RANGELANDS
NRM CLUSTER

CLIMATE CHANGE IN AUSTRALIA

IMPACTS & ADAPTATION INFORMATION FOR AUSTRