accessions into genetic resource centres of Australia. Of these, he says that 450 have been grown for seed increase, the step prior to field evaluation. These numbers do not include early accidental or direct introductions by visitors (Hall 2000). Most of the available literature does not distinguish between cultivars and so it should be borne in mind that 'buffel grass' generally refers to a complex which may have a diversity of attributes.

Consequently, assertions and anecdotal evidence about the growth and spread of buffel grass can be vehemently defended and denied but can all be true in particular circumstances. Its behaviour can vary widely depending for example on soils, climate, position in the landscape, fire or grazing regimes and time, as well as the particular cultivar. Silcock (1994) advised against attempting to separate cultivars on the basis of morphology, citing experienced pasture agronomists and Ferguson *et al.* (1978) who were unable to develop an unambiguous key despite using gel electrophoresis of seed protein. The data obtained in this study, using both field-collected samples and known cultivars that could be identified with a DNA fingerprinting toolkit, revealed that rarely were morphological observations able to establish cultivar accurately. In fact, evidence of between-cultivar hybridisation was obtained, suggesting new forms are emerging in the wild, making cultivar identification impossible.

4. A mixed blessing

Traits that distinguish successful introduced pasture grasses also facilitate their success as invaders of non-target areas, often at a landscape scale (Lonsdale 1994, Whitehead and Wilson 2000). Resilience to disturbance, ability to invade and establish self-sustaining populations in sites surrounding established stands, and to out-compete native grasses under grazing conditions are highly valued characteristics for grasses introduced for pasture improvement (Whitehead and Wilson 2000). However these are the same traits which enable extensive invasion of non-target areas and most jeopardize the diversity and function of native ecosystems (Whitehead and Wilson 2000, Franks 2002).

A review of exotic pasture species in northern Australia (Lonsdale 1994) found that the strongest predictors of whether an introduced pasture species would become a serious weed were whether a plant was useful, a good performer in trials, or persisted at a field site. A plant's successful introduction as a pasture species, and its subsequent value to the pastoral industry are therefore good predictors of its weedy potential: 'useful' introduced pasture species are found in significantly more weed lists than are 'non-useful' species (Lonsdale 1994). In semi-arid and arid environments buffel grass is considered to be both a useful pasture grass whose naturalisation is highly desirable (Humphreys 1967, Walker and Weston 1990, Cavaye 1991) and a serious environmental weed whose range expansion places native ecosystems at considerable risk (Humphries *et al.* 1991, Low 1997, Fairfax and Fensham 2000).

High levels of disturbance, such as flood, fire and heavy grazing, can assist the establishment of buffel grass (e.g. Hall 2000, Leighton and Van Vreeswyk 2004, Payne *et al.* 2004a). In the Ashburton River catchment in Western Australia, buffel grass spread extensively after a major flood in 1997 (Payne *et al.* 2004a). Across 21 land systems, the proportion dominated by buffel grass remained steady or increased, in some cases dramatically. It covered an estimated 64, 80 and 88% of three land systems in 2002 (up from 5, 80 and 34% in 1978) and, of 13 land systems that had none in 1978, the proportion dominated by buffel grass in 2002 was estimated to range from 2 to 12%. This can be viewed as a significant benefit, for example in terms of increased carrying capacity and stabilisation of land, or as a loss of natural landscapes and increased fire hazard.

Likewise, continuing selection of cultivars for specific conditions, e.g. growth in response to winter-spring rains or capacity to establish on heavy clay soils (Hacker and Waite 2001), may allow increased carrying capacity over wider areas but also enhance opportunities for invasion of conservation lands.

In undertaking an evaluation of the advantages and disadvantages of buffel grass use, we found very little information about particular cultivars which would suggest, for example, that some have been more or less invasive than others, given the diversity of environments open to colonisation. This review will refer to buffel grass in a generic sense, unless otherwise specified.

5. Value for pastoral production

5.1 Advantages

To the pastoral industry, buffel grass has generally been a great boon. It has been the species of choice because it is easy to establish and maintain (McDonald and Clements 1999). 'Buffel grass has brought great financial benefit to many individual producers and companies … as well as supported many rural communities, because of its benefit to the pastoral industries. Its wide adaptation and tolerance of drought, fire and over-grazing have been major assets' (Hall 2000). Some of the benefits which Hall (2000) identifies include:

- maintaining livestock during droughts
- increased production per head and per hectare compared with alternative grasses
- increased returns per kilogram for better finished cattle
- increased options for management and livestock turn-off age
- protection of soil
- reduced dominance of unpalatable grasses due to heavy grazing in dry seasons.

These benefits particularly relate to areas of Queensland where land clearing and planting of buffel grass are economically viable. In lower rainfall regions where land clearing is not an economic option, introduction of buffel grass has also brought significant production benefits. In the Ashburton River region of Western Australia the potential carrying capacity increased by an average of 60% between 1978 and 2002 following the spread of buffel grass and to a lesser extent Birdwood grass (*Cenchrus setiger*) throughout the catchment (Leighton and Van Vreeswyk 2004). For stations with extensive river frontage the increase was up to 150%. In central Australia, where the costs of establishing buffel grass over broad areas are high relative to returns, White (1996) recommended only attempting to establish buffel grass in special circumstances. Using buffel grass in combination with ponding banks in a severely degraded area increased grazing capacity 10-fold after five years and doubled the value per head for one central Australian property (Bastin 1991). Costs were recouped within five years.

5.2 Disadvantages

A summary of disadvantages follows but should be kept in context. Broadly speaking, the disadvantages are usually localised and are greatly outweighed by the likely economic benefits to producers. Buffel grass is not recommended for agricultural regions (e.g. Thomas 2004, for Western Australia) because it is not as productive or palatable as other candidates.

5.2.1 Introduction of weeds

Imported buffel grass seed can be contaminated with weed species (Hall 2000 re parthenium, Thomas 2004). As a consequence, the production capacity of pastures can be reduced, and producers can be faced with increased costs and reduced income. Other consequences include constraints on sale of buffel grass seed from affected areas and unwillingness of producers to plant buffel pastures in case the seed is contaminated. Contaminated machinery has also affected crop growers.

