Developing a research agenda for the distribution and rate of spread of buffel grass (*Cenchrus ciliaris*) and identification of landscapes and biodiversity assets at most risk from invasion

A report to the Department of the Environment and Water Resources

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The views and opinions expressed in this report represent the outcomes of a workshop held in Alice Springs on 12–13 September 2007, and do not necessarily reflect the views and opinions of the Department of the Environment and Water Resources, or of the Australian Government.

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1 Executive summary

This report presents the outcomes of a workshop to examine issues in relation to the distribution and rate of spread of buffel grass (*Cenchrus ciliaris*), and of those landscapes and biodiversity assets at most risk from invasion. The workshop was held on 12–13 September 2007, in Alice Springs.

The need to address issues relating to buffel grass was identified by the Biodiversity Working Group of the Australian Collaborative Rangelands Information System (ACRIS) in a report to the ACRIS Management Committee earlier in 2007. They recognised the paucity of information about buffel grass, which they identified as a transformer weed with potentially serious implications for biodiversity.

In accordance with its brief, this report provides:

- a summary of the state of knowledge for specific issues relating to the spread and potential distribution of buffel grass, and to the identification of landscapes/environments where biodiversity assets are at most risk, outlining where we are now, what we can currently do and what needs to happen
- a prioritisation according to importance for management and the feasibility of research, relevant to the diversity of landscape types in arid and semi-arid regions
- a proposed research agenda; including the development and implementation of a robust methodology for monitoring spread and impacts of buffel grass on biodiversity assets
- potential collaborating organisations including CSIRO, government agencies and academic institutions with skills relating to the specific issues.

In brief, the proposed research agenda is:

1. Develop a national GIS of buffel grass distributions consistent with that sponsored by the National Land and Water Resources Audit (NLWRA) (2007) for invasive weeds.

2. Conduct an expert workshop to determine (a) the most appropriate approach(es) to modelling buffel grass distribution at a range of spatial scales (local, regional and national) and (b) the most appropriate approach(es) to modelling buffel grass spread at local and regional scales.

3. Develop and validate regional (sub-IBRA) buffel grass distribution modelling capability in one case study region where regional GIS and data availability are good. Develop and validate regional (sub-IBRA) model of high biodiversity value areas in the same sub-IBRA. Combine models to predict high risk areas.

4. Research functional understanding to improve management e.g. Are there thresholds for cover levels of native vegetation which limit spread of buffel grass? Can we predict the distribution of buffel grass under climate change scenarios in case study areas?

5. Monitoring may not require specific research activities if it is ‘piggy-backed’ on existing or planned biodiversity monitoring systems. Researching data integration from different monitoring systems for national reporting could occur under 1. The capacity to conduct reliable aerial surveys of at-risk high biodiversity value areas may need testing.

6. Develop an on-line bibliography for buffel grass (and potentially other transformer weeds) as part of research activities, and host it on the ACRIS website.

2 Background

Buffel grass has been widely introduced to the Australian rangelands for its production values (Hall 2000) and has spread into many non-target areas. While it has brought major benefits to many pastoral landholders, it is contentious because it also threatens biodiversity values in diverse inland regions (Friedel *et al*. 2006). Buffel grass is almost certainly present in all rangeland bioregions (see Interim Biogeographic Regionalisation for Australia (IBRA) 2007 for definition) and is continuing to establish in new areas and to increase where it already exists.

In its 2007 report, the Biodiversity Working Group of the Australian Collaborative Rangelands Information System recognised the importance of tracking changes in transformer weeds such as buffel grass, where transformer weeds are invasive plants that can transform the basic attributes of habitats (Bastin *et al.* in press). The Working Group noted that detailed information on the distribution and density of buffel grass was very poor. Detailing the specific impacts of buffel grass on biodiversity, especially for those assets at greatest risk, was also important, as was documenting the potential for control.

2.1 Prioritising issues – where do we start?

Regarding the potential impacts of buffel grass on biodiversity assets, there is a great deal of anecdotal evidence but only a limited amount of scientific evidence. The lack of scientific evidence is due to the inherent difficulties of researching impacts in highly spatially and temporally diverse arid and semi-arid environments. Research funding is usually constrained to a time period of 1-5 years, perhaps for the life of a PhD study, and yet if effective rainfall events in that time are infrequent, no impacts may be discerned. Rainfall at different times of the year may elicit different outcomes. Spatial scale is also an issue – where and how should impact be assessed? While Jackson (2005) detected a relationship between native species richness and buffel grass biomass at a 1 m^2 scale, no relationships were evident at larger scales. Unpublished data of Smyth, Friedel and O'Malley suggest that, at larger scales, any influence of buffel grass is embedded in the effects of other environmental variables like aspect and soil pH and so the effects of low amounts of buffel grass on native plant species composition will be difficult to detect unless these other variables can be filtered out by analytical or experimental means. This is a complex area that should be addressed but it will take considerable time and resources.

The potential for control of buffel grass is also a challenge for research. Since buffel grass is regarded as valuable for production and a threat to biodiversity values, the issue of widespread control is controversial. There are few control options but what is more difficult is determining what methods of broad-acre control, if any, are acceptable to diverse stakeholders. This is a complex task , and thus might not be the best starting point for a research agenda.

Determining the spread of buffel grass and its potential distribution is likely to be more amenable to research in the short term, and would facilitate a strategic approach to control and further research. Lawson *et al.* (2004) have used CLIMEX climate modelling with the addition of soils information to predict the distribution of buffel grass at a fairly coarse continental scale (0.5 degree [approximately 50 km] grid cells). A predictive understanding of the potential for buffel grass invasion at the scale of land type (1-10 km) is not yet possible. However understanding at this scale is desirable because it is at this level that management for production or conservation takes place. Presently, differential rates of spread and drivers of spread are not sufficiently quantified to support better modelling and forecasting, nor are there effective landscape-scale methods for assessing distribution and relative abundance of buffel grass or for monitoring its spread or contraction.

