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 as invaders can be contentious. Often they are either treated as weeds and their use prohibited or their unfettered exploitation is permitted and land managers must individually contend with any negative effects. The pasture species buffel grass (*Cenchrus ciliaris*) is contentious in Australia and there have been no attempt to broadly and systematically address the issues surrounding it. Recent research into perspectives on buffel grass has indicated that there is some mutual acceptance by proponents and opponents of each others' views and concerns about buffel grass. We propose that this provides the basis for a national approach. It would be important to devise and implement a strategy in consultation with stakeholders, developing realistic goals that are applicable across a range of scales and responsive to regional differences in costs, benefits and socio-economic and biophysical circumstances. A clear-cut allocation of responsibilities would also be necessary as would ascertaining the most appropriate balance between legislative and non-legislative mechanisms. Legislative arrangements other than those provided by state-level pest management regulations may be most effective. Possible practical elements of a national approach include 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 in order to protect high-value environmental assets, containing strategically located populations and focusing control on the varieties that are least important for pastoralism. This approach could be applied to other contentious plant species.

Keywords: contentious plants, invasion, policy, production, strategy, weed

39 It is difficult and expensive to address the problems caused by abundant, widespread
40 invasive plants. Difficulties are exacerbated when the species in question is also useful or
41 desirable, or perceived to be so by some interest groups. In such situations it is not only
42 necessary to develop, resource and apply solutions that are practical at large scales, but also
43 to overcome the contentions that inevitably exist.
44
45 Around 28,000 plant species have been introduced to Australia since European settlement,
46 and approximately one-tenth of them have naturalised (Randall 2007). Most were
47 deliberately introduced as garden plants (e.g. *Lantana camara* L., lantana; Swarbrick 1986) or
48 for use in horticulture (e.g. European olive *Olea europaea* L.; Spennemann and Allen 2000),
49 forestry (e.g. radiata pine *Pinus radiata* D.Don,; Williams and Wardle 2007, 2009) or pastures
50 (Lonsdale 1994; Cook and Dias 2006). Some species introduced as potential pasture plants
51 are highly productive without being problematic; some are invasive without being useful;
52 others are productive *and* problematic (Lonsdale 1994). Pasture introduction programs
53 have contributed significantly to the suite of contentious plants in Australia (Grice *et al.*
54 2008).
55
56 Progress with species that are both problematic and productive requires practical and
57 economic biophysical solutions and resolution of any contentions surrounding them. In
58 this paper we consider biophysical and social factors in examining prospects and
59 approaches for developing broad-scale strategic solutions for one contentious naturalised
60 pasture species in Australia, buffel grass *Cenchrus ciliaris* L. (syn. *Pennisetum ciliare* (L.) Link).
61

The basis of contention over buffel grass

Buffel grass is arguably the most successful introduced pasture grass in northern Australia (Humphreys 1967). Early introductions were incidental if not accidental, and probably took place in the 1870s (Friedel *et al.* 2006). Through the twentieth century, buffel grass and other *Cenchrus* spp./*Pennisetum* spp. were included in various pasture plant introduction programs, with material being obtained from collections in various parts of the species' native range in Africa, the Middle East and parts of southern Asia (Hall 2000; Tu 2000). There were many informal and formal releases of the species in central, tropical and sub-tropical Australia and it was widely promoted.

Buffel grass is now common and widespread in Australia, most notably in Queensland, the Northern Territory and Western Australia, but it is also present in New South Wales and South Australia. It is a common component of many extensively used pastoral systems and has been responsible for substantial increases in livestock carrying capacities (Friedel *et al.* 2006). Buffel grass has also been used in erosion control and restoration of areas degraded by livestock grazing (Keetch 1981). There are no detailed national data on how much land has been sown to buffel grass or over what area it has naturalised but it is clearly of great economic importance (Hall 2000).

Buffel grass has demonstrated a strong propensity to naturalise in Australia (Griffin 1993), its range covering extensive areas of the mainland (Australia's Virtual Herbarium 2010) as well as islands off the northern coast (Dixon *et al.* 2002) (Fig. 1) and including at least 53 of Australia's 85 Interim Biogeographical Regions (van Klinken *et al.* 2004). It is often a common or even dominant component of the herbaceous stratum of natural or semi-

86 natural vegetation and it dominates large areas of sown pasture. There is potential for
87 further range expansion under current climate scenarios (Lawson *et al.* 2004).
88
89 At least since the early 1990s, the species' distribution and capacity to dominate the
90 herbaceous vegetation have raised concerns about the possibility of negative environmental
91 impacts (Humphries *et al.* 1991; Griffin 1993; Friedel *et al.* 2006). Several studies have
92 attempted to quantify these impacts. Griffin (1993) showed that, in central Australia, the
93 species is most frequent on alluvial and other high nutrient soils and in drainage lines and
94 suggested that this could reduce the capacity of these parts of the landscape to provide
95 refuge for threatened central Australian fauna. Buffel grass was also frequent in more
96 restricted, sheltered micro-sites on cliffs and ledges where it competes with rare and relict
97 plant species and alters fire regimes and the habitats of native flora and fauna (Griffin
98 1993). The species can generate positive fire-invasion feedbacks in central Australian
99 woodlands (Miller *et al.* 2010) and affects fire regimes in *Acacia cambagei* F.Muell. ex
100 R.T.Baker (gidgee) and brigalow (*A. harpophylla* Benth.) communities (Butler and Fairfax
101 2003). In keeping with impacts recorded for invasive plant species in general (Grice *et al.*
102 2004), buffel grass has significant negative effects on plant species richness (Clarke *et al.*
103 2005; Fairfax and Fensham 2000; Franks 2002; Jackson 2005; McIvor 1998). Some negative
104 effects of buffel grass on selected fauna have been quantified (Best 1998; Eyre *et al.* 2009;
105 Ludwig *et al.* 2000; Smyth *et al.* 2009) and the species has been singled out in assessments of
106 threats to a number of native plants and animals (Friedel *et al.* 2006). Together, these
107 studies and assessments suggest that buffel grass has a significant negative impact on native
108 flora and fauna. Humphries *et al.* (1991) listed buffel grass as a Category 1 weed of
109 Australian natural ecosystems.
110

Thus, buffel grass provides major economic benefits and poses significant environmental threats but there is neither universal agreement about the species' status, nor open, mutual recognition of the costs and benefits by all stakeholders. Rather, it has been the subject of contrasting perspectives and conflicting opinions.

Strategic options for 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 the 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 precludes the legal cultivation of declared plants so there is often only limited capacity for managed beneficial cultivation of species that are formally recognised as pests. A compromise has been attempted in the case of gamba grass in the Northern Territory where the species' declaration status differs between a "Management zone" and an "Eradication zone" (Table 1).

There has been little concerted action to deal with any negative effects of buffel grass in Australia. It is not listed in 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. However, 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 an important natural resource management issue (Friedel *et al.* 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. The introduction of non-indigenous plants, such as buffel grass, is not permitted without written approval of the Pastoral Board that is responsible for overseeing management of these lands. Moreover, the SAAL NRM Board has developed a Buffel Grass Management Plan for the SAAL, its purpose being to identify priority actions for the management of buffel grass (Greenfield 2007). In South Australia, soils and climate are probably less suitable for buffel grass than they are in 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 reduced opposition to such legislation.

In the case of buffel grass, failure to explore options other than unregulated use is probably due to three reasons. First, there is the perception that it is technically and/or economically difficult to control buffel on a practical scale and, second, there would be overwhelming opposition to using technical capacity if it was available. Proponents have often denied deleterious impacts of buffel grass and tend to attribute to the species greater environmental benefits than do opponents (Friedel *et al.*, submitted). Opponents have not fully acknowledged the species' value. Thus, proponents down-play the costs, while opponents down-play the benefits. Third, the advice of government agencies has long promoted the use of buffel grass and other invasive forage species including leucaena

160 *Leucaena leucocephala* (Lam.) de Wit (Walton 2009), gamba grass (Cameron and Lemcke
161 2006) and Olive hymenachne (Hall 2000).
162
163 ## Foundations for a broad-scale buffel grass strategy
164 Given that buffel grass is already widespread and abundant (Friedel *et al.* 2006), that
165 northern and central Australian pastoral industries are strongly dependent on it (Marshall *et*
166 *al.* 2010) and that there is likely to be resistance to any restrictions on its use (Friedel *et al.*
167 submitted), it is important to seriously consider whether broad-scale, strategic options,
168 other than unfettered use, are viable and how such options might be developed.
169
170 A broad-scale strategic approach to buffel grass would aim to reduce deleterious effects
171 without severely diminishing the species' productive value. It would need to be (1)
172 consultative in its development and application; (2) realistic in its goals; (3) applicable at a
173 range of scales; (4) responsive to regional differences in costs, benefits and socio-economic
174 and biophysical circumstances; (5) decisive in its allocations of responsibilities; (6)
175 supported by appropriate legislative and non-legislative measures; and (7) based on sound
176 information.
177
178 **Consultation**
179 Broad consultation would be crucial to the development and implementation of a national,
180 strategic approach to the management of a species as contentious as buffel grass (Fraser
181 and Dougill 2006). A stakeholder driven strategy is far more likely to be effective than a
182 top-down approach. However, it would be naïve to assume that such consultation can lead
183 to a "win-win" situation. Rather, a compromise between unfettered exploitation and
184 complete prohibition is a realistic expectation.

185

186 The purpose of consultation is to agree on the issues and the ways in which they can be
187 addressed. It should identify common ground between the various stakeholders, engender
188 mutual acceptance of others' needs and approaches, help devise broadly accepted
189 objectives and facilitate sharing of knowledge on patterns of distribution and abundance,
190 impacts, possible management tools, and how and where those tools might be used
191 effectively (Smith 1998).

192

193 Consultation could be staged (Nelson and Pettit 2002). Initial, broad engagement should
194 increase the likelihood that any subsequently developed strategy would be socially,
195 economically and politically acceptable. Later, an advisory group, incorporating stakeholder
196 organisations, including relevant government agencies, could help develop and implement
197 the strategy itself. One role of this group could be to express the variety of views amongst
198 government agencies and progress toward consensus and compromise amongst them to
199 catalyse more productive approaches amongst stakeholders at large.

200

201 During consultation, the proponents of buffel grass would be more vulnerable than the
202 opponents to any changes from the *status quo*. Actions designed to reduce the deleterious
203 effects of buffel grass could impose some costs on its proponents, whether that be reduced
204 production, increased production costs, opportunity costs associated with development
205 prospects that are denied or the costs of engaging in a process to devise and agree on
206 solutions. Effective stakeholder consultation is likely to involve significant transaction costs.

207

208 **Realistic strategic goals**

209 A strategy that aims to reduce negative impacts while retaining production benefits would,
210 ideally, incorporate goals applicable to national, state, regional and finer scales. They can be
211 logically grouped into four categories: prevention, eradication, containment and asset
212 protection (Grice 2009).

213

214 Prevention usually relates to the introduction phase of an invasion, that is, the goal is to
215 prevent introduction at the very broad (e.g. national or continental) scale (Grice 2000),
216 which is not an option for buffel grass in Australia. However, it may be useful to preclude
217 the introduction of new genetic material to restrict the species' capacity to occupy 'new'
218 habitats. Such measures would involve a trade-off against the desirability of new strains or
219 ecotypes of buffel grass that could enhance the species' value to pastoralism in particular
220 locations or management systems.

221

222 We define eradication as the elimination of the species (or other taxon or cultivar) from a
223 specified area. Some introduced plants have been eradicated from Australia (e.g. Dodd
224 2004; Rudman and Goninon 2002; Tomley and Panetta 2002) and other efforts are still in
225 progress (e.g. Brooks and Galway 2006; Csurhes 2004; Mitchell and Schmid 2002; Warren
226 2006,), but eradication at that scale is generally an unlikely prospect (Groves and Panetta
227 2002; Mack and Foster 2009). It requires considerable resources over an extended period.
228 Continental-scale eradication of buffel grass is neither possible nor desirable though
229 eradication at finer scales may be a valid and achievable goal. Isolated populations of buffel
230 grass in vulnerable land types on high value conservation reserves could be targeted for
231 eradication, as could populations on off-shore islands, where the prospects of

232 recolonisation are likely to be lower than on the mainland (Dixon *et al.* 2002). After
233 eradication it would be necessary to monitor to detect recolonisation and respond to
234 incursions in a timely way. The temporal intensity of monitoring required would depend on
235 the likelihood of recolonisation while the locations of monitoring sites would need to
236 reflect the routes whereby recolonisation is most likely to take place.
237
238 We define containment as stopping a problem spreading from one location to another. A
239 containment strategy attempts to impose anthropogenic limits to a species' distribution
240 rather than allowing it to expand its range to limits set by, for example, climatic or edaphic
241 factors (Grice 2009; Grice *et al.* 2010). Containment targets could be identified at a fine
242 scale, for example, small infestations on individual land-use units (e.g. conservation
243 reserves; non-pastoral Aboriginal lands). At the regional scale (e.g. parts of central
244 Australian deserts) the goal could be to minimise range expansion by targeting dispersal
245 routes and mechanisms to counter spread to areas that are currently free from the species.
246 A first step to developing realistic containment goals is to identify areas of habitat suitable
247 that are currently free from the species and to prioritise those areas. It would need to
248 encompass the range of perspectives and needs in relation to buffel grass, considering the
249 costs and benefits associated with the species in different regions. Perhaps the greatest
250 challenge to the containment of buffel grass is that in most parts of Australia where buffel
251 grass is present there are multiple populations and ecotypes. Cacho (2004), on the basis of
252 a conceptual model of weed spread that included partial benefit-cost analysis, argued that in
253 some cases the optimum weed management strategy may be 'partial containment', that is
254 slowing the rate of spread. Benefit-cost analysis may help determine the value of
255 attempting to contain one local population in the face of the risks posed by other local
256 sources of seeds.

Asset protection strategies would aim to minimise the impacts of the species in a particular location (Grice 2009). They rely on there being means available to limit its prevalence in the community that it is invading. The prevalence of buffel grass can be expressed 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. It is important to specifically identify the assets that are to be protected and the level of suppression that is required to provide that protection. Such decisions should be based on knowledge of the processes whereby the invasive species has an impact. There has been little research on how the abundance of buffel grass can be managed, particularly on how its abundance can be constrained (rather than promoted). There is, however, evidence from the experience of those who have attempted to do so and a range of options has been canvassed (Friedel *et al.* submitted).

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, the resources to make those means operational and the incentive on the part of those whose commitment is required. For contentious species, one aspect that determines the validity of a set of goals is the extent to which different goals can be applied to different areas without there being undue interference between them. For example, will actions taken at some locations devalue those applied to adjacent areas and what degree of spatial separation is required to minimise such interference? In particular, it is important that measures taken to reduce negative environmental impacts do not unduly interfere with the productive value of the species, especially where no realistic alternatives exist. In some situations this would require relatively fine-scale spatial separation of areas for which there

281 are different strategic goals. A robust strategy will consist of elements between which there
282 is minimum devaluation and interference between locations.
283
284 **Scale**
285 A continental-scale strategy for buffel grass would provide a context in which regional
286 elements might be framed. National recognition of the issues could facilitate interstate
287 collaboration and co-ordination, yield economies of scale and improve access to federal
288 resources (e.g. to support research). Some of the organisations (Commonwealth
289 government departments and agencies; non-governmental organisations) whose
290 engagement would be essential to the success of a strategy are themselves national in scope,
291 and they may be more likely to engage with a national strategy. Beneath the national level,
292 strategic elements could be applied at finer spatial scales in a hierarchical way. Some of
293 these elements may benefit from legislative backing but it would be important, where
294 legislative mechanisms are used, that they reflect nuances in need that are more likely to
295 operate at regional levels, that is, below the state level at which much natural resource
296 legislation is enacted. Many of the actions that would be required to make a strategy
297 effective at higher scales would actually be implemented at finer scales in the hierarchy.
298
299 **Regional responsiveness**
300 Physical, social and economic environments will drive inter-regional differences in a buffel
301 grass management strategy. These include: the contributions that buffel grass makes to
302 pastoral production; the ways in which it is managed; the environmental services it
303 provides (e.g. control of soil erosion); its extent; the impacts it has on native flora and
304 fauna; its status under legislation; and the suitability and effectiveness of the measures
305 available (Friedel *et al.* submitted; Marshall *et al.*, in press).

306

307 Projects currently underway to address buffel grass issues indicate the need for and validity
308 of different responses in different areas. For example, at the very finest scale, a 54 ha core
309 area of the Alice Springs Desert Park has been the target of a buffel grass control program
310 that has, since 1996, reduced the species to very low abundance with the ultimate goal of
311 local eradication (CRCAWM 2008). Programs to control buffel grass have also been
312 implemented on other conservation reserves, for example, Uluru-Kata Tjuta National Park
313 in central Australia (Anon. 2009). These actions aim to alleviate perceived or demonstrated
314 impacts at sites with high conservation values. The only regional scale strategic plan for
315 buffel grass is the devised for the SAAL (Greenfield 2007).

316

317 **Allocation and acceptance of responsibilities**

318 A national buffel grass strategy would require that areas of responsibility are defined and
319 accepted. In Australia, natural resource management is primarily a state or local
320 government responsibility. National strategies for dealing with problematic plants have
321 been possible, most notably with Australia's twenty Weeds of National Significance
322 (WONS), under a joint Commonwealth-State initiative. For these species, national
323 strategies have been required through Australia's National Weeds Strategy, a development
324 facilitated by significant Commonwealth funding (ARMCANZ 1999; Martin and van
325 Klinken 2006). While most of these strategies have not had to deal with contentions as
326 extreme as those associated with buffel grass, there are some cases where, at least initially,
327 dissenting views have been part of the mix (e.g. blackberry *Rubus fruticosus* L (CRCAWM
328 2003a); Olive hymenachne (CRCAWM 2003b), prickly acacia *Acacia nilotica* (Benth.)
329 Brenan) (CRCAWM 2003c); and willows *Salix* spp. (CRCAWM 2003d)). However, in all of

these cases, actions taken under collaborative 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 arena for dealing with pest plants, including the Weeds of National Significance mechanisms within the National Weeds Strategy.

Legislative and non-legislative measures

Strategic management of any contentious plant species requires an appropriate combination of legislative and non-legislative measures. In several prominent Australian cases (e.g. Olive hymenachne and gamba grass) watershed decisions have applied pest plant legislation leaving little scope for exploiting the productive potential of the species. In the Northern Territory the legislation has been framed to allow continued exploitation of existing gamba grass pastures while attempting to constrain the species' invasive capacity. For instance, a draft Weed Management Plan for Gamba Grass (NRETAS 2009) delineates an "eradication zone" and a "management zone". In the management zone the aim is to "[contain] established pasture areas (e.g. through the use of grazing land management principles and the maintenance of buffer zones)". Currently, there are no legislative measures to deal with buffel grass, or other contentious pasture grasses such as aleman grass *Echinochloa polystachya* (Kunth) Roberty and para grass *Urochloa mutica* (Forssk.) T.Q.Nguyen (Table 1).