5.2.2 Pasture run-down

Pasture run-down or 'N tie-up' has been reported in Queensland (Hall 2000, Lloyd 2000) and in subtropical Mexico (Ibarra-Flores *et al.* 1999). Productivity of buffel grass declines as nitrogen becomes bound up in microbes, plant roots and organic residues or is removed by grazing. The problem is accentuated by heavy grazing (Graham 2000) and it may not be economic to fertilise established pastures or introduce legumes. On the other hand, Schmidt and Lamble (2002) proposed that, on low nutrient eucalypt woodlands in Queensland, clearing may lead to an initial short-term pasture response, followed in the medium-term (10 years) by nitrate leaching and nutrient depletion. In Mexico, areas with higher rainfall and better soil fertility may be more susceptible to pasture run-down due to excessive removal of nutrients (Ibarra-Flores *et al.* 1999). Hence causes of pasture run-down may differ depending on site capability and grazing management.

5.2.3 Unpalatable increasers

Cultivars can vary in important traits, including palatability. There is also some indication that cultivars vary in their palatability depending on where in Australia they are grown e.g. Biloela is recommended in Queensland but not in central Australia. It is possible that invasion of pastures, through replacement or hybridisation by less palatable forms, will result in lower carrying capacities due to selective grazing of palatable cultivars.

5.2.4 Monocultures

Monocultures of buffel grass may be susceptible to pests and diseases. Monocultures can develop in planted pastures and also with natural spread where soil water and fertility are favourable and selective grazing or high disturbance occurs, e.g. central Australian floodplains. Lack of diversity in pastures may also limit nutritive value due to seasonal conditions or pasture run-down.

5.2.5 Diseases of buffel grass

Buffel blight, caused by fungal pathogen *Pyricularia grisea*, and ergot (*Claviceps* spp.) affecting seed production, are the most important diseases of buffel grass (Perrott 2000). Buffel blight causes 'extensive losses' in monocultures, affecting the persistence of the grass through 'ill-thrift', but its economic significance is not known. *Fusarium oxysporum* has also been found in association with buffel dieback (Makiela *et al.* 2003). Hall (2000) indicates that dieback from fungal attack occurs in isolated cases in Queensland, so that the economic impact may not be great, although a small number of producers have reported production reduced to a third of previous levels in infected areas (Perrott 2000).

5.2.6 Insect pests

The only major insect pest of buffel grass is the buffel grass seed caterpillar (Mampava rhodoneura), a paralid moth. It has been recorded in warmer, higher rainfall areas of Queensland, feeding on the seeds and webbing the heads together, but control is not considered economic on a broad acre basis (http://www.tropicalforages.info/key/Forages/Media/Html/Cenchrus_ciliaris.htm; http://www2.dpi.qld.gov.au/pastures/4140.html accessed 14/10/2006). However, for seed crops, it can be controlled by spraying crops with methomyl 10 days after heads emerge.

5.2.7 Livestock impacts

Buffel grass contains oxalates and can cause acute oxalate poisoning in ruminants, most often in young and hungry sheep (Thomas 2004). 'Big head' can develop in horses due to a calcium/phosphorus imbalance, as a consequence of eating pure buffel grass for an extended time (Hall 2000). This is an induced calcium deficiency caused by oxalates (Cameron 2004).

6. Value for other purposes

Buffel grass has been used widely and successfully in reclamation of damaged grazing lands. For example, on the Ord River catchment in western Australia, rehabilitation with mechanical treatments and introduced species kapok bush (*Aerva javanica*), buffel grass and Birdwood grass (*Cenchrus setiger*) begun in the 1960s has dramatically improved conditions (Payne *et al.* 2004b). By 2002, active soil erosion was rarely observed, large gully systems were at least partly stabilised and expected to improve as ground cover continued to increase, and the majority of the most sensitive and previously severely degraded areas were dominated by dense stands of introduced *Cenchrus* spp. The ground cover of introduced and native perennial grasses was dense over much of the area.

In central Australia, where rainfall is considerably lower, buffel grass has still been used successfully for land reclamation on pastoral land e.g. Bastin (1991). It has also been used for revegetation and erosion control in parks and reserves (Low and Foster 1990, Albrecht and Pitts 1997) and for dust control e.g. Alice Springs airport (Keetch, 1981) and around many Aboriginal communities (http://www.nt.gov.au/nreta/naturalresources/plans/inrm/inrmplan/biodiversity/issues.html accessed 14/10/2006).

Post-mining land has been returned to pastoral land use following rehabilitation with buffel grass in central Queensland (Bisrat *et al.* 2004).

7. Negative impacts on environment

While the benefits of buffel grass for the pastoral industry were well recognised by the 1950s, its detrimental effects were not widely recognised for another twenty or more years, when its ability to invade non-target areas became apparent after high rainfall across the arid zone. Chudleigh and Bramwell (1996) suggested that the negative impacts of introduced pasture plants in general were reported to be of increasing significance to society after 1980. By the 1990s, buffel grass had been identified as a major environmental weed of northern Australia, category one (terrestrial species capable of destroying an ecosystem), with extensive continental distribution (Humphries *et al.* 1991). Mesic habitats within the arid zone were considered to be most at risk.

Considering exotic pasture plants in general in northern Australia, Woinarski (unpubl.) reported that impacts on native plants occurred through competition, altered soil nutrients and water availability, constraints to recruitment such as shading, altered fire regimes, changes in availability of dispersal or pollination agents, allelopathy and increased grazing pressure. Less information was available for impacts on fauna, and he proposed that impacts were likely to be reduced foraging efficiency due to dense grass, increased mortality and decreased reproductive success due to changes in the fire regime, and dietary constraints. Evidence of buffel grass impacts on the environment has been documented progressively since the 1990s.

7.1 Biodiversity

Increasing cover of buffel grass had a significant negative impact on ground cover species in eucalypt remnants in south-central Queensland (Franks 2002). As well, the establishment of buffel grass following tree clearing in central Queensland reduced floral diversity in brigalow and eucalypt woodlands to a far greater extent than the effects of land clearing on its own (McIvor 1998, Fairfax and Fensham 2000). Fensham and McCosker (2000) suggested that it is likely that fauna species richness also decreased, due to removal or structural and compositional diversity and hence shelter and dietary needs. They also suggested that buffel grass affected ecosystem functionality, fire regimes, nutrient cycling and overland water flows.

Specifically, Ludwig *et al.* (2000) reported a decrease in abundance of Carnaby's skink (*Cryptoblepharus carnabyi*) and the delicate mouse (*Pseudomys delicatulus*) with increasing cover of buffel grass in cleared eucalypt woodlands of central Queensland. Decline in the grey butcherbird (*Cracticus torquatus*) was also correlated with increasing buffel grass cover, while changes in other bird populations were related more to woodland clearing.

Buffel grass caused the decline of all native plant growth forms (nine classes of ground layer species) and species richness at Simpsons Gap National Park in central Australia, over a 27-year period (Clarke *et al.* 2005). As well, responses of native plants to summer and winter rainfalls were strongly attenuated. A study by Best (1998) found that the total number of invertebrate species were significantly reduced by buffel grass invasion in two central Australian land types. Some species that are reported as being particularly threatened are listed in Table 1.

Table 1. Species threatened by buffel grass.

Affected species	Note	Source
ANZECC-rated rare and threatened plant species	Details are not provided.	Groves et al. (2003)
Northern hairy-nosed wombat (*Lasiorhinus krefftii*), central Queensland, endangered	Buffel intrusion into last refuge; has overgrown burrows. Dietary range probably reduced.	Low (1997)
Slater's skink (*Egernia slateri*), central Australia, endangered	Decline is correlated with buffel introduction. Type locality is now dominated by buffel grass.	Pavey (2002a)
Desert sand skipper (*Croitana aestiva*), central Australia, endangered	Buffel is now the dominant ground cover, probably displaces larval food plants. Wildfire also a risk.	Wilson and Pavey (2002)
Bridled nailtail wallaby (*Onychogalea fraenata*), central Queensland, endangered	Invasion of habitat has reduced suitable habitat and established physical barriers to dispersal.	J. Lowry and G. Keith, pers. comm., cited in Neave et al. (2004)
Minuria tridens, central Australia, vulnerable	Buffel grass may compete, and altered fire regimes may be a risk.	Kerrigan et al. (2002)
Long-tailed dunnart (*Sminthopsis longicaudata*), central Australia, vulnerable	Threatening processes could include invasion by buffel grass.	Pavey (2002b)
Land snails, central Australia, three species susceptible	Threats include buffel grass fires.	Wilson (2002)

Note: This is a preliminary list based on readily accessible literature.

Wetland biodiversity is also considered to be under threat by buffel grass. In the Northern Territory 'Some of the most serious invasive plant species affecting the biodiversity of wetlands include … buffel grass …', INRMP-NT (2005) Chapter 5 Inland waters, p 52. In the Fortescue Plains region of the Pilbara, buffel grass is listed as a threatening process for wetlands of national significance (http://www.calm.wa.gov.au/science/bio_audit/pdf_files/pilbara02_p559-567.pdf, p. 560, accessed 14/10/2006).

7.2 Fire

Fire can threaten environments as well as life and property. While fire is an integral part of arid Australia, landscapes dominated by buffel grass can burn more frequently and at higher intensity than uninvaded vegetation. The consequence of this positive feedback loop is an increased rate of degradation as buffel grass out-competes native species and further dominates the ground layer (Butler and Fairfax 2003).

Miller (2003) predicted that central Australian woodland overstorey flora were likely to be adversely affected by increased fire severity associated with buffel grass invasion and that future recruitment of canopy species would be hindered by dense post-fire re-establishment of buffel grass cover. Loss of canopy cover after fire can also be associated with weed invasion. In central Queensland, invasion of parthenium weed was enhanced by a high intensity buffel grass fire (Butler and Fairfax 2003).

The Bushfires Council NT (http://www.nt.gov.au/nreta/natural resources/bushfires/management.html, accessed 14/10/2006), stated:

> *The rapid build-up of buffel grass fuel has increased the fire frequency in many areas and long-lived woody species, such as river red gums (*Eucalyptus camaldulensis*), corkwoods (*Hakea *species) and beefwoods (*Grevillea striata*), are suffering from the frequent fires. There are many areas in central Australia where it is desirable to exclude fire. These include sheltered gullies in range country, and long-lived fire sensitive communities such as mulga and lancewood. Protecting these areas from fire is a very difficult task.*

The threat to river red gums by buffel grass in central Australia due to the gums' low tolerance to fire is also reported in INRMP-NT (2005) Appendix 3 Terrestrial Biodiversity, Table 5.

INRMP-NT (2005) Chapter 4 Land, p.40, reviewing issues and threats to land, considered that high intensity fires, often increased by large fuel loads generated from introduced grass species such as gamba grass and buffel grass, were a factor contributing to accelerated soil erosion in the Northern Territory.

The threats due to fire are not confined to biodiversity impacts. The Northern Territory Fire and Rescue Service considered that in the southern regions the introduction of buffel and couch grass had greatly increased the risk to property owners and fire fighters. These introduced grasses could increase the fuel loads by four to five times the region's natural fuel loads (http://www.nt.gov.au/pfes/fire/community/guides/pdf/bushfire_mgmt_mitigation.pdf, p.2, accessed 14/10/2006).

7.3 Hydrology

The potential impacts on hydrology are unknown. However, the buffel grass root system is extensive (> 1 m in depth) allowing it to remain actively growing long after other species, which suggests buffel grass has a competitive advantage.