This latter research agenda is worth pursuing, because information and tools are becoming available which will advance the understanding of distribution and spread. In addition, it should be possible from new landscape scale information and expert knowledge to become more specific about what landscapes/environments are at greatest risk of invasion.

3 Current understanding

This report is a summary of the outputs from a workshop help in September 2007 and additional literature searches. It outlines the extent of knowledge about the spread and potential distribution of buffel grass and the identification of environments where biodiversity values are at most risk. It does not attempt to comprehensively reference all the topics that were identified because, as the workshop members noted, a compilation of literature was a substantial task that should be undertaken as part of developing specific research areas (see Appendix 1(a) for participants and Appendix 2 for the agenda). Workshop participants represented a wide geographical spread of expertise in buffel grass and weed ecology, management and modelling, and in biodiversity conservation.

3.1 Spread and potential distribution

The establishment and spread of buffel grass is dictated by its life history attributes, e.g. germination requirements (Table 1) and by environmental preferences (Table 2). Environmental preferences include physical aspects such as climate and soil characters, but also extend to the biotic environment and factors such as tree cover, competition from other grasses, and the effects of herbivores. These environmental preferences also place bounds on the potential distribution of buffel grass. While its preferred habitats are the well-watered and fertile elements of the landscape, there is a widely held view that many other arid and semi-arid habitats are also susceptible to colonisation if not invasion. Puckey & Albrecht (2004) for example cite, in addition to alluvial plains, water-courses and run-on areas, “undulating to mountainous terrain with shallow soils, and basic soils, such as those derived from dolomite, limestone or calcrete”. They suggest that deep infertile soils dominated by *Triodia* spp., red earth plains dominated by mulga (*Acacia aneura*), salt lakes and cracking clay plains are less susceptible, although they point out that deep infertile sandy soils under desert oaks (*Allocasuarina decaisneana*) may support buffel grass due to a raised soil pH. Furthermore with the development of new cultivars such as Bella (Hacker & Waite 2001), which may be better adapted to clay soils, and Frio (Ben Wilder, pers. comm. 1/8/2007), which is frost tolerant, plus evidence of hybridisation in central Australia (Friedel *et al.* 2006), there are good reasons to expect adaptation to a wider range of environments over time. A substantial proportion of the published information regarding phenology and habitat preference is from studies of buffel grass in a planted pasture setting, especially in Queensland, so that its relevance for other regions is uncertain.

McIvor (2003) has proposed that buffel grass is a coloniser rather than an invader in semi-arid Queensland since its seedlings can establish in bare areas but not in dense vegetation. Hence it can colonise riparian areas that have bare patches as a result of grazing, but is not so successful in higher rainfall riparian areas. He also argues that drought can create bare areas in the absence of grazing, enabling seedlings to establish after rain. How generalisable this may be to other environments is uncertain and needs testing. Arguably buffel grass can invade its most preferred habitats, e.g. sandy/loamy alluvial soils where soil moisture is reasonably assured, although disturbance may be a factor. There are many observations linking the presence or expansion of buffel grass to disturbances such as grazing, fire, clearing and road grading (e.g. Griffin 1993, Franks 2002, Butler & Fairfax 2003, Puckey *et al.* in press) but less is known about the potential for enhanced spread following the occurrence of episodic/rare events like high rainfall periods and flooding (e.g. Griffin 1993, Payne *et al.* 2004a).

3.2 Identifying areas at risk

Some environments or landscapes of high biodiversity value have been identified through various State, Territory and national processes, such as the declaration of parks and reserves, recording of locations of rare and endangered species, listing of significant wetlands, national ‘hot spots’ and regionally significant ecological communities. Also requiring consideration are those areas of high ecological integrity, for example, environments remote from livestock watering points (Landsberg *et al.* 1997). To identify areas where biodiversity values are at greatest risk from buffel grass invasion, information about areas of high biodiversity value needs to be intersected with information about the environmental preferences of buffel grass. Of these, riparian areas and landscape components with relatively high soil fertility and assured moisture are at greatest risk (Table 3), although many other arid and semi arid habitats may also be susceptible, as noted above. Furthermore, areas where assets are at greatest risk will also depend on proximity to disturbance and sources of seed, and the degree of disturbance.

4 What needs to happen

At a broad level, two actions are needed in order to understand distribution, spread and risk. These are to (i) model the future distribution and spread of buffel grass on the basis of where it is now, and (ii) develop a system for monitoring the spread of buffel grass, targeting those areas of high conservation value which are at greatest risk. Monitoring would also be an integral part of any control program to reduce the threat to biodiversity assets.

4.1 Modelling

4.1.1.Distribution

The scale of modelling to be attempted will depend on how the outcome will be used. If it is to be useful to managers, the target resolution for a predictive tool should be landscape-scale (Kolomeitz & van Klinken 2004). Puckey *et al.* (in press) used Generalised Linear Modelling and the Watarrka National Park (Northern Territory) GIS to predict the potential distribution of buffel grass and to identify threats to rare species. Similarly Ferdinands *et al.* (2005) used a Bayesian spatial modelling procedure to infer habitat suitability for para grass (*Urochloa mutica*) in a tropical catchment. Lawes and Grice (2007) modelled spread and distribution of *Parkinsonia aculeata* along a semi-arid river system in northeast Queensland, providing an example of linear spread by satellite populations from an upstream core population. While these approaches have been useful locally, they are unlikely to be cost effective for regional decision-making or national policy development because of their detailed data requirements.

Modelling at the regional level, possibly at sub-IBRA bioregion level, is desirable for higher level decision-making, in part because areas of high biodiversity values are determined in a regional context. Regional NRM planning and investment strategies, for example, are devised at this scale and regional level modelling could be used to prioritise areas for more intensive landscape scale studies. There are also differences amongst regional attributes and uncertainties of extrapolating landscape model outcomes from one region to another. For example, buffel grass does not have uniform habitat preferences amongst regions. In the arid Northern Territory it favours rocky ranges (Albrecht & Pitts 1997) whereas in Queensland it does not readily occupy rocky hills (Franks *et al.* 2000), perhaps due to differences in rock type and associated soil fertility. Cultivars which are recommended in one region are not recommended in another e.g. Biloela is preferred in Queensland but not in the Northern Territory (Cavaye 1991, Cameron 2004), possibly due to seasonal soil moisture differences. Clearing for planted pasture is a significant issue in the eastern rangelands of Queensland (Fairfax & Fensham 2000, Ludwig *et al.* 2000) but not elsewhere. Given the diversity of climate, landscape and disturbance factors amongst rangeland regions, regional models of distribution should be explored.

Broader level models have been attempted. The model tested by Lawson *et al.* (2004) provided a broad prediction of buffel grass distribution at a national scale at a resolution of 0.5 degrees, based on the regional-level CLIMEX climate model and maps of 13 major soil types across Australia that had been scored for buffel grass growth potential derived from global data. Lawson *et al.* (2004) pointed out the limits to reliability of the climate-soil model below a coarse continental scale and suggested that it could be more useful at a state or regional level, especially if incorporated with other information in a GIS environment. Kolomeitz & van Klinken (2004) took initial steps towards landscape scale prediction, testing CLIMEX and CLIMEX algorithms run within a GIS, and using moisture holding capacities of soils at a finer (six minute [0.1 degree] grid cell) spatial scale. They obtained parameters for buffel grass from both data and expert opinion.

At a regional scale, quantitative data may not be readily available for all components. For instance, the present distribution of buffel grass or the degree of disturbance may be unquantified. Consequently, in order to make progress initially without extensive data gathering, expert opinion could be incorporated into models using Bayesian belief networks (e.g. Martin *et al.*, 2005, Smith *et al.*, 2007). Workshop participant Teresa Eyre, for example, provided a ‘rule of thumb’ that, where clearing for buffel grass pasture is extensive in the Brigalow bioregion of Queensland, about 35% of retained native vegetation appears to be the threshold for preventing further incursions. Expert opinion such as this could be sought from local landholders and agency staff, with the caveat that this knowledge may be region-specific. In addition production and conservation agencies have many data sets from inventory and monitoring for other purposes which could provide the basis for a GIS and better indicate the current distribution of buffel grass (see Australian Natural Resource Atlas (2007) and Bastin *et al.* (in press) for information on jurisdictional reporting and data sets).

There is a diversity of methods available for predicting the distribution of species. Elith *et al.* (2006) have reviewed and compared well-established and new methods for predicting distribution from occurrence data gathered from museums and herbaria. Their conclusion that the new methods consistently out-performed more established methods suggests that an investigation of modelling approaches is warranted for predicting buffel grass distribution. However, as Roger Lawes (pers. comm.) advised "When selecting an approach, you should always stipulate the question first, in great detail, and what resources (data, simulations) you have to address the question". Modelling approaches are context-specific. Scale and the quality of data for buffel grass, other species and environmental variables will be critical to this exercise. As a first step, an assessment of the current distribution of buffel grass at regional scales, drawing mainly on expert opinion, could yield a useful product and could help to clarify the information available to model the species potential distribution.

4.1.2 Spread

Temporal modelling of spread is more complex. Local and frequent events which drive spread will be easier to model than infrequent events, such as exceptional rainfall and/or floods, which may cause extensive germination or long distance dispersal. Fox *et al.* (2007) have modelled local spread of Chilean needle grass (*Nassella neesiana*) in Queensland within a 60 x 60 km area using Python as the programming language, with GIS data layers including a high-resolution DEM, the streams and road networks and classification of habitat preference, and life-history and dispersal information. At this scale, data requirements are considerable. Event-scale modelling will be challenging and difficult to validate. Depending on the density of data points within a region, e.g. SILO (2007), an analysis of episodic rainfall events could be useful, if it could be linked to major expansions of density or range of buffel grass. Multiple dispersal mechanisms make the task more complex, and may ultimately limit spread modelling to a local scale.

4.1.3 Biodiversity values and risk

Modelling risk to areas of high biodiversity should be based on a diversity of regional case studies to ensure that any future national synthesis is robust. These case studies should also be suitable for testing monitoring methodologies. A number of case study areas were proposed at the workshop (Table 4) and the following criteria for selection were suggested:

- Wide geographic coverage, to provide contrast in biophysical, economic and social characteristics
- Past data available
- Range of biodiversity values
- Various stages of invasion
- Range of disturbance types/land uses
- Intact versus fragmented landscapes, where clearing occurs
- Attempted control (for testing monitoring methodologies)

Where areas of high biodiversity values have not been previously identified, predictive spatial modelling at the community level (e.g., general dissimilarity modelling, MARS mentioned in Elith *et al.* 2006) and complementarity approaches (Ferrier *et al.* 2002; Ferrier and Guisan 2006) may help identify priority places of high biodiversity values. Species particularly at risk from increasing buffel grass include ground layer flora and fire sensitive trees and shrubs, granivores, ground dwelling fauna, and fauna most at risk from structural change, especially any that are susceptible to fire. As with buffel grass distribution, high value biodiversity areas can be modelled using existing field data but it must be possible to validate such models. Expert opinion using Bayesian belief models could be used to refine predictions. Likewise, when the model of buffel grass distribution (either current or predicted) is superimposed on the model of high biodiversity values, further validation and adjustment based on expert opinion will be required.

4.2 Monitoring

The distribution and spread of buffel grass should be monitored as well as predicted. Modelling helps with predictions of where it will be found and hence where to monitor, while monitoring determines where it is over time and helps refine predictions. Together they help target management interventions.

4.2.1 What to monitor

As with modelling the purpose of monitoring must be clear at the outset. In this context the purpose is likely to be twofold: to quantify current distribution and spread of buffel grass over time and to quantify impacts on biodiversity assets. Quantifying distribution and spread is more amenable to immediate action, because quantifying impacts will be compounded by frequency and amount of rainfall, fire, grazing, clearing and other disturbances, and the requirement to distinguish at a local level the interactions with biophysical attributes of landscapes. The choice of surrogates to represent the biodiversity attributes being impacted, and the design of biodiversity monitoring systems in general, have been addressed in considerable detail (Whitehead *et al.* 2000, Smyth *et al.* 2003, and Austral Ecology 29(1) 2004) and will not be specified further.

The Australian Collaborative Rangelands Information System (ACRIS) (2007), through its Biodiversity Working Group, identified 10 indicators where there is currently some potential for reporting change in biodiversity. Of these, four are ‘operational’ in terms of on-going data collection: protected areas (CAPAD), threatened species and communities (EPBC data base); habitat loss – tree clearing (SLATS data base in Queensland and similar procedures in New South Wales and the northern part of the Northern Territory) and Birds Australia data base (Bastin *et al.* in press). Transformer weeds, of which buffel grass is one, are another indicator but suitable data are lacking to report change in distribution and relative abundance for the 11 species listed. Subsequent to the Bastin *et al.* (in press) report, the ACRIS Management Committee (as part of its 2008-11 workplan) has proposed that rangeland states and the Northern Territory work towards agreed procedures for on-ground monitoring of biodiversity and, when agreed, test and refine these procedures, leading to their implementation as part of an expanded jurisdictional capacity for monitoring biodiversity (Bastin pers. comm.).

4.2.2 How to monitor

There is little likelihood of a purpose built monitoring system for buffel grass alone at a regional or broader scale due to cost. Any monitoring of buffel grass will generally have to be embedded in existing monitoring systems except where dedicated surveys occur for specific assets such as Uluru-Kata Tjuta National Park. Bioregional surveys should provide a practical opportunity to assess buffel grass attributes (presence/absence, cover, density) and provide a baseline from which monitoring could proceed. Established pastoral monitoring systems may already include information about buffel grass, although coverage will be limited by definition to pastoral lands and will often be confined to the more productive parts of the landscape.

The attributes of buffel grass that can be assessed by available technologies place considerable constraints on where and how often it can be monitored. Broad assessments from satellite data at the scale of Landsat TM are unlikely to be successful because buffel grass lacks spectral differentiation (and is therefore indistinguishable) from other ground-layer species, whether green or dry (G. Bastin pers. comm.). Satellite data could, however, provide useful contextual information about general cover levels, and change over time, of bare ground, litter, ground vegetation and trees and shrubs. Aerial survey can be cost-effective for assessing large and inaccessible areas (Greenfield 2007, Puckey *et al.* in press) but will be too expensive for comprehensive monitoring, especially where risk of invasion is low, and it will require a degree of ground validation. Remotely gathered data are also unlikely to detect low densities of buffel grass and hence early stages of invasion. The trade-off amongst cost, level of detail possible and invasion risk suggests that on-ground monitoring will be an important quantitative tool but should be focussed on at-risk areas within a monitoring framework for other biodiversity attributes.

Timing may be a matter of compromise where biodiversity monitoring is driven by institutional imperatives but, ideally, buffel grass distribution could be monitored strategically in key areas in the year following major events such as clearing, fire or rainfalls eliciting mass germination. A complementary option for regional monitoring is the use of community-based reporting, as undertaken by voluntary observers for Birds Australia, possibly using their sites and monitoring strategically, although there would be limitations to data quantity and quality. Greenfield (2007) reported using landowner surveys to map the density of buffel grass at a coarse paddock scale for properties in the South Australian Arid Lands NRM region, and she proposed that these should be followed by on-ground surveys or aerial survey to more accurately map extent and density of infestations.

Two scales of monitoring are feasible: regional (sub-IBRA) and local (areas of high biodiversity risk). At the local level, there is potential to detect and assess new incursions and low-level densities in land units using quantitative measures. At the regional level, quantitative assessment might be restricted to ratings of degrees of invasion in land units or land systems through direct observation or through local expert opinion, depending on the methodology of the broader biodiversity monitoring system in which it is embedded. More quantitative assessments are desirable to support modelling but cost is likely to be prohibitive. Assessment of rates of spread is possible at both these scales. National scale reporting will be derived from synthesis of data at regional levels or from modelling supported by sufficient regional monitoring to validate the result. At this scale, distribution of buffel grass would be described at the sub-IBRA scale, or using some broad sub-IBRA subdivisions.

A key action which follows from the preceding discussion is negotiation to include buffel grass where possible in biodiversity surveys and monitoring being undertaken by State and Territory agencies and NRM boards. Negotiation should be coordinated at a national level, possibly through the ACRIS Management Committee, to ensure that data compatibility is maximised. The rationale should clearly demonstrate the benefits to states of sharing information. Negotiation could also include the potential for states to make available existing data sets, for example from regional inventory surveys and pastoral monitoring programs, to underpin clarification of distribution, spread and risk. It will be necessary to research how to integrate possibly diverse data sources and outcomes should help to inform the way in which new data gathering is done. Experience gained through data integration in the ACRIS will be valuable for this.

