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PROFILE

Tackling Contentious Invasive Plant Species: A Case Study of Buffel Grass in Australia

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Abstract Introduced plants that have both production values and negative impacts can be contentious. Generally they are either treated as weeds and their use prohibited; or unfettered exploitation is permitted and land managers must individually contend with any negative effects. Buffel grass (*Cenchrus ciliaris*) is contentious in Australia and there has been no attempt to broadly and systematically address the issues surrounding it. However, recent research indicates that there is some mutual acceptance by proponents and opponents of each others' perspectives and we contend that this provides the basis for a national approach. It would require thorough and on-going consultation with stakeholders and development of realistic goals that are applicable across a range of scales and responsive to regional differences in costs, benefits and socio-economic and biophysical circumstances. It would be necessary to clearly allocate responsibilities and ascertain the most appropriate balance between legislative and non-legislative mechanisms. A national approach could involve avoiding the introduction of additional genetic material, countering proliferation in regions where the species is sparse, preventing incursion into conservation reserves where it is absent, containing strategically located populations and managing communities to prevent or reduce dominance by buffel grass. This approach could be applied to other contentious plant species.

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Introduction

It is difficult and expensive to address the problems caused by abundant, widespread invasive plants. Difficulties are exacerbated for species that are also useful or desirable, or perceived to be so by some interest groups, and contentions often arise. Pasture introduction programs have contributed significantly to the suite of contentious plants in Australia (Cook and Dias 2006; Grice 2004; Grice and others 2008). Some species introduced during these programs are highly productive without being problematic; some are invasive without being useful; others are simultaneously problematic *and* productive (Lonsdale 1994). Progress with contentious species requires practical and economic biophysical solutions that are effective at large scales as well as resolution of any contentions (Grice 2006). In this paper we consider biophysical and social factors in examining prospects and approaches for developing broad-scale strategic solutions for one contentious naturalised pasture species in Australia, buffel grass *Cenchrus ciliaris* L. (syn. *Pennisetum ciliare* (L.) Link).

The Basis of Contention Over Buffel Grass

Buffel grass is arguably the most successful introduced pasture grass in northern Australia (Humphreys 1967). Early, incidental or accidental introductions probably took place in the 1870s (Friedel and others 2006). Through the twentieth century, buffel grass and other *Cenchrus* spp. were included in pasture plant introduction programs, material

being collected in various parts of the species' native range in Africa, the Middle East and southern Asia (Hall 2000). There were many informal and formal releases of the species in central, tropical and sub-tropical Australia and it was widely promoted (Hall 2000). As a result it has naturalised across much of mainland Australia (Australia's Virtual Herbarium 2010) and islands off the northern coast (Dixon and others 2002) (Fig. 1), including in at least 53 of Australia's 85 Interim Biogeographical Regions (van Klinken and others 2004). There is potential for further range expansion (Lawson and others 2004).

Buffel grass is now common and widespread in Australia, most notably in the centre and north. It is common in many extensively used pastoral systems and substantial increases in livestock carrying capacities have been attributed to it (Chudleigh and Bramwell 1996; Hall 2000; Friedel and others 2006). Buffel grass has also been used in erosion control and restoration of areas degraded by livestock grazing (Keetch 1981). There are no reliable, detailed national data on how much land has been sown to buffel grass or over what area it has naturalised but it is clearly economically important (Hall 2000; Friedel and others 2006).

At least since the early 1990s, concerns have been expressed about possible negative environmental impacts of buffel grass (Humphries and others 1991; Griffin 1993; Friedel and others 2006). Several studies have attempted to quantify them. In central Australia, buffel grass may reduce or degrade refuges for threatened central Australian fauna (Griffin 1993; Puckey and others 2007). It is also frequent in restricted, sheltered micro-sites on cliffs and ledges where it competes with rare and relict plant species and alters fire regimes and the habitats of native flora and fauna (Griffin 1993). The species can generate positive fire-invasion feedbacks in central Australian woodlands (Miller and others 2010) and affects fire regimes in *Acacia cambagei* F.Muell. ex R.T.Baker (gidgee) and *A. harpophylla* Benth. (brigalow) communities (Butler and Fairfax 2003). Buffel grass has significant negative effects on plant species richness (Grice and others 2004; Clarke and others 2005; Fairfax and Fensham 2000; Franks 2002; Jackson 2005; McIvor 1998) and some negative effects on particular fauna (Best 1998; Ludwig and others 2000; Eyre and others 2009; Smyth and others 2009). It has been singled out in assessments of threats to a number of native plants and animals (Friedel and others 2006) and listed among species of "extensive continental distribution" that are "capable of destroying" Australian ecosystems (Humphries and others 1991).

In spite of assessments that buffel grass both provides major economic benefits and poses significant environmental threats, there is neither universal agreement about the issues, nor open, mutual recognition by all stakeholders of the costs and benefits. Rather, it has been the subject of contrasting perspectives and conflicting opinions.

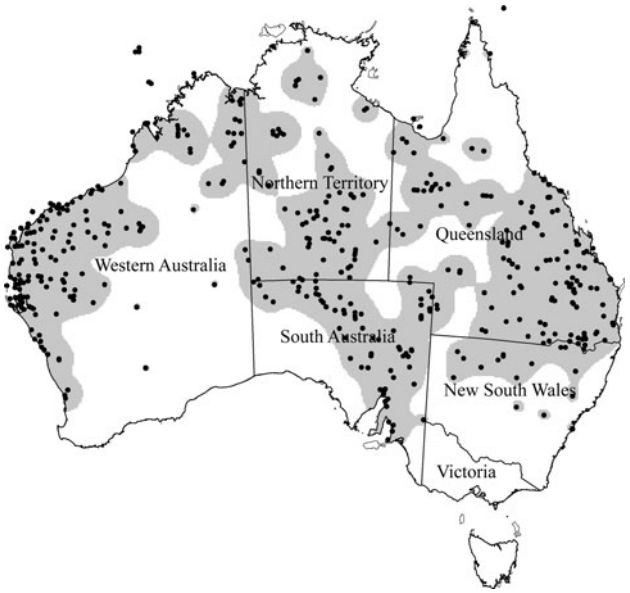

Fig. 1 Approximate current distribution of buffel grass in Australia based on herbarium records. The locations of individual records from Australian herbaria are shown (*filled circle*) (Australia's Virtual Herbarium 2010). The *shaded area* encompasses 90% of locations of all herbarium records

Strategic Options for the Management of Buffel Grass

In Australia there have been few attempts to address contentious plant species in a strategic, broad-scale, systematic way in order to simultaneously attract their benefits and avoid or minimise their deleterious effects. Either no resolution to the contention is sought and no concerted action is taken or the resolution favours one group of stakeholders over others. Where no concerted action is taken, both proponents and opponents are left to respond to their circumstances as individual land managers.

Where concerted action is taken it usually involves prohibition of cultivation, as with gamba grass (*Andropogon gayanus* Kunth) and Olive hymenachne (*Hymenachne amplexicaulis* Nees) which have been declared to be pest plants in some Australian states (Table 1). The legislation of most Australian states overtly prohibits the cultivation of plants that are formally recognised as pests though a compromise has been attempted in the case of gamba grass in the Northern Territory (Table 1).

Buffel grass has been listed among the "prohibited, regulated and restricted noxious weeds" of Arizona, USA (USDA 2011) but there has been little concerted action to deal with its negative effects in Australia. It is not listed in

Table 1 Legislative status of five important contentious pasture grasses in each State and Territory jurisdiction of Australia

State/Territory	*C. ciliaris*	*A. gayanus*	*H. amplexicaulis*	*E. polystachya*	*U. mutica*
Australian Capital Territory[a]	Not declared	Not declared	Declared class 4	Not declared	Not declared
New South Wales[b]	Not declared	Not declared	Declared class 1	Not declared	Not declared
Northern Territory[c]	Not declared	Declared class A/C Declared class B/C	Declared class B/C	Not declared	Not declared
Queensland[d]	Not declared	Declared class 2	Declared class 2	Not declared	Not declared
South Australia[e]	Not declared	Not declared	Declared—control not required	Not declared	Not declared
Tasmania[f]	Not declared	Not declared	Not declared	Not declared	Not declared
Victoria[g]	Not declared	Not declared	Declared—restricted	Not declared	Not declared
Western Australia[h]	Not declared	Declared P1, P2	Declared P1, P2	Not declared	Not declared

[a] Australian Capital Territory: Class 4: Propagation and supply is prohibited

Source: http://www.tams/act.gov.au/_data/assets/pdf_file/0019/123706/Pest_Plants_and_Animals_Declaration_DI200844.pdf (accessed August 13 2009)

[b] New South Wales Class 1: plant must be eradicated and the land must be kept free of the plant

Source: http://www.dpi.nsw.gov.au/agriculture/pests-weeds/weeds (accessed August 12 2009)

[c] Northern Territory: Class A/C: plants to be eradicated/new entries prevented; Class B/C: growth and spread to be controlled/; Class C: new entries prevented. For *A. gayanus* the Northern Territory is divided into a "Management Zone" (Class B/C) and an "Eradication Zone" (Class A/C)

Source: http://www.nt.gov.au/nreta/natres/weeds/legislation/declared.html (accessed August 12 2009)

[d] Queensland Class 2: landholders must try to keep their land free of these plants and sale and supply are prohibited unless a permit is issued

Source: http://www.dpi.qld.gov.au/cps/rde/dpi/hs.xsl/4790_7024_ENA_HTML.htm (accessed August 12 2009)

[e] South Australia: Class: control not required

http://www.dwlbc.sa.gov.au/biodiversity/apc/projects/weeds/plants_list.html

[f] Tasmania: Source: http://www.dpiw.tas.gov.au/inter.nsf/WebPages/SSKA-73U3QA?open

[g] Victoria: Restricted—cannot be traded as plants, seeds or contaminants

Source: Melville, R. Declared Noxious Weeds—Listed by Scientific Names. Landcare Notes (LC0252b), Department of Primary Industries, Victoria. ISSN 1329-833X. http://www.dpi.vic.gov.au/DPI/nreninf.nsf/v/D7685D9BB33B4DB1CA25740A0011E32F/$file/Declared_Noxious_Weeds_Listed_by_Scientific_Name.pdf (accessed August 13 2009)

[h] Western Australia: P1: Movement of plants or seeds prohibited; P2: Infestations to be eradicated; spread of plants must be prevented