It has been suggested that colonising and stabilising otherwise unstable sand ‘islands’ by buffel grass in arid river beds may lead to choking of river channels and an increase in flooding of the surrounding plains (http://www.nt.gov.au/nreta/wildlife/nature/riparian.html, accessed 14/10/2006). Changes to water infiltration and surface flows on broad expanses are also possible due to the presence of barriers created by dense buffel grass stands.

7.4 Allelopathy

There is some evidence that buffel grass can release allelopathic chemicals which alter soil properties to the extent that germination and growth of other plants is inhibited (Cheam 1984).

At a national level, buffel grass is acknowledged as posing a serious threat to natural resource values in rangeland Australia (Table 2, Van Klinken, Friedel and Grice, 2006).

Table 2. Examples of how buffel grass is viewed in regional-level planning documents.

Region	Plan	Statement
Arid Lands (SA)	Pest Management Strategy (Draft)	Buffel grass was the only weed species identified as a ‘very high weed risk’ (in 5 of 6 bioregions)
Rangelands (WA)	NRM Strategy	Buffel grass is widespread throughout the region and is used for soil stabilisation, dust suppression and reducing erosion, and provides significant productivity benefits to pastoralists but it is also an environmental weed of concern. It can also have a secondary impact of increasing the frequency and size of wildfires. [I]ts wholesale removal is probably impractical. Management solutions are [therefore] needed that provide outcomes for productivity and biodiversity. There may however, be particular circumstances where eradication ... in localised areas is necessary to protect high value biodiversity assets.
Northern Territory	NRM Strategy	Buffel grass is listed as an ecologically invasive species. It has been deliberately introduced as a major pasture species and for dust suppression in Central Australia, and has significantly spread outside its original area of use, replacing native plants and increasing fire fuel loads. (p 30, 34)
Uluṟu–Kata Tjuṯa NP	NA	Buffel grass is the most threatening weed in the park and has spread to invade water and nutrient rich drainage lines. Where infestations are dense, it prevents the growth of native grasses – a source of food for animals and humans. (http://www.deh.gov.au/parks/uluru/natural/flora.html, accessed 14/10/2006)
Fitzroy (Qld)	NRM Strategy	Buffel is the most important production asset to the grazing industry in Central Qld. Its ability to spread rapidly by seed and increase available feed also makes it a threat to biodiversity in some locations. The shift to a simplified vegetation community or structure, [which] tends to happen with the introduction of buffel ... reduces habitat diversity and also causes a decline in native fauna diversity. In uncleared communities of brigalow and gidgee, buffel grass can greatly increase ... fuel loads which can dramatically increase the risk of fire. Since brigalow and gidgee communities are susceptible to long-term damage as a result of fire, the expansion of buffel grass in remnant communities is an issue in managing protected areas. (p. 48)

8. Other negative impacts

Social and economic impacts unrelated to pastoral production are not well documented. While buffel grass has been established around Aboriginal communities for dust control in central Australia (see earlier), there are now concerns about increased risk to infrastructure from fires and the harbouring of snakes around community housing (C. O’Malley, personal observation). Keighery (1991) reported that traditional Aboriginal people in the Rudall River area regarded buffel grass as a major threat to their food plants. Other cultural values may also be affected, while community health may suffer due to seasonal allergies, which cause significant discomfort at times in non-Indigenous communities as well.

It has been proposed that ecotourism is or will be impacted by buffel grass. No literature has been located to this effect although it may exist. Only 4% of visitors to tourist attractions in the western MacDonnell Ranges in central Australia rated introduced plants as an environmental threat (Hillery *et al.* 1998). It is possible that bushfires fuelled by buffel grass will have a negative impact on tourists but their response is likely to be to the aftermath of fire regardless of fuel type. On the other hand, tourists can be agents of spread as Friedel *et al.* (1996) found at Uluṟu, where buffel grass invasion was enhanced by disturbance, particularly on depositional soils.

Chudleigh and Bramwell (1996) suggested that buffel grass in national parks and along roadsides may reduce their aesthetics, as well as affect road safety along roadsides, and increase costs of control for local councils. Other impacts might be felt by the bush products industry due to competition from buffel grass and increased fire risk. Increased fire risk in general, to people and property, has already been mentioned. A summary of social impacts of invasive species in general appears in Agtrans (2005), Table 3.7.

9. An analysis of benefits and costs

Chudleigh and Bramwell (1996) undertook a benefit-cost analysis of buffel grass as part of an assessment of the impact of introduced tropical pasture plants in northern Australia. They acknowledged both positive and negative impacts of buffel grass, but observed that not all these impacts were easily quantified or readily included in a benefit-cost analysis. Positive impacts were more readily quantifiable than negative impacts. They listed the major positive and negative impacts of buffel accordingly.

The positive impacts of buffel grass include:

- increased productivity of land for beef cattle production
- increased productivity of land for sheep production
- soil conservation benefits in some areas
- other minor positive impacts.

The negative impacts of buffel grass include:

- loss or deterioration of native ecological systems
- reduction of plant (and animal) biodiversity in some systems
- invasion of production systems by buffel grass (e.g., cropping, horticultural and other systems)
- cost of controlling buffel grass in areas where it is unwanted
- other minor negative impacts.

Details of the analysis, including assumptions, are provided in Chudleigh and Bramwell (1996) pp. 38–53. Regarding positive impacts, the most significant quantifiable benefit of buffel grass was increased beef production. The quantifiable costs associated with this benefit were the research, development and extension costs associated with the development and maintenance of buffel grass, and any costs incurred with the establishment, maintenance and utilisation of buffel grass pasture.

Chudleigh and Bramwell acknowledged that the negative effects of naturally spread buffel grass could not be included as a cost because estimates of areas influenced were highly variable, and valuing the negative impacts was very difficult within the time available. However they suggested that the costs that should be included in this figure were control costs and the cost of damage inflicted on ecosystems and biodiversity. To this should be added other costs as noted in the previous section, including damage to property. As the authors point out, the negative impacts of buffel grass should be distinguished from the impacts of overgrazing or the impacts of clearing marginal land not suited for development, or other negative impacts caused by management.

The benefits and costs associated with the introduction of buffel grass were estimated for the period 1960 to 2020. The analysis indicated that the net present value of investment in buffel grass was approximately $1.5 billion at a 5% discount rate, and $1.3 billion at a 7% discount rate, using 1995 as the base year. The benefit-cost ratio for buffel grass was estimated to be 4.0:1 using a 5% discount rate, and 2.7:1 using a 7% discount rate. The estimated internal rate of return was 13.2% (Chudleigh and Bramwell 1996). These results indicate the significant positive benefits of buffel grass to beef production in northern Australia, without taking into account some further positive impacts of buffel grass (see list above) that were not quantified within the benefit-cost analysis.

A break-even analysis was undertaken in order to gain some perspective on the magnitude of the negative impacts of buffel grass. According to the authors, for buffel grass over the period 1980 to 2020, starting from the time when its disadvantages were recognised as significant, the negative impacts would have to be of the order of $40 million per annum to reduce the overall impact to zero. However, as Clements (1996) pointed out, the debate about benefits and costs will not be ended by one side 'proving' large economic benefits from improved pastures, since an economic value system may not be the only value system to be taken into account.

10. Outcomes of Desert Knowledge CRC project *The dispersal, impact and management of buffel grass (*Cenchrus ciliaris*) in desert Australia*.

Outcome 1. Improved efficiency in the detection and mapping of buffel grass incursions into conservation areas.

The effectiveness of aerial survey for mapping buffel grass distribution was trialled at Watarrka National Park in central Australia (Puckey *et al.* submitted). Prior to this study, known buffel grass locations had been recorded in a database from ground observations over a period of approximately 8–10 years and stored within the park's geographic information system (GIS). Records in these databases were limited to presence data only (rather than any record of areas free from buffel grass) and were restricted to areas of the park accessible to ranger staff. Aerial survey provided a means of collecting data rapidly over a much larger geographic area. The study greatly increased the known distribution of buffel grass on the park, especially for the more remote or rugged areas. A further benefit of the aerial survey was its repeatability, which enables monitoring change over time.

In total, 7262 observations were recorded from 15 hours of flying, of which 391 (5.4%) were for buffel grass presence. Another 2532 observations were recorded from ground transects (150 km in total), of which 425 (16.8%) were for buffel grass presence. The aerial survey cost $14,500 for helicopter charter. The staff resources required approximately 15 ranger days for aerial and ground data collection, and approximately 30 scientist days for survey design and analysis. While costs might seem high, they were far lower and certainly more informative at landscape scale than the on-going ground-based surveys that had been current practice. Aerial survey provided a systematic way of appraising the whole park for the identification of buffel grass infestations, essential for developing a strategic approach to prioritising resource allocation.

Outcome 2. Improved understanding of buffel grass dispersal.

The data gained from aerial survey of Watarrka National Park were subsequently used to build a probability surface model for the entire park, using Generalised Linear Modelling to predict the occurrence of buffel grass on the basis of a set of environmental variables and then applying the predictions using the park's GIS. Distance to drainage and tracks, followed by ruggedness, hummock grass cover and soil texture were the most important variables in determining the occurrence of buffel grass.

Distances to drainages and tracks tell us something about dispersal mechanisms and pathways as well as favourable conditions for persistence, while ruggedness, hummock grass cover and soil texture reflect favourable (or not) conditions. The high probability of occurrence close to drainage and roads presumably reflects not only dispersal pathways for seed, but also habitats with high levels of disturbance and favourable moisture availability, which allow establishment. Dispersal along roadsides is widely observable (e.g. Low and Foster 1990), and may be caused by wind generated by passing vehicles (Griffin 1993), or by inclusion in soil attached to graders and other vehicles. Other mechanisms include water flow and wind in general, since seeds are light and fluffy. Isolated plants occur in areas remote from tracks and may have originated from seed carried on the wind, or by wildlife or feral horses and camels (Puckey *et al.* submitted; Peter Latz, pers. comm.; Glenn Edwards, pers. comm.). Livestock have also been proposed as a dispersal mechanism and they may be key carriers on grazing lands. However, due to their dependence on water, feral livestock are unlikely to be in sufficient numbers to account for the wide distribution of buffel grass outside grazing lands.

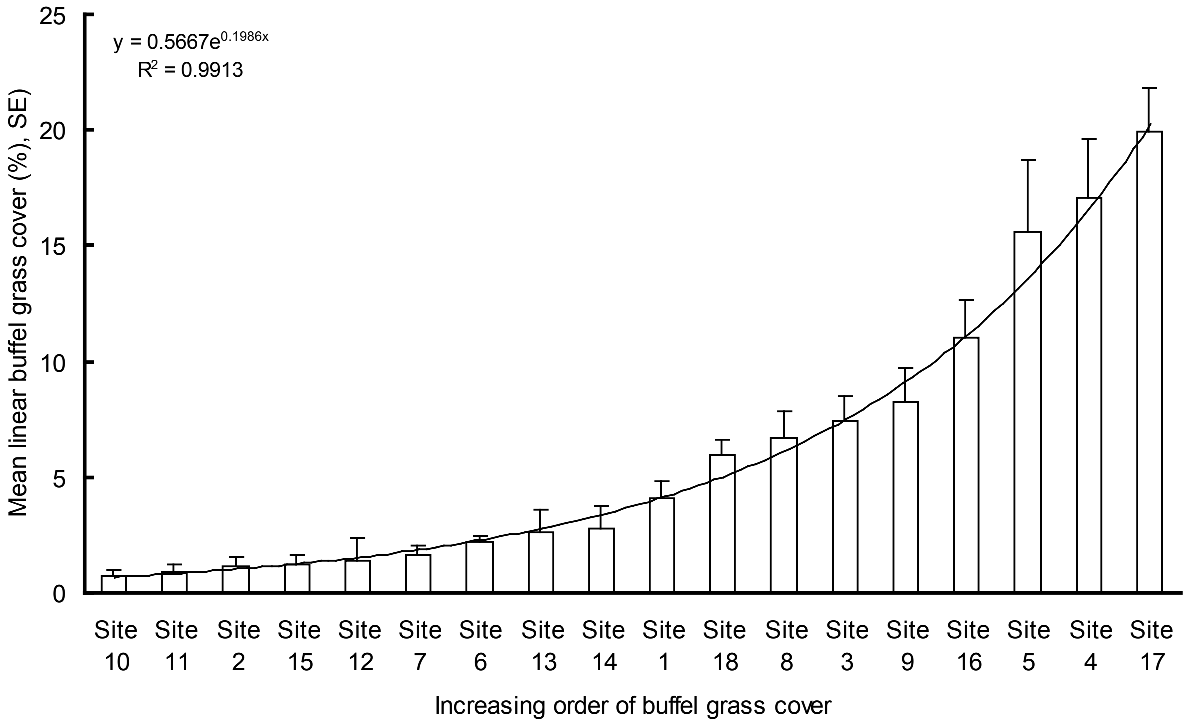
In the case of Watarrka, and very likely other protected areas, resources for management of invasive species are limited, and so absolute control is not possible. Instead a hierarchy of decisions is needed, based on biodiversity values, park resources, logistics, reservation status of species and communities and information about habitats potentially at risk. Priority areas for control might be, for instance, those with high biodiversity values, near to established seed sources and a high probability of buffel occurrence.

We had anticipated at the outset that it might be possible to identify cultivars with varying abilities to colonise different habitats. Puckey *et al.* (submitted) observed what appeared to be at least three varieties on Watarrka and thought that they might be behaving in ecologically different ways within the environment. Genetic analysis revealed that there were more than three varieties present in the region and that in fact they included evidence of apparent hybridisation among varieties. The presence of morphological forms which differ ecologically may not be surprising in light of this observation if morphology is principally evidence of ecological status rather than varietal status. This is supported by the observations of Silcock (1994) discussed earlier in this review.

Outcome 3. Improved understanding of biodiversity impacts.

The impact of buffel grass cover on vegetation, bird and ant species composition was investigated on rocky hills supporting witchetty-mulga shrublands. While floodplains might have been targeted for study due to their susceptibility to invasion, sites representing zero or low buffel grass cover could not be found. We chose to work instead on the rocky hillslopes because they are currently being colonised. At the time of site selection, seasonal conditions were poor, so that likely cover of buffel grass on rocky hill habitats following rainfall was assessed from moribund tussocks. The first effective rainfall occurred late in the project and was in late winter. Vegetation response on the 18 sampling sites was only modest and the maximum assessed cover of buffel grass did not exceed 20% (Fig. 1). Cover was patchily distributed (Fig. 2) and there were more and larger buffel grass clumps on the south-facing slopes (including the eastern and western aspects) of the ridge crests.

Figure 1. Distribution of buffel grass cover measured at 18 sites located on the crest and upper slopes of ridges in the MacDonnell Ranges, Alice Springs, Australia.

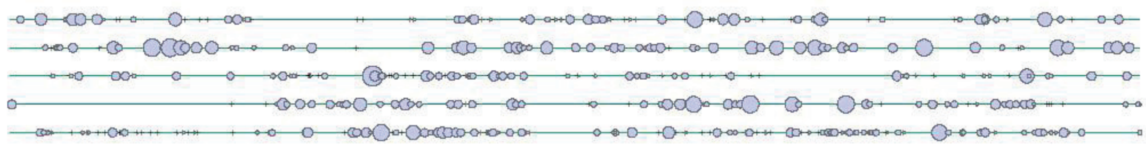


A total of 106 ground plant taxa (including ferns, forbs, grasses, sedges, sub-shrubs, vines and seedlings of woody species) were identified from the flora surveys. Vegetation at each of the 18 sites was assessed with 60 x 1 m^2 quadrats, for a total area of 1080 m^2. The mean floristic diversity within a site was high (mean = 32.3, standard error = 1.4), ranging between 24 and 44 taxa which is consistent for the central Australian ranges based on previous studies. Buffel grass cover by itself did not consistently explain the composition of native ground vegetation but, together with the extent of bare soil, the cover of litter fall and to a lesser extent low shrubs, tall shrubs and trees, aspect and fire history, it contributed 8% to the 49% total variation in composition explained by all the variables.

Figure 2. Linear spatial distribution of buffel grass cover in Sites 1 (4%) and 17 (20%) along 100m transects replicated 5 times and spaced 20 m apart.

Site 1

Site 17



A total of 48 morphospecies of ants were captured of which eight were seed harvesters, one was a seed-eating omnivore, 11 were predators and the remainder unknown. Mean ant richness per site was 7.4. Ordinations (not shown) on those taxa which occurred in more than 10% of the sites revealed that neither buffel grass cover by itself nor any of the habitat variables (ground vegetation, low shrubs, tall shrubs and tree cover, fire history, aspect, or bare soil) significantly influenced ant species composition.

A total of 31 diurnal and one nocturnal bird species were observed in the study sites of which seven were known to be breeding. Ordinations of the 20 species which occurred at two or more of the 18 sites showed that buffel grass cover contributed only 5% to the overall variation in composition; neither it nor the other habitat variables consistently influenced bird species composition. By grouping the species into habitat guilds based on food groups and the foraging and nesting substrates, we found a significant relationship between the guild composition of ground-dwelling species and fire history, low shrubs, trees and bare soil, and, to a lesser extent, buffel grass cover. However only 54% of the variation was captured by the ordination, indicating that the relationships were not very strong and that significance should be interpreted cautiously.

We were unable to demonstrate that buffel grass had a significant effect on biodiversity under the study conditions. Only minor effects, in combination with other habitat factors, were detected in plants and birds. This is not conclusive evidence for no impact, because the study was constrained by inadequate rainfall in winter, when forbs rather than grasses are generally favoured. The levels of buffel grass cover encountered may never have reached the thresholds necessary to have an impact, since cover did not exceed 20% and was patchily distributed.

The Watarrka aerial survey provided insights into biodiversity impacts of buffel grass. The Watarrka probability surface model was overlaid with the available vegetation mapping for the park to quantify the level of threat to native plant diversity, in particular rare plant species diversity. The proportion of rare species with part of their range currently invaded by buffel grass was predicted to be 28% (see Table 3 for details of rare species), while 30 native species had >20% of their park distribution affected by buffel grass. Indeed, some of the habitats within Watarrka with the highest plant species richness are under threat from the current and predicted occurrence of buffel grass distribution. Sixty-three percent of cells with the highest species richness scores for native plants were currently affected by buffel grass and 96% of these cells were predicted to be suitable for future buffel grass invasion.

Table 3. Rare native plant species with the greatest proportion of their range on Watarrka National Park threatened by buffel grass.

Species	Status	% Range at threat (p>0.2)	% Range at threat (p>0.01)
Bulbine alata	Poorly known*	86	97
Bulbostylis pyriformis	Rare	36	70
Phyllanthus erwinnii	Poorly known	18	49
Harmsiodoxa puberula	Rare	13	44
Oxalis radicosa	Poorly known	10	29
Calotis cymbacantha	Poorly known*	9	44
Sclerolaena parallelicuspis	Rare	6	56
Heliotropium inexplicitum	Poorly known*	6	40
Sida A43017 *Ambalindum*	Poorly known*	6	26
Corynotheca licrota	Rare	4	32
Dodonaea microzyga	Rare*	3	29
Sida D70364 *Huckitta*	Poorly known*	2	19
Hydrocotyle A39600 Watarrka	Rare*	2	14
Eragrostis lanicaulis	Poorly known*	1	14
Sida A90797 Rainbow Valley	Poorly known	1	13
Juncus continuus	Rare	1	3
Stylidium inaequipetalum	Rare	1	3

(indicates species which are only reserved within Watarrka NP.)*

Those species affected by the current distribution of buffel grass are mostly associated with water-courses, alluvial plains and/or soils with greater clay content. This information is important for developing a strategy for managing buffel grass at a landscape scale that is based on invasive potential and known biodiversity values, where previous management had focused on small-scale site-specific control actions.

11. Future directions for research

11.1 Management

Various aspects of sustainable use and management will have a research component. Referring to South Australia, Pitt (2004) proposed the development of a risk assessment model to help prioritise areas for management, where the greatest benefit is likely to result from control activities. Proposals developed by Sam Setterfield (CDU) and colleagues in 2005 addressed issues of benefit-cost analysis for weed risk assessment, based on case studies in the Northern Territory. While these proposals have not yet been funded they will be valuable contributors to this research area if they are successful.

A challenge Pitt (2004) perceived was the implementation of a strategic management program that would be ‘embraced and adopted by the wider community’. This requires social research which negotiates diverse attitudes and seeks acceptable options. It should not be state-based but encompass national perspectives to ensure a wide spectrum of views. Rieks Van Klinken (CSIRO) and colleagues have proposed research which will identify areas of agreement and contention across key stakeholder groups, with a view to assessing environmental, social and economic costs and benefits to these groups and will produce agreed key principles and priority actions as a platform for the development of a national strategy. This proposal, if it succeeds, will complement the Setterfield proposal, and offer opportunities for greater collaboration. Issues relating to benefit and cost analyses are dealt with in greater detail in the following section.

Interestingly, a survey of various industry and research groups (McDonald and Clements 1999) did not rate conservation issues highly as a threat to future use of sown tropical pasture plants. They pointed out that this 'could be an encouraging sign that all involved in the industry are willing to move towards more sustainable systems and to deal with issues of biodiversity. Alternatively, it could be an indication that everyone is under-estimating the potential difficulties in developing a stable balance between conservation and productivity.'

Humphries' (1993) proposal that the relationship between invasion potential and underlying disturbance should be better understood is still relevant. Speaking generally, she said:

> *Linkages between a plant's introduction, its establishment, survival and spread need to be examined in relation to specific human activities … grazing, fertilisation, manipulation of fire, transport or vegetation fragmentation. By defining the disturbance-invasion link more precisely … opportunities for mitigating practices may occur.*

In this present study we have observed between-cultivar hybridisation, which suggests that there may be locally adapted plants which are better suited to survival of environmental perturbations. Amongst other things, they may have lower value as fodder, although fodder value remains untested. Clarifying whether there are locally adapted forms of buffel grass emerging through sexual reproduction would help to determine whether or not it is possible to select for varieties with distinctive characteristics that can be used to select for desirable traits such as palatability or non- (or reduced) invasibility. Pastoralists' desire to select for palatability is made additionally complex by the influence of substrate nutrient status which may interact with inherent palatability of varieties.

Hall (2000) has drawn attention to the potential for buffel status to change in comparison to the past, if its competitiveness relative to native grasses is affected by climate change. This also warrants research attention.

One issue that is not recommended for research is biocontrol. Biocontrol is a realistic option when the target species has little or no perceived value. Major economic losses to pastoral communities would follow if an agent of control for buffel grass was released, since it is improbable that it could be confined to conservation areas or restricted to action on just a select subset of varieties (e.g. unpalatable ones).

Fensham and McCosker (2000) suggest that livestock grazing may be the only practical management option where buffel grass dominates fire-sensitive vegetation in national parks recovering from fire. This is likely to be a contentious issue, but one which needs exploration, in view of the lack of broad acre tools for management in protected areas.

Research questions addressing this issue and that of containing buffel grass in pastoral areas where it is desirable could include:

- Are there effective grazing regimes – in land systems of different susceptibility to colonisation – for containing buffel grass, reducing fuel loads in key locations, and minimising impacts on biodiversity?
- What are the key factors affecting recovery potential for landscapes colonised by buffel grass? Are some land systems more recoverable (assessed in terms of effort invested for biodiversity gains achieved) than others. What is native seed bank survivability under varying buffel regimes? Is recovery potential affected by density or duration of buffel colonisation?

A methodology has been developed by this project for modelling areas of high biodiversity value at risk from buffel grass colonisation in Watarrka National Park. Consideration should be given for extending this methodology to other areas, both on- and off-reserve, to determine priorities for conservation management. However, this begs various questions including what cost-effective management interventions are available, how priorities should be set and traded off against other land use priorities at a local or regional scale, how financial compensation might be negotiated and how much or whether society is willing to pay.

11.2 Benefits and costs

Analyses of benefits and costs can potentially help set management priorities but researchers are inevitably confronted with the fact that production values can be fairly readily quantified while environmental values like biodiversity and environmental services, and social values cannot (Chudleigh and Bramwell 1996, Sinden *et al.* 2004, Agtrans 2005). Chudleigh and Bramwell (1996, p. 53) proposed that:

> *One possible method of quantifying the negative impacts of buffel grass could be to analyse the costs incurred with controlling buffel grass in areas where this pasture grass is unwanted. For this assessment to be made, data would need to be assembled regarding the rate of spread of buffel grass in areas where it is unwanted, and the area of buffel grass infestations in the past that have been detrimental to plant biodiversity and contributed to degradation of habitats. These and other data required would require significant resources to assemble. Further, valuing the negative impacts would also be quite time-consuming as the monetary value of loss of biodiversity and habitats would vary with the individual. If the negative impacts of buffel grass were to be quantified, difficulties would be faced in isolating the negative impacts of the grass from the negative impacts caused by other factors, such as mismanagement of resources. The negative impacts of buffel grass would need to be distinguished from the impacts of overgrazing or the impacts of clearing marginal land not suited for development, or other negative impacts caused by management.*

Moreover, the economics of control would also depend on factors such as how society values various weed free environments.

Chudleigh and Bramwell forecast increasing negative impacts of introduced pasture plants in the future. Since the significance of the negative impacts of introduced pasture plants has only been recognised in recent years, they suggest that:

> *If an analysis were to be conducted of the negative impacts of buffel, one further consideration would be the significant time lag between when benefits commenced to accrue and when significant negative impacts commenced. Due to the discounting processes used in the analysis, a low weighting would be placed upon future negative impacts compared to the positive impacts that started much sooner than the negative impacts. To some extent this represents a problem of intergenerational distribution of benefits and costs.*

More recently, Agtrans (2005) recommended valuing environmental impacts and potential benefits from action, to assist with ranking and priority setting. However, they warned that there was no commonly accepted method for priority setting amongst alternative options and integration with activities that lessen industry impact. Willingness-to-pay methods (contingent valuation, choice modelling) had improved they suggested, and multi-criteria analysis was another possibility. They also flagged the current inability to specify or quantify social impacts – health, safety and quality of life/choice impacts – and recommended a review.

There is also an issue regarding sustainability of production benefits from introduced pasture plants. Schmidt and Lamble (2002) argued that increased pasture production following tree clearing in low nutrient savannas in Queensland may be relatively short term, and that nutrient leaching over time may lead to productivity decline. They suggested that there were insufficient long-term data to determine whether productivity can be maintained or not. If forecasts of economic benefits from pasture improvement are to be realistic, this issue needs further investigation. Burrows (1993) took the view that clearing would not be justified if subsequent productivity was not greater than it was before, for at least ten years.

12. Conclusions

Breaking away from polarised perceptions of buffel grass as ‘good’ or ‘bad’ is a major challenge. Buffel grass is here to stay and the task ahead is to develop sustainable use in a setting of conflicting value systems. Clearly this is a complex economic, environmental, social and political problem. The role of research is to provide information, tools and strategies that help stakeholders to explore options and determine appropriate courses of action. Recommendations for research and implementation are provided below; further details are provided in the preceding text.

13. Recommendations

A strategic management program for sustainable use of buffel grass for production and conservation should be developed and implemented, supported by the following research:

13.1 Better targeted management

1. Determine whether there are effective grazing regimes – in land systems of different susceptibility to colonisation – for maintaining/containing buffel grass, reducing fuel loads in key locations, and minimising impacts on biodiversity. Are there threshold levels of buffel grass cover below which biodiversity impact is minimised and pastoral production is not compromised?
2. Improve understanding of the relationship between invasion potential of buffel grass and underlying disturbance in order to identify opportunities for mitigating practices
3. Determine the key factors affecting recovery potential for landscapes colonised by buffel grass. Are some land systems more recoverable (assessed in terms of effort invested for biodiversity gains achieved) than others? What is native seed bank survivability under varying buffel regimes? Is recovery potential affected by density or duration of buffel colonisation?

13.2 Understanding varieties

4. Investigate whether there are locally adapted forms of buffel grass emerging through sexual seed production
5. Determine whether, in view of 4, there are varieties (cultivars or locally adapted forms) of buffel grass with distinctive characteristics that can be used to select for:
   (a) pastorally desirable traits, e.g. palatability
   (b) environmentally desirable traits, e.g. low invasiveness
   How does substrate influence palatability vis-à-vis variety?

13.3 Assessing benefits and costs

6. Further develop benefit-cost analysis at local or regional scale, valuing economic, environmental and social/cultural impacts of buffel grass for key land uses, to support priority-setting and trade offs

13.4 Improved prediction

7. Further develop and implement a risk assessment model to help prioritise areas for management, where the greatest benefit is likely to result from control activities
8. Investigate the potential for buffel grass status to change as a consequence of climate change. For example, will buffel grass become more or less competitive relative to native grasses, are there implications for disease spread or nutrient decline, and what should be the management response?

13.5 Integration

9. Identify areas of agreement and contention across key stakeholder groups
10. Develop agreed key principles and priority actions as a platform for the development of a national strategy.

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