A strategic approach to monitoring and modelling the spread of buffel grass should vary the intensity of effort across regions according to the estimated potential for spread and threat to biodiversity values. An example of such a strategic framework is outlined (Table 5) but would of course depend on available operational resources.

5 Research prioritisation

Table 6 presents a prioritisation of prospective research activities according to their importance for management and the feasibility of research, and taking into account the availability of data. The activities are confined to those relevant to the spread and potential distribution of buffel grass, and to the identification of landscapes/environments where biodiversity assets are at greatest risk. Research into impacts of buffel grass is not addressed.

The highest priority is to determine where buffel grass is now, where it might establish in future and how these current and forecast distributions impinge on areas of high biodiversity value. The expertise of workshop participants was too broad to enable a definitive recommendation on modelling methods to be made. Research into refining monitoring systems and developing the capacity to model spread rate is somewhat less important for obtaining immediate management outcomes and, moreover, some aspects such as modelling event driven spread may be harder to achieve. Lower priority activities are not unimportant in an absolute sense but they may require extensive resources to progress; they will add refinements to the highest priority activities.

The workshop demonstrated that the ecology of buffel grass in natural systems and the functional implications of hybridisation are not understood in any detail (Tables 1 & 2), but there is sufficient knowledge to make progress with modelling distribution and identifying risk. Further research into ecology and hybridisation of buffel grass is desirable in the longer term because it will allow models to be refined and it is also likely to inform management intervention.

6 Proposed research agenda

1. Develop a national GIS of buffel grass distributions consistent with that sponsored by the National Land and Water Resources Audit (NLWRA) (2007) for invasive weeds. At present the level of available NLWRA mapping at 1: 100,000 scale is too coarse for detecting change. Better resolution data is needed for modelling. Where available, compile data from subregional data bases, including estimates of abundance if possible, stratified at least to the level of none, rare, restricted, widespread (see Table 5, 1(b) for description of classes). Depending on record dates and adequacy of data, stratify in 10 year or less time slices.

2. Conduct an expert workshop to determine (a) the most appropriate approach(es) to modelling buffel grass distribution at a range of spatial scales (local, regional and national) and (b) the most appropriate approach(es) to modelling buffel grass spread at local and regional scales. Develop a project proposal relating to each, with priority being given to developing distribution models. Participants should represent a diversity of

modelling approaches and should include experts in buffel grass and weed ecology, to ensure the purpose of models is clear.

3. Develop and validate regional (sub-IBRA) buffel grass distribution modelling capability in one case study region where regional GIS and data availability are good. Develop and validate regional (sub-IBRA) model of high biodiversity value areas in the same sub-IBRA. Combine models to predict high risk areas. Validate, then test and adapt procedures in other sub-IBRAs.

   Gather data in support of spread modelling (e.g. life-history, dispersal and habitat preference) as part of other activities e.g. 4.

4. Research functional understanding to improve management e.g. Are there thresholds for cover levels of native vegetation which limit spread of buffel grass? Can we predict the distribution of buffel grass under climate change scenarios in case study areas?

5. Monitoring may not require specific research activities if it is ‘piggy-backed’ on existing or planned biodiversity monitoring systems. Researching data integration from different monitoring systems for national reporting could occur under 1. The capacity to conduct reliable aerial surveys of at-risk high biodiversity value areas may need testing, although detecting new incursions may not be achievable.

6. Develop an on-line bibliography for buffel grass (and potentially other transformer weeds) as part of research activities, and host it on the ACRIS website.

7 Potential collaborating organisations

People who might contribute to the proposed research are listed in Appendix 1(a) & (b), with their organisational affiliations and areas of expertise where known. All workshop participants (Appendix 1(a)) expressed interest in contributing; proposed contributors (Appendix (b)) have not been consulted and so the list is indicative only. Organisations represented in the list are:

- CSIRO Entomology
- CSIRO Sustainable Ecosystems
- Department of Agriculture and Food WA
- Department of Environment & Conservation WA
- EPA Queensland (Biodiversity Sciences, Herbarium)
- James Cook University (Tropical Biology)
- Botanic Gardens and Parks Authority, Kings Park, WA
- NRETA NT (Biodiversity Conservation, Parks & Wildlife Service, Weed Management Branch)
- Natural Resource Management Boards (in SA South Australian Arid Lands and Alinytjara Wilurara)
- Rural Solutions SA (Animal and Plant Control)
- SA Department for Environment and Heritage (Biodiversity Conservation Program, Seed Research Centre, Outback and West Regions)
- SA Department of Water, Land and Biodiversity Conservation
- University of Adelaide
- University of Melbourne (Botany)

- University of Queensland
- Ecosystem Research Group, School of Plant Biology, University of Western Australia
- School of Animal Biology, University of Western Australia

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Table 1. State of knowledge about the spread of buffel grass

Attribute	Information available or comment	Adequacy of knowledge[1]
Seed bank longevity	Estimates vary – 2 years (Silcock & Smith 1990), at least 4 years (Winkworth 1971), up to 30 years (anecdotal for Pakistan)	1
Germination requirements	Temperature, soil moisture, (in planted pasture Paull & Lee 1978, Hacker & Radcliff 1989, Cavaye 1991; in central Australia Winkworth 1971)	1-2
Drivers of establishment and spread		2
	Fire (Pitts & Albrecht 2000, Miller 2003, Butler & Fairfax 2003, Jackson & Williams unpubl.)	
	Grazing (Hodgkinson *et al.* 1989, Franks 2002)	1
	Clearing (Fairfax & Fensham 2000, Franks 2002, Butler & Fairfax 2003)	2
	Effects of rare/episodic events and interactions	0.5
Longevity of tussocks	16-20 years (J. McIvor pers. comm., extrapolating from McIvor 2007), 20 years (Latz 1997)	1
Buffel rundown	In planted pasture (Cavaye 1991), anecdotal elsewhere	1
Seed production	Seed head production (Bosch & Dudzinski 1984)	1
Vectors of spread	Controllable vs uncontrollable vectors	2
	cultivation (see below), vehicles, animals, water and wind, etc (Low & Foster 1990, Griffin 1993, Pitt 2004, Greenfield 2007, Puckey *et al.* in press)	1-3
	relative importance of vectors	1.5
Cultivation	Agronomic knowledge of how to establish (e.g. Paull & Lee 1978, Cavaye 1991)	1-3
Varietal differences	Morphological vs functional differences (Silcock 1994, Puckey *et al.* in press)	0.2
	Old and new varieties (Paull & Lee 1978, Hacker & Radcliff 1989, Cavaye 1991, Hacker & Waite 2001)	0.2
	Hybridization and adaptation (Paull & Lee 1978, Friedel *et al.* 2006)	0

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[1] 0 = nil, 1 = some, 2 = adequate, 3 = extensive

Table 2. State of knowledge about the distribution of buffel grass

Attribute	Information available or comment	Adequacy of knowledge[2]
Habitat preferences	For Queensland (Cavaye 1991), central Australia (Griffin 1993, Puckey & Albrecht 2004), and others – needs compiling	0.5-3
climate	See above	2
soil type	For planted pasture in Queensland (e.g. Muller 2000), for central Australia (Griffin 1993, Puckey *et al.* in press)	2
soil moisture regime – run-on, run-off	Griffin (1993), Albrecht & Pitts (1997)	2
mineralogy/lithology	For planted pasture in Queensland (e.g. Muller 2000), for central Australia (Griffin 1993)	2?
soil fertility under agronomic conditions	For planted pasture in Queensland (e.g. Muller 2000)	3
soil fertility under naturalised conditions	Griffin (1993), anecdotal	1
habitat condition/patch size	For Queensland (McIvor 2003)	0.5
cover of woody vegetation	For Queensland (Butler & Fairfax 2003, Franks 2002)	1?
Disturbance regime	Clearing, cultivation (Fairfax & Fensham 2000, Franks 2002, Butler & Fairfax 2003) road grading, grazing, fire, flood (Low & Foster 1990, Griffin 1993, Payne *et al.* 2004a, Pitt 2004, Puckey *et al.* in press)	1-2
Competition	In planted pasture (McIvor 2003)	1
Interactions amongst attributes		0.5
Varietal differences	Morphological vs functional differences (Silcock 1994, Puckey *et al.* in press)	0.2
	Old and new varieties (Hacker & Radcliff 1989, Cavaye 1991, Hacker & Waite 2001)	0.2
	Hybridization and adaptation (Friedel *et al.* 2006)	0
Geographic distribution	Puckey & Albrecht (2004), Greenfield (2007)	

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[2] 0 = nil, 1 = some, 2 = adequate, 3 = extensive

Table 3. Capacity to identify landscapes/environments where biodiversity assets are at greatest risk from buffel grass.

Scale	Information available or comment	Adequacy of knowledge[3]
Local	Riparian areas	1-3
	Remnants in fragmented landscapes e.g, brigalow	1
	High biodiversity value areas abutting roadsides	1
Regional	Wetlands (lake margins, stream margins, floodplains, etc)	
	High biodiversity value areas which include habitats with favourable moisture and fertility and a potential source of seeds and disturbance:*	
	refuge areas for native (flora and?) fauna e.g. from drought	
	areas of high endemism	
	areas of high diversity of rare and threatened species or threatened communities	
	uninvaded areas of high ecological integrity	
	identified areas of high biodiversity e.g. national ‘hot spots’, State and Territory ‘special places’	

* This information may be obtainable at a national scale from remotely sensed tools like NDVI but at local scales will be very patchy. In WA it will be based on expert opinion in most instances (Stephen van Leeuwen pers. comm.).

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[3] 0 = nil, 1 = some, 2 = adequate, 3 = extensive

Table 4. Potential case study areas in arid and semi-arid rangelands, as proposed by workshop participants

1. Alinytjara Wilurara NRM Region (SA)
    - new incursions
    - some long-standing infestations
    - high priority, intact ecosystems
    - areas of heavy grazing
    - very few data
    - difficulties of working in the area

2. South Australian Arid Lands NRM Region (SA)
    - 7 bioregion
    - good understanding of buffel distribution (Greenfield 2007)
    - representative land use types (Aboriginal lands, pastoral etc)
    - good potential for community awareness and engagement
    - high biodiversity values and good data on it
    - some biodiversity surrogate modelling
    - extensive control activities in some locations eg Stuart Highway

3. Western MacDonnell Ranges (NT)
    - vegetation maps available
    - high landscape diversity
    - high biodiversity values
    - different fire regimes
    - gradient of buffel abundance but in all the rivers
    - biodiversity surrogate models been done
    - good mapping of surrounding regions

4. Where control is being attempted (NT)
    - Rainbow Valley Conservation Reserve – 5 year program
    - Alice Springs Desert Park

5. Kidman Springs (NT)
    - lots and lots of data
    - not so susceptible to invasion?

6. Pilbara islands e.g. Airlie Island(WA)
    - absence of grazing, trampling and fire, enabling studies of autecology and natural spread
    - no large mammals
    - spread of seed by avian vectors
    - hard to access and work there – expensive
    - maybe less variation in buffel
    - few other disturbances
    - possible location for impact studies

7. Pilbara mainland (WA)
    - very extensive data potentially available to quantify the species-environmental envelope and model potential distributions
    - 1940s monitoring sites; invertebrate study sites

8. Ord River Regeneration Reserve (WA)
    - dense ground cover of introduced (*Cenchrus ciliaris* and *C. setigerus*) and native perennial grasses after 40 years of regeneration (Payne *et al.* 2004b)

9. Brigalow belt (Queensland)
    - diversity of land types
    - different buffel varieties
    - good regional ecosystem mapping
    - high biodiversity values, well documented
    - lots of other current research
    - could identify sub-regions to target (e.g. Southern Downs)

10. Mitchell grass downs (Queensland)
    - an example of an area where buffel is less abundant/less potential

11. Mt Isa highlands (Queensland)
    - lots of data and current work
    - Cloncurry buffel (*Cenchrus pennisetiformis*) is present

Table 5. Example of strategic approach to landscape scale modelling and monitoring of the spread of buffel grass based on regional scale modelling of the difference between current and potential distribution.

Overall objective is to stratify monitoring of buffel grass spread and impact, using differences between the potential (modelled) and current realised distributions of buffel grass in IBRA subregions.

1. Assess differences between potential and realised distribution of buffel grass at subregional scale to stratify subregions for which modelling indicates moderate or high suitability for buffel grass, based on the current realised distribution of buffel grass in the subregion and biodiversity values in the subregion.

1(a) Model suitability of IBRA subregions for buffel grass, using available geological and soils mapping, expert knowledge and climatic data (see Table 6).

1(b) Survey people with knowledge of subregions that are suitable or highly suitable for buffel grass to rate abundance of it in natural systems and planted pastures, for example:
0 = absent or very rare, even in cultivation
1 = occasional/uncommon in wild e.g. on only one land type
2 = frequent or abundant on one or a few land types
3 = abundant on many land types.

1(c) Get this checked by whatever means available. Add subregions if model looks wrong.

1(d) Assess differences between modelled suitability and current distribution in natural systems (i.e. not cleared or cultivated) based on survey in 1(b) and 1(c).

1(e) Classify subregions according to differences in 1(d), for example:
class 1 = suitable or highly suitable but currently absent or rare (rating 0, above)
class 2 = suitable or highly suitable, currently rating 1 or 2
class 3 = suitable or highly suitable, currently rating 3.

1(f) Rank subregions within classes 1, 2 and 3 according to biodiversity values and information on other threatening perennial grasses (or other threats). For example:
+ve – numbers of threatened species and communities in region and subregion
+ve – numbers of endemics in region and subregion
+ve – high “naturalness”
-ve – number of other serious perennial grass weeds recorded in subregion
etc.

2. Use results of 1 to stratify monitoring and more detailed modelling.

2(a) Use ranking from 1(f) to select subregions or clusters of adjacent subregions from classes (1, 2 & 3) that cover the geographic spread of buffel grass. The size of the selected sets will depend upon resources. The highest priority for further action should be given to subregions in classes 1 and 2. For example:

i For selected class 1 subregions: model habitat suitability at landscape scale and consider vectors to identify areas for targeted monitoring and possible intervention; communicate threat of buffel grass to regional land managers and weed managers

ii For selected class 2 subregions: undertake landscape scale assessment of current buffel grass distribution (which could inform habitat suitability for class 1) and biodiversity assets; target monitoring to high biodiversity areas and study impact or intervene

iii For selected class 3 subregions: document unsuitable habitats; document impacts; check occasionally to see if unsuitable habitats are still so.

Table 6. Research prioritisation according to data availability, importance for management and the feasibility of research. A-C = score from most to least. Locally, priorities may vary.

	Research activity	Spatial scale	Data availability	Importance	Feasibility	Priority
1.	Determine where buffel grass is now - initial stratification as none, rare, restricted, widespread?	(i) Local (land unit)	Jurisdictional data bases	A	B	A
		(ii) Sub-IBRA (land unit/system)	Jurisdictional data bases and expert opinion	A	B	A
		(iii) National	Compile from sub-IBRA data above	A	A?	A
2.	Determine the relative susceptibilities of different landscapes components and predict where buffel grass might go. Validate model. Potential to improve susceptibility assessments using type and degree of disturbance	(i) Local (land unit)	Model probability; up-scale to sub-IBRA level	A	A?	A
				A	B?	B
		(ii) Sub-IBRA (land unit/system	Model, incl. Bayesian belief networks; test in adjoining sub-IBRAs	A	A?	A
				A	B?	B
		(iii) National	Upscale sub-IBRA models and/or refine Lawson *et al.* (2004), using CLIMEX and	A	B?	B

			soil attributes (or equivalent)			
3.	Determine areas of high biodiversity values, overlay with 1 or 2 to identify areas of high biodiversity risk currently invaded by buffel grass, and with potential to be invaded.	(i) Local (land unit)	Jurisdictional data bases of biodiversity values	A	B?	B
		(ii) Sub-bioregion (land unit/system)	Jurisdictional data bases of biodiversity values	A	B?	B
		(iii) National	National data bases of biodiversity values	A	B?	B
4.	Evaluate monitoring systems for specific purposes e.g. aerial survey for buffel grass in areas of high biodiversity value	(i) and possibly (ii)	Existing jurisdictional and research data; new data required	B-C	B	B
5.	Develop capacity to model spread of buffel grass	(i) and (ii)	Existing jurisdictional and research data; new data required. Bayesian spatial modelling?	B		
	- on 5-10 year time frame				B	B
	- following infrequent large events (e.g. high rainfall, flood, cyclone)				C	C
	- role of vectors				C	C
6.	Assess resilience of susceptible landscape elements vs invasion by buffel grass – degree of invasion cf. degree of disturbance; are there thresholds?	(i)	Existing research data; new data	B	B	B

		required			
7. Test management interventions for buffel grass: options, prioritisation of place and time for interventions, where and when to monitor outcomes	(i)	Existing jurisdictional and research data; new data required	A	B	B
8. Determine relationship between genetic variability and functionality of buffel grass	(i)	New data required	B-C	C	C
9. Develop capacity to predict response of buffel grass to climate change (on seasonal gradients, contrasting landscape types, thence fire regimes, clearing and grazing)	(i), (ii) and (iii)	Existing jurisdictional and research data; new data required	C	C	C