Source: http://www.agric.wa.gov.au/objwr/imported_assets/content/pw/weed/decp/dec_plants_lits.pdf (accessed August 13 2009)

the weed legislation of any Australian state, and there have been no state-level and few regional-level attempts to regulate sale, planting or spread of the species. Several regional Natural Resource Management (NRM) bodies or Catchment Management Authorities (e.g., South Australian Arid Lands (SAAL), Western Australian Rangelands, Northern Territory NRM) have identified buffel grass as presenting important natural resource management issues (Friedel and others 2006). Under its Pastoral Land Management and Conservation Act (1989) South Australia has developed a policy to control non-indigenous plants on leasehold pastoral lands and their introduction is not permitted without written approval of the Pastoral Board that is responsible for overseeing their management. Moreover, the SAAL NRM Board has developed a Buffel Grass Management Plan, its purpose being to identify priority actions (Greenfield 2007). In South Australia, soils and climate are probably less suitable for buffel grass than those of other regions of Australia, so that historically there has been less incentive to use it as a pasture species, increased likelihood of legislative controls and less opposition to such legislation.

Failure to explore options other than unregulated use is probably due to perceptions that it is technically and/or economically difficult to control buffel grass on a practical scale and that there would be overwhelming opposition to using technical capacity that is available. Proponents have often denied deleterious impacts of buffel grass (Marshall and others 2011) and tend to attribute to the species greater environmental benefits than do opponents (Friedel and others 2011). Opponents have not fully acknowledged the species' value. Thus, proponents down-play the costs, while opponents down-play the benefits. Government agencies have long promoted the use of buffel grass and other invasive forage species including leucaena *Leucaena leucocephala* (Lam.) de Wit (Walton 2009), gamba grass (Cameron and Lemcke 2006) and Olive hymenachne (Hall 2000).

Foundations for a Broad-Scale Buffel Grass Strategy

Given that buffel grass is already widespread and abundant (Friedel and others 2006), northern and central Australian pastoral industries are strongly dependent on it (Marshall and others 2011) and there is likely to be resistance to any restrictions on its use (Friedel and others 2011), it is important to seriously consider whether broad-scale, strategic options, other than unfettered use, are viable and how such options might be developed.

A broad-scale strategic approach to buffel grass would aim to reduce deleterious effects without severely diminishing the species' productive value. It would need to be consultative, realistic in its goals, applicable at a range of scales, responsive to regional differences, clear in its allocations of responsibilities, supported by appropriate legislative and non-legislative measures and based on sound information.

Consultation

Broad consultation would be crucial to the development and implementation of a national, strategic approach to the management of any contentious species (Fraser and Dougill 2006). A stakeholder-driven strategy is far more likely to be effective than a top-down approach but it would be naïve to assume that consultation can provide a "win-win" solution; compromise is a more realistic expectation (Friedel and others 2011).

Consultation could be staged (Nelson and Pettit 2004). Initial, broad engagement should increase the likelihood that any subsequently developed strategy would be socially, economically and politically acceptable. Later, an advisory group incorporating stakeholder organisations could help develop and implement the strategy. One of its roles could be to progress toward consensus and compromise amongst government agencies and catalyse more productive approaches amongst stakeholders at large.

Proponents of buffel grass would be more vulnerable than opponents to any changes from the *status quo*. Actions designed to reduce the deleterious effects of buffel grass could impose costs on proponents, whether they be reduced production, increased production costs and opportunity costs associated with development prospects that are denied. Consultation will itself impose significant transaction costs.

Realistic Strategic Goals

Ideally, a strategy would include goals applicable at national, state, regional and finer scales. They can be logically grouped into four categories: prevention, eradication, containment and asset protection (Grice 2009).

Preventing introduction at the very broad (e.g., national or continental) scale (Grice 2000) is no longer an option but it may be useful to preclude new genetic material to restrict the species' capacity to occupy 'new' habitats. This would involve a trade-off against the desirability of new strains or ecotypes that could enhance the species' value to pastoralism in particular locations or management systems. Risk assessment for new genetic material would be valuable though it is not currently required for species already in Australia (Spafford-Jacob and others 2004).

While some introduced plants have been eradicated from Australia (e.g., Dodd 2004; Rudman and Goninon 2002; Tomley and Panetta 2002) and other efforts are still in progress (e.g., Brooks and Galway 2006; Csurhes 2004; Mitchell and Schmid 2002; Warren 2006), continental-scale eradication of buffel grass is neither possible nor desirable. However, eradication at finer scales may be a valid and achievable goal. Isolated populations of buffel grass in vulnerable land types on high value conservation reserves could be targeted for eradication, as could populations on off-shore islands, where the prospects of recolonisation are likely to be lower than on the mainland (Dixon and others 2002). Following eradication it would be necessary to monitor in order to promptly detect and respond to further incursions (Holcombe and Stohlgren 2009). The frequency and location of monitoring should respectively reflect the likelihood of recolonisation and the routes whereby recolonisation is most likely.