In the case of buffel grass, there is an important place for non-legislative measures. This would be consistent with a strong role for broad stakeholder consultation, during both development and implementation of a strategy. Non-legislative elements could include

355 voluntary codes of practice (Walton 2009), insurance mechanisms (Martin 2008) and
356 certification procedures related to the exploitation of species that could be problematic off-
357 site. Consensus and/or compromise may be more likely by not using conventional pest
358 plant legislation (Walton 2004). Precedents exist in regards the cultivation of species such
359 as poppies in Tasmania (Department of Justice 2010) and Indian hemp in New South
360 Wales (Zurbo 2008) which are problematic not because of impacts they have as weeds but
361 because they are potential sources of illicit drugs.
362
363 A buffel grass code of practice could be developed analogous to the Leucaena Code of
364 Practice (Walton 2009) given the strong parallels between the two species. Both are
365 important, extensively cultivated and exploited forage species used by pastoral industries in
366 northern Australia. However, there are also important differences between the two cases
367 (Grice 2006). At its best, leucaena is used in horticultural-style plantations and its
368 productive exploitation does not require that it be free-seeding or even self-propagating;
369 the situation lends itself to the use of sterile varieties and containment of plantings may be
370 relatively straight-forward. Exploitation of buffel grass, on the other hand, depends
371 strongly on its free-seeding characteristics and its capacity to self-propagate in extensively
372 managed areas. Moreover, there is currently no reliable assessment of the effectiveness of
373 codes of practice weakening any arguments for the approach. An approach to buffel grass
374 that included a code of practice would have to address issues of non-compliance and the
375 pre-existence of extensive naturalised populations.
376

377 Specific practical elements

378 Developing and implementing national strategies for the management of highly productive
379 contentious species such as buffel grass presents major challenges. However, recently

published data suggest that both technical and social barriers to resolution of the specific contentions relating to buffel grass in Australia may not be as great as commonly perceived. "Resolution" does not necessarily require that stakeholders reach a point where they all agree on every aspect of a situation or how that situation should be dealt with but a broadly accepted way forward that comes with a significant net benefit and at a tolerable total economic and social cost to major individual stakeholders and stakeholder groups. On the basis of a survey of pastoralists in four divergent regions of Australian rangelands, Marshall *et al.* (in press) concluded that pastoralists in three of them perceive that they are strongly dependent on buffel grass, that they generally do not accept that buffel grass has negative environmental consequences, but that they are generally supportive, at least in principle, of efforts to control buffel grass on conservation reserves.

Studying the same four regions, Friedel *et al.* (submitted) concluded that the contention amongst diverse organisations was not as great as might have been supposed. The benefits and costs of buffel grass were acknowledged by a wide range of participants. There was general agreement in relation to management objectives for environmental reserves and pastoral lands of low conservation value, although the objectives for pastoral lands of high conservation value were contentious, either within or amongst regions. A variety of management tools and strategies were broadly supported, with exceptions that could be explained to a considerable extent by regional differences in the 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 is dependent on adequate resourcing in terms of both 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 of buffel grass in Australia. 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.

Across extensive areas of central Australia, buffel grass is relatively sparse, and/or patchily distributed, pastoralism is not a significant land-use and there are important land values that could be compromised should the species increase. These areas include 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 conservation value and their value to indigenous people. A containment goal could be appropriate and acceptable for such areas. Effort to this end would focus on the routes whereby buffel grass is likely to spread, principally transport corridors, and managing plant communities to build resistance to invasion. Overall, there is a case for a geographical differentiation of management objectives.

Keep buffel grass out of conservation reserves where it is absent or sparse.

There are many conservation reserves in areas where buffel grass is already abundant and widespread and where the species constitutes a significant threat. For reserve managers and conservation interests there is merit in preventing it from becoming abundant or dominant on the reserves themselves or, if the species is not already present, in keeping them free from buffel grass. Doing so would not compromise pastoral production given that livestock grazing is not permitted on most Australian conservation reserves. Establishing priorities amongst conservation reserves would be important because of resource constraints. 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. Lower priority should be given to conservation reserves where it is unlikely that buffel grass will have a major impact, for example due to land or soil types being sub-optimal for the species.

Negotiate compromise solutions for biodiverse areas outside conservation reserves.

In Australia, particularly in the extensive rangelands, areas outside conservation reserves retain considerable environmental value (Smyth and James 2004). Areas of very high biodiversity that are outside conservation reserves present what is probably the greatest challenge to a broad, strategic approach to buffel grass. A crucial piece of information concerns the relationship between, on the one hand, the abundance and distribution of buffel grass in a landscape of high conservation value, and on the other, the effects of that buffel grass on those values. Areas of high conservation value are where financial compensation for any losses to productive capacity or some other incentive scheme would be of greatest benefit.