Appendix 1. Potential contributors to proposed research activities

(a) Workshop participants and main expertise, where supplied

Gary Bastin (CSIRO Sustainable Ecosystems, Alice Springs) – monitoring
Chris Brock (Parks & Wildlife Service NT, Alice Springs) – management pertaining to control of buffel, local scale modelling, native vegetation mapping, biodiversity prioritisation
Don Butler (Queensland Herbarium, EPA, Brisbane)
Amber Clarke (SA Department for Environment and Heritage, Clare)
Teresa Eyre (Biodiversity Sciences, EPA, Brisbane)
Julian Fox (University of Quueensland, Brisbane) – modelling of weed spread
Marg Friedel (CSIRO Sustainable Ecosystems, Alice Springs) – rangeland ecology
Tony Grice (CSIRO Sustainable Ecosystems, Townsville) – plant ecology; fire
Stephen van Leeuwen (Department of Environment & Conservation WA, Woodvale)
John Pitt (Animal and Plant Control, Rural Solutions SA, Clare) – rangeland pest management
Helen Puckey (Parks & Wildlife Service NT, Alice Springs) – landscape scale modelling and monitoring
Anita Smyth (CSIRO Sustainable Ecosystems, Adelaide)

(b) Additional contributors proposed by workshop participants and main expertise where available

Geoff Axford (SA Department for Environment and Heritage, Port Augusta)- general knowledge of the SA pastoral region
Yvonne Buckley (University of Queensland, Brisbane) – population modelling
Chris Chilcott (Department of Agriculture WA)
Mark Cowan (Department Environment & Conservation WA)
Jane Elith (University of Melbourne) – species distribution modelling
Rod Fensham (Queensland Herbarium, EPA, Brisbane)
Keith Ferdinands (Weed Management Branch, NRETA NT, Darwin)
Simon Ferrier (Department of Environment & Climate Change NSW, Armidale; CSIRO Entomology, Canberra in 2008) – species modelling
Alaric Fisher (Biodiversity Conservation, NRETA NT)
Jeff Foulkes (SA Department for Environment and Heritage, Adelaide) – bioregional survey
Beth Greenfield (Animal and Plant Control, Rural Solutions SA, Port Augusta)) – rangeland pest management
Kings Park personnel – life history, genetics, control on Airlie Island
Peter Kendrick (Department Environment & Conservation WA, Karratha)
Alex Kutt (CSIRO Sustainable Ecosystems, Townsville) – biodiversity impacts
Roger Lawes (CSIRO Sustainable Ecosystems, Perth) – modelling
Andy Lowe (University of Adelaide and SA Department for Environment and Heritage) – genetics
Clive McAlpine (University of Queensland, Brisbane) – modelling
Paul Novelly (Department of Agriculture WA, Kununurra)
Seed Research Centre, Millennium Seedbank partnership, SA Department for Environment and Heritage) – threatened species
Carl Smith (University of Queensland, Brisbane) – Bayesian belief modelling
Collette Thomas (CSIRO Sustainable Ecosystems, Townsville) – Bayesian belief modelling
Grant Wardell-Johnson (University of Queensland, Brisbane) – Bayesian belief modelling

Rieks van Klinken (CSIRO Entomology, Brisbane)
John Virtue (SA Department of Water, Land and Biodiversity Conservation) – weeds ecology
Michelle Waycott (James Cook University) – genetics
Brendan Wintle (University of Melbourne) – ecological modelling

Appendix 2

A WORKSHOP TO EXAMINE THE ISSUES IN RELATION TO THE DISTRIBUTION AND RATE OF SPREAD OF BUFFEL GRASS (*CENCHRUS CILIARIS*), AND OF THOSE LANDSCAPES AND BIODIVERSITY ASSETS AT MOST RISK FROM INVASION

Wednesday 12th – Thursday 13th September 2007
CSIRO Conference Room, Heath Road, Alice Springs

AGENDA

Wednesday 12th

12 noon Lunch. Workshop attendees from Adelaide and Brisbane arrive at CSIRO from airport

1.15 pm Workshop begins

- Participants outline experience and expertise relating to workshop theme (10 minutes maximum each – written or electronic material in addition will be welcome)
- What are the issues relating to the spread and potential distribution of buffel grass, and to the identification of landscapes/environments where biodiversity assets are at greatest risk?

Small groups and whole group discussion

3.00 pm Break

3.30 pm Discussion continues – how do these issues affect the development and implementation of a robust methodology for monitoring spread and impacts of buffel grass on biodiversity assets?
Small groups and whole group discussion

5.30 pm Finish

Thursday 13th

9.00 am Workshop reconvenes

- Review the issues – any more to include?
- What is known already? (Please bring relevant literature or references and websites)
- What can we do now and what are the knowledge gaps?
- Prioritise according to importance for management and the feasibility of research, relevant to the diversity of landscape types in arid and semi-arid regions
- Outline a research agenda, including the development of monitoring methodologies, and identify case study areas if appropriate
- Identify potential collaborating organisations

5.30 pm Finish

Morning, lunch and afternoon breaks by consensus

The workshop is funded by the Commonwealth Department of the Environment & Water Resources