Containment, that is imposing anthropogenic limits to a species' distribution (Grice 2009; Grice and others 2010), is likely to be difficult for buffel grass because wind is a major dispersal agent (Friedel and others 2006; CRCAWM 2008). Containment targets could be identified at a fine scale, for example, small infestations on individual land-units (e.g., conservation reserves; non-pastoral Aboriginal lands). At the regional scale (e.g., parts of central Australian deserts) the goal could be to minimise range expansion by targeting dispersal routes and mechanisms to counter spread to areas that are currently free from the species. Such areas would have to be identified and prioritised, addressing the range of perspectives and needs in relation to buffel grass, considering its costs and benefits in different regions. Perhaps the greatest challenge to the containment of buffel grass is that in most parts of Australia where buffel grass is present there are multiple populations and ecotypes (Friedel and others 2006). Cacho (2004), on the basis of a conceptual model of weed spread that included partial cost-benefit analysis, argued that in some cases the optimum weed management strategy may be 'partial containment', that is slowing the rate of spread. Cost-benefit analysis may help determine the value of

attempting to contain one local population in the face of the risks posed by others (Buckley 2008).

Asset protection strategies would aim to minimise impact of buffel grass by suppressing particular populations (Grice 2009), reducing its prevalence in terms of its proportional contribution to total biomass or biomass of the lower stratum of the vegetation, its density or the average size of plants. This goal requires that specific assets and the level of suppression necessary to protect them are identified. There has been little research on how buffel grass can be suppressed but there is the experience of those who have attempted to do so and several options have been canvassed (Friedel and others 2011).

Each of these four broad strategic goals may be appropriate in different situations. Whether a goal is realistic in a particular situation depends on there being the biophysical means of achieving it, resources to make those means operational and incentive on the part of stakeholders. For contentious species the extent to which different goals can be applied to different areas, without there being undue interference between them, is important. A robust strategy requires that actions taken at one location do not devalue those applied to adjacent areas. Measures taken to reduce negative environmental impacts should not unduly interfere with the productive value of pastures, especially where no realistic alternatives exist. In some situations this would require relatively fine-scale spatial separation of areas targeted for different strategic goals.

Scale

A continental (national)-scale strategy would provide a context in which regional (State or large catchments) elements might be framed. National recognition of the issues should facilitate interstate collaboration and co-ordination, yield economies of scale and improve access to Commonwealth resources (e.g., to support research). A national strategy may help attract the necessary involvement of national organisations (Commonwealth government departments and agencies; non-governmental organisations). Many of the actions required to make a national strategy effective would actually be implemented at finer scales in a hierarchical way. For example, a national strategy would require the backing of state legislation that should also reflect nuances in need at finer scales.

Regional Responsiveness

A strategy should reflect inter-regional differences in physical, social and economic environments. These include: the contributions that buffel grass makes to pastoral production; the ways in which it is managed; the environmental services it provides; its extent; the impacts it has on native flora and fauna; its status under legislation; and the suitability and effectiveness of the measures available (Marshall and others 2011; Friedel and others 2011).

Current projects managing buffel grass reflect the need for and validity of different responses in different areas. For example, at the very finest scale, a 54 ha area of the Alice Springs Desert Park has been the target of a buffel grass control program that has, since 1996, reduced the species to very low abundance, the ultimate goal being local eradication (CRCAWM 2008). Programs to control buffel grass have also been implemented on conservation reserves such as Uluru-Kata Tjuta National Park in central Australia (Anon 2009). These actions aim to alleviate perceived or demonstrated impacts at sites with high conservation values. The regional-scale strategic plan for buffel grass for the SAAL (Greenfield 2007) reflects how the status of buffel grass in that region differs from its standing elsewhere.

Allocation and Acceptance of Responsibilities

In Australia, local, state and Commonwealth governments have responsibilities in weed management and national strategies have been developed for Australia's twenty Weeds of National Significance (WONS) under a Commonwealth-State initiative (ARMCANZ 1999; Martin and van Klinken 2006). Some of these have had to address divergent views among stakeholders [e.g., Olive hymenachne (CRCAWM 2003a); willows *Salix* spp. (CRCAWM 2003b)] though the contentions were not as extreme as those associated with buffel grass. However, in all of these cases, actions taken under the agreement between Commonwealth and State governments have emphasised, to the virtual total exclusion of other possibilities, the costs associated with the plants' impacts, precluding exploitation. For buffel grass, regulation and co-ordination might be more effective if it was conducted outside the conventional pest plant arena, including Australia's National Weeds Strategy (ARMCANZ 1999), thus more clearly acknowledging the species' economic values. A national strategy would also need to consider responsibilities of local government and individual landholders.

Legislative and Non-Legislative Measures

Strategic management of any contentious plant species requires an appropriate legislative framework and balance between legislative and non-legislative measures. In Australia's Northern Territory there has been some move away

from "watershed" decisions based on typical pest plant legislation. A draft Weed Management Plan for Gamba Grass (NRETAS 2009) delineates a "management zone", in which the aim is to "[contain] established pasture areas (e.g., through the use of grazing land management principles and the maintenance of buffer zones)" and an "eradication zone". However, there are no legislative measures to deal with most other contentious pasture grasses (Table 1).

Non-legislative measures could play an important role but would require broad stakeholder consultation during both development and implementation. Non-legislative elements may encourage consensus and/or compromise (Walton 2004) and could include voluntary codes of practice (Walton 2009), insurance mechanisms (Martin 2008) and certification procedures related to off-site impacts. Valid Australian precedents address species that are potential sources of illicit drugs (e.g., poppies in Tasmania (Department of Justice 2010); Indian hemp in New South Wales (Zurbo 2008)), which present many of the same issues as invasive pasture species.

The code of practice for leucaena (Walton 2009) provides a precedent though there are currently no reliable assessments of its effectiveness. Leucaena and buffel grass are both important, extensively cultivated forage species in northern Australia but a code of practice for buffel would have to be tailored for it (Grice 2006). Leucaena is most useful when grown in horticultural-style plantations in which self-propagation is unnecessary; the use of leucaena lends itself to the use of sterile varieties and containment of plantings may be relatively straight-forward. Exploitation of buffel grass, on the other hand, depends strongly on its free-seeding characteristics and its capacity to self-propagate in extensively managed areas. A code of practice would also have to address issues of non-compliance and the pre-existence of extensive naturalised populations.

Specific Practical Elements

Marshall and others (2011) concluded that pastoralists in three out of four divergent regions of Australian rangelands are strongly dependent on buffel grass. Generally, they do not accept that buffel grass has negative environmental consequences but are supportive, at least in principle, of efforts to control buffel grass on conservation reserves. Studying the same four regions, Friedel and others (2011) concluded that the contention amongst diverse organisations was not as great as might have been supposed: benefits and costs of buffel grass were widely acknowledged; there was general agreement in relation to management objectives for environmental reserves and pastoral lands of low conservation value. However, the objectives for pastoral lands of high conservation value were contentious. A variety of management tools and strategies were broadly supported, with exceptions that could be explained largely in terms of regional differences in ability to apply them.

A national approach could initially respond to these perceptions by focusing on practical elements that relate to the less contentious, relatively straightforward aspects. Clearly, their effectiveness would depend on adequate resourcing (expertise and funding). Possible actions include the following.

Avoid Development, Movement and Introduction or Release of New Varieties

Preventing the introduction, movement or development of new buffel grass varieties could help minimise further range expansion. Buffel grass varieties that are more cold-tolerant or capable of growing well on clay soils, for example, could increase the species' potential distribution. Avoiding the introduction of new varieties may also reduce the development, through mutation and/or hybridisation of genotypes that are better adapted to particular environments. Adaptation could involve natural selection for less palatable genotypes and countering such selection might be difficult in practice. Restrictions on the introduction of new varieties could impose opportunity costs on proponents of the species.

Identify Regions Where Buffel Grass is Sparse and Counter Its Proliferation

Containment could be a valid and acceptable goal for populations of buffel grass in the extensive areas of central and southern Australia where it is relatively sparse, where pastoralism is not a significant land-use and where there are important land values that could be compromised should the species increase. There are large conservation reserves and non-pastoral Aboriginal lands in Western Australia, the Northern Territory, Queensland and South Australia. The absence of buffel grass from these lands would not detract from pastoral production and may enhance their value for conservation and indigenous people. Effort would focus on the routes whereby buffel grass is likely to spread, principally transport corridors, and managing plant communities to be more resistant to invasion.

Keep Buffel Grass Out of Conservation Reserves Where It is Absent or Sparse

Because livestock grazing is prohibited on most Australian conservation reserves, buffel grass could be excluded, contained or suppressed without compromising pastoral production. Priority should be given to conservation reserves where (i) buffel grass is rare or absent and yet

there is a significant risk of incursion and; (ii) important natural assets are or would be threatened by an abundance of buffel grass.

Negotiate Compromise Solutions for Biodiverse Areas Outside Conservation Reserves

In Australia, many areas outside conservation reserves have considerable environmental value, particularly in the extensive rangelands (Smyth and James 2004). They present the greatest challenge to broad-scale, strategic management of buffel grass. It is crucial to understand how the abundance and distribution of buffel grass affects conservation values in biodiverse landscapes. Financial compensation for any losses to productive capacity, or some other incentive scheme, may be appropriate for areas of high conservation value.

Contain Strategically Located Populations of Buffel Grass That Cannot be Eradicated

If there are isolated but important plantings of buffel grass in regions where buffel grass is not otherwise widespread and abundant, effort could be made to contain them though containment of free-seeding species presents a major challenge (Grice and others 2010).

Focus Control on the Most Detrimental Varieties of Buffel Grass

In Australia, genetic and environmental factors drive considerable variation in how palatable buffel grass is to livestock. It would be valuable to ascertain how the different varieties relate to one another, their comparative distributions, the scales at which they co-occur and their relative advantages and disadvantages for animal production and the environment. This knowledge could be used to determine whether it is likely to be worthwhile specifically targeting less palatable varieties of buffel grass for suppression or containment. The situation is complicated by the fact that different varieties are more suitable for pastoralism in different regions (Friedel and others 2006).

Need for Further Information

A strategy for dealing with buffel grass requires better information in the following areas.

Environmental Impacts

Better quantification of the environmental impacts of buffel grass in different situations and geographical areas would link both production benefits and conservation outcomes to the abundance of buffel grass. A better understanding of the ecological processes involved would help prioritise between locations and identify environmental values that are at greatest risk.

Cost-Benefit Analysis

Sound cost-benefit analysis is required. A major challenge here is to weigh the many costs and benefits that are typically expressed in very different currencies, expanding on the work that has been done to date (e.g., Chudleigh and Bramwell 1996; Ferdinands and others 2010). For contentious species in general, cost-benefit analysis could be used to help decide between broad strategic options: no regulation of the species; prohibition of cultivation and a requirement for control through weeds legislation; or a compromise approach that seeks to attract benefits from cultivation whilst avoiding costs associated with invasion. More discerning cost-benefit analysis would be required to develop regionally differentiated goals.