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. This would have to be done by targeting the routes whereby buffel grass is moving or is likely to move away from the source populations.

Focus control on the least productive varieties of buffel grass

In Australia, buffel grass varies considerably in how palatable they are to livestock. This could be due to genetic or environmental variation. In each region it may be possible to target the less palatable or productive varieties without detracting greatly from the productivity of cattle enterprises and industries that rely on the species as a whole. In order to do this it would first be necessary to identify varieties of buffel grass that are less palatable or productive. It would also be valuable to ascertain how the different varieties relate to one another, including 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 control or containment. The situation is complicated by the fact that different varieties are more suitable for pastoralism in different regions (Friedel *et al.* 2006).

Need for further information

A strategy for dealing with contentious species should be based on sound information. For buffel grass, better information in the following areas would be useful.

1. Quantify environmental impacts

There is a need for better quantification of the environmental impacts of buffel grass in different situations and geographical areas. A broad-scale strategic approach to buffel grass should link both production benefits and conservation outcomes to the abundance of buffel grass. A deeper understanding of environmental threats and their mechanisms would help prioritise between locations and identify environmental assets that are at greatest risk.

2. Benefit-cost analysis

Sound cost-benefit analysis should underlie the development of broad-scale buffel grass management strategies. A major challenge here is to weigh the wide range of 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 *et al.* 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 retain opportunities to acquire benefits from cultivation whilst avoiding some of the costs associated with the invasive behaviour of the species. More discerning cost-benefit analysis would be required to develop regionally differentiated goals.

3. Management options

There is a need for better knowledge of how buffel grass can be best managed for different purposes. Friedel *et al.* (submitted) tabulated management tools potentially applicable to buffel grass. There is considerable information in the minds of numerous land managers on how grazing, fire, herbicides and other techniques may or may not be applicable in different situations. There would be value in capturing this information in as much detail as

possible, combining it with the results of more formal testing and using it to refine "best bet" management practice for different goals and circumstances.

4. Distribution and abundance

Higher resolution 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.

5. Intra-specific variation

It would be useful to quantify and map the variation that exists in the buffel grasses currently present in Australia. Information presently available 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. 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

In Australia, buffel grass is a prominent example of a contentious, introduced plant species with a strong polarisation between proponents, who are concerned principally with pastoral production, and opponents, who are focused mainly on the preservation of environmental values. Initial effort in regards buffel grass should focus on identifying and exploiting viewpoints and interests that different stakeholder groups have in common in order to make cost-effective progress. There is ample evidence that useful common ground exits. 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 of this contentious species. The approach that we advocate for buffel grass should be broadly applicable to other contentious, invasive plant species.

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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[1]	Not declared	Not declared	Declared Class 4	Not declared	Not declared
New South Wales[2]	Not declared	Not declared	Declared Class 1	Not declared	Not declared
Northern Territory[3]	Not declared	Declared Class A/C Declared Class B/C	Declared Class B/C	Not declared	Not declared
Queensland[4]	Not declared	Declared Class 2	Declared Class 2	Not declared	Not declared
South Australia[5]	Not declared	Not declared	Declared – control not required	Not declared	Not declared
Tasmania[6]	Not declared	Not declared	Not declared	Not declared	Not declared
Victoria[7]	Not declared	Not declared	Declared – Restricted	Not declared	Not declared
Western Australia[8]	Not declared	Declared P1, P2	Declared P1, P2	Not declared	Not declared

[1] 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)
[2] 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)
[3] 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)
[4] 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)
[5] South Australia: Class: control not required.
http://www.dwlbc.sa.gov.au/biodiversity/apc/projects/weeds/plants_list.html
[6] Tasmania: Source: http://www.dpiw.tas.gov.au/inter.nsf/WebPages/SSKA-73U3QA?open
[7] 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)
[8] 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)

Figure caption

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