Management Options

There is a need for better knowledge of how buffel grass can be best managed for different purposes. Friedel and others (2011) tabulated management tools potentially applicable to buffel grass. Numerous land managers hold knowledge of how grazing, fire, herbicides and other techniques may or may not be applicable in different situations. There would be value in capturing this information, combining it with the results of more formal testing and using it to refine "best bet" management practice for different goals and circumstances.

Distribution and Abundance

Higher resolution spatial data on the current and potential distribution and abundance of buffel grass would facilitate a more targeted approach to setting spatial priorities and in determining what is achievable.

Intra-Specific Variation

It would be useful to quantify and map the variation that exists in the buffel grasses currently present in Australia. Current information suggests that registered cultivars are not readily distinguishable amongst the genotypic and phenotypic variety that exists in the field but also that for both proponents and opponents of the species there are more and less desirable varieties (Friedel and others 2006). In documenting existing variation it would be important to align it with invasiveness and its usefulness as a pasture

plant. It is likely that the geographical variation in the form and function of buffel grass in Australia is a product of some combination of environmental and genetic factors.

Conclusions

As is often the case with contentious plant species, little effort has been made to resolve conflicting perspectives toward buffel grass in Australia. However, there is sufficient common ground between interest groups to encourage resolution and development of a systematic, co-ordinated and consultative approach to the species. The geographical focus should be on regions where buffel grass is currently scarce or not present and on specific locations whose high conservation value is threatened by invasion of buffel grass. There is scope for the sharing of practical knowledge between stakeholders who hold divergent views. The approach that we advocate for buffel grass should be broadly applicable to other contentious, invasive plant species.

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References

Anon. (2009) Uluru-Kata Tjuta National Park, Draft Management Plan 2009–2019. Director of National Parks, Australian Government, Canberra. Accessed online January 14, 2011: http://www.environment.gov.au/parks/publications/uluru/pubs/draftplan.pdf

ARMCANZ (Agriculture and Resource Management Council), ANZECC (Australian and New Zealand Environment and Conservation Council) and FM (Forestry Ministers) (1999) The National Weeds Strategy (Revised Edition). Commonwealth of Australia, Canberra

Australia's Virtual Herbarium (2010) *Cenchrus ciliaris*. Accessed online February 19, 2010: http://www.anbg.gov.au/avh/cgi-bin/avh.cgi

Best RA (1998) The effect of introduced buffel grass (*Cenchrus ciliaris* L., Poaceae) on the diversity and abundance of invertebrates in semi-arid central Australia. Masters Thesis, Northern Territory University, Darwin

Brooks SJ, Galway KE (2006) Progress towards the eradication of two tropical weeds. In: Preston C, Watts JH, Crossman ND (eds) Proceedings of the 15th Australian Weeds Conference. Weed Management Society of South Australia, Adelaide, pp 641–644

Buckley YM (2008) The role of research for integrated management of invasive species, invaded landscapes and communities. Journal of Applied Ecology 45:397–402

Butler DW, Fairfax RJ (2003) Buffel grass and fire in a gidgee and brigalow woodland; a case study from central Queensland. Ecological Management and Restoration 4:120–125

Cacho O (2004) When is it optimal to eradicate a weed invasion? In: Sindel BM, Johnson SB (eds) Proceedings of the 14th Australian Weeds Conference. Weed Society of New South Wales, Sydney, pp 49–54

Cameron AG and Lemcke B (2006) Kent Gamba Grass. Agnote E8, Serial No. 413, Agdex No. 131/10. Department of Primary Industry, Fisheries and Mines, Northern Territory Government. Accessed online January 18 2011. www.nt.gov.au/dpifm

Chudleigh P, Bramwell T (1996) Assessing the impact of introduced tropical pasture plants in northern Australia. Report to CSIRO taskforce interested in introduced pasture plants. March 11 1996

Clarke PJ, Latz PK, Albrecht DE (2005) Long-term changes in semi-arid vegetation: Invasion of an exotic perennial grass has larger effects than rainfall variability. Journal of Vegetation Science 16:237–248

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

CRCAWM (Co-operative Research Centre for Australian Weed Management) (2003a) Weed Management Guide: Hymenachne (*Hymenachne amplexicaulis*). CRC Australian Weed Management, Adelaide

CRCAWM (Co-operative Research Centre for Australian Weed Management) (2003b) Weed Management Guide: Willows (*Salix* spp.). CRC Australian Weed Management, Adelaide

CRCAWM (Co-operative Research Centre for Australian Weed Management) (2008) Weed Management Guide: Buffel grass (*Cenchrus ciliaris*). CRC Australian Weed Management, Adelaide

Csurhes SM (2004) Succesful control of honey locust trees (*Gleditsia triacanthos* L.) in Queensland. In: Sindel BM, Johnson SB (eds) Proceedings of the 14th Australian Weeds Conference. Weed Society of New South Wales, Sydney, pp 673–675

Department of Justice (2010) Poppy advisory and control board (Tasmania). Accessed online January 18, 2011. http://www.justice.tas.gov.au/poppy/

Dixon IR, Dixon KW, Barrett M (2002) Eradication of buffel grass (*Cenchrus ciliaris*) on Airlie Island, Pilbara Coast, Western Australia. In: Veitch CR, Clout MN (eds) Turning the tide: the eradication of invasive species. IUCN SSC Invasive Species Specialist Group. IUCN, Gland, Switzerland and Cambridge, pp 92–101

Dodd J (2004) Kochia (*Bassia scoparia* (L.) A.J. Scott eradication in Western Australia: a review. In: Sindel BM, Johnson SB (eds) Proceedings of the 14th Australian Weeds Conference. Weed Society of New South Wales, Sydney, pp 496–499

Eyre TJ, Wang J, Venz MF, Chilcott C, Whish G (2009) Buffel grass in Queensland's semi-arid woodlands: response to local and landscape scale variables, and relationship with grass, forb and reptile species. The Rangeland Journal 31:293–305

Fairfax RJ, Fensham RJ (2000) The effect of exotic pasture development on floristic diversity in central Queensland, Australia. Biological Conservation 94:11–21

Ferdinands KB, Setterfield SA, Clarkson JR, Grice AC, Friedel MH (2010) Embedding economics in weed risk assessment to assess contentious plants. In: Zydenbos SM (ed) Proceedings of the 17th Australasian Weeds Conference. New Zealand Plant Protection Society, Christchurch, pp 482–485

Franks AJ (2002) The ecological consequences of buffel grass *Cenchrus ciliaris* establishment within remnant vegetation of Queensland. Pacific Conservation Biology 8:99–107

Fraser ED, Dougill AJ (2006) Bottom up and top down: analysis of participatory processes for sustainability indicator identification as a pathway to community empowerment and sustainable environmental management. Journal Environmental Management 78:114–127

Friedel M, Puckey H, O'Malley C, Waycott M, Smyth A, Miller G (2006) Buffel grass: both friend and foe. An evaluation of the advantages and disadvantages of buffel grass use and recommendations for future research. Desert Knowledge Cooperative Research Centre, Alice Springs. http://www.desertknowledgecrc.com.au/resource/DKCRC-Report-17-Buffel-Grass.pdf (Accessed 23 May 2011)

Friedel MH, Grice AC, Marshall NA, van Klinken RD (2011) Reducing contention amongst organisations dealing with commercially valuable but invasive plants: the case of buffel grass. Environmental Science and Policy. doi:10.1016/j.envsci.2011.08.001

Greenfield B (2007) SA Arid Lands buffel grass management plan, DRAFT. South Australian Arid Lands Natural Resource Management Board, Port Augusta

Grice AC (2000) Weed management in rangelands. In: Sindel BM (ed) Australian weed management systems. RG and FJ Richardson, Meredith, pp 431–458

Grice AC (2004) Perennial grass weeds in Australia: impacts, conflicts of interest and management issues. Plant Protection Quarterly 19:42–47

Grice AC (2006) Commercially valuable weeds: can we eat our cake without choking on it. Ecological Management and Restoration 7:40–44

Grice AC (2009) Principles of containment and control of invasive species. In: Clout MN, Williams PA (eds) Invasive species management: a handbook of principles and techniques. Oxford University Press, Oxford, pp 61–76

Grice AC, Field AR, McFadyen REC (2004) Quantifying the effects of weeds on biodiversity: beyond Blind Freddy's test. In: Sindel BM, Johnson SB (eds) Proceedings of the 14th Australian Weeds Conference. Weed Management, Balancing People, Planet, Profit; Wagga Wagga. Weed Society of New South Wales, Sydney, pp 464–468

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

Grice AC, Clarkson JR, Friedel MH, Ferdinands K, Setterfield S. 2010. Containment as a strategy for tackling contentious plants. In: Zydenbos, SM (ed) Proceedings of the 17th Australasian Weeds Conference. New Zealand Plant Protection Society, pp 486–489

Griffin GF (1993) The spread of buffel grass in inland Australia: land use conflicts. In: Proceedings of the 10th Australian Weeds Conference and the 14th Asian Pacific Weed Science Society Conference. Weed Society of Queensland, Brisbane, pp 501–504

Hall TJ (2000) History and development of buffel grass pasture lands in Queensland. In: Cook B (ed) Proceedings of buffel grass workshop, Theodore Qld, 21–23 February 2000, Department of Primary Industries, Queensland, pp 2–12

Holcombe T, Stohlgren TJ (2009) Detection and early warning of invasive species. In: Clout MN, Williams PA (eds) Invasive species management: a handbook of principles and techniques. Oxford University Press, Oxford, pp 36–46

Humphreys LR (1967) Buffel grass (*Cenchrus ciliaris*) in Australia. Tropical Grasslands 1:123–134

Humphries SE, Groves RH, Mitchell DS (1991) Plants invasions of Australian ecosystems: a status review and management directions. Kowari 2:1–116

Jackson J (2005) Is there a relationship between herbaceous species richness and buffel grass (*Cenchrus ciliaris*)? Austral Ecology 30:505–517

Keetch RI (1981) Rangeland rehabilitation in Central Australia. Alice Springs, Conservation Commission of the Northern Territory, Darwin

Lawson BE, Bryant MJ, Franks AJ (2004) Assessing the potential distribution of buffel grass (*Cenchrus ciliaris* L.) in Australia using a climate-soil model. Plant Protection Quarterly 19:155–163

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

Ludwig JA, Eager RW, Liedloff AC, McCosker JC, Hannah D, Thurgate NY, Woinarski JCZ, Catterall CP (2000) Clearing and grazing impacts on vegetation patch structures and fauna counts in eucalypt woodland, Central Queensland. Pacific Conservation Biology 6:254–272

Marshall NA, Friedel M, van Klinken RD, Grice AC (2011) Considering the social dimensions of contentious species: the case of buffel grass. Environmental Science and Policy 14(3):327–338

Martin P (2008) Cross pollination or cross-contamination? Directions for informing the management of invasives with market-economy concepts. In: van Klinken RD, Osten VA, Panetta FD, Scanlan JC (eds) Proceedings of the 16th Australian Weeds Conference. Queensland Weeds Society, Brisbane, pp 6–13

Martin TG, van Klinken RD (2006) Value for money? Investment in weed management in Australian rangelands. The Rangeland Journal 28:63–75

McIvor J (1998) Pasture management in semi-arid tropical woodlands: effects on species diversity. Australian Journal of Ecology 23:349–364

Miller G, Friedel M, Adam P, Chewings V (2010) Ecological impacts of buffel grass (*Cenchrus ciliaris* L.) invasion in central Australia: does field evidence support a fire-invasion feedback? The Rangeland Journal 32:353–365

Mitchell A, Schmid M (2002) Case history of the eradication of fringed spider flower, *Cleome rutidosperma* DC. In: Spafford-Jacob H, Dodd J, Moore, JH (eds) Proceedings of the 13th Australian Weeds Conference. Plant Protection Society of Western Australia, Perth, pp 297–299

Nelson AL, Pettit C (2004) Effective community engagement for sustainability: wombat community forest management case study. Australian Geographer 35:301–315

NRETAS (Department of Natural Resources, Environment, The Arts and Sport) (2009) Weed Management Plan for Gamba Grass (*Andropogon gayanus*) August 2009. Northern Territory Government, Palmerston. Accessed online January 18 2011: http://www.nt.gov.au/nreta/natres/weeds/find/gamba/pdf/draft_weedmgmtplan.pdf

Puckey H, Brock C, Yates C (2007) Improving the landscape scale management of buffel grass *Cenchrus ciliaris* using aerial survey, predictive modelling, and a Geographic Information System. Pacific Conservation Biology 13:264–273

Rudman T, Goninon C (2002) Eradication case history, *Hieracium pilosella* L. ssp. *nigrescens* (Fr.) Nägeli & Peter in Tasmania. In: Spafford-Jacob H, Dodd J, Moore JH (eds), Proceedings of the 13th Australian Weeds Conference. Plant Protection Society of Western Australia, Perth, pp 304–306

Smyth AK, James CD (2004) Characteristics of Australia's rangelands and key design issues for monitoring biodiversity. Austral Ecology 29:3–15

Smyth A, Friedel M, O'Malley C (2009) The influence of buffel grass (*Cenchrus ciliaris*) on biodiversity in an arid Australian landscape. The Rangeland Journal 31:307–320

Spafford-Jacob H, Randall RP, Lloyd SG, King C (2004) Quarantine law loophole: an examination of the known weed species permitted for import without weed risk assessment. In: Sindel BM, Johnson SB (eds), Proceedings of the 14th Australian Weeds Conference. Weed Society of New South Wales, Sydney, pp 684–689

Tomley AJ, Panetta FD (2002) Eradication of the exotic weeds *Helenium amarum* (Rafin) H.L. and *Eupatorium serotinium* Michx. from south-eastern Queensland. In: Spafford-Jacob H, Dodd J, Moore JH (eds), Proceedings of the 13th Australian Weeds Conference. Plant Protection Society of Western Australia, Perth, pp 293–296

USDA (United States Department of Agriculture), Natural Resource Conservation Service (2011) NRCS Invasive Species Policy, Invasive Species Executive Order 13112. http://plants.usda.gov/java/noxious?rptType=State&statefips=04 (Accessed 14 October 2011)

van Klinken RD, Panetta ED, Ross B, Wilson C (2004) A pain in the grass: what's the diagnosis? In: Sindel BM and Johnson SB (eds), Proceedings of the 14th Australian Weeds Conference. Weed Society of New South Wales, Sydney, pp 480–483

Walton C (2004) To declare or not to declare? That is the question. In: Sindel BM, Johnson SB (eds), Proceedings of the 14th Australian Weeds Conference. Weed Society of New South Wales, Sydney, pp 62–67

Walton C (2009) *Leucaena leucocephala* (Lam.) de Wit. In: Panetta FD (ed) The biology of Australian weeds, vol 3. RG and RF Richardson, Melbourne, pp 143–156

Warren P (2006) The branched broomrape eradication program in Australia. In: Preston C, Watts JH, Crossman ND (eds), Proceedings of the 15th Australian Weeds Conference. Weed Management Society of South Australia, Adelaide, pp 610–613

Zurbo B (2008). Growing low THC hemp under licence in NSW – frequently asked questions. Primefact 841. NSW DPI. Accessed online January 18 2011: http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/255225/Growing-low-thc-hemp-in-NSW-faq.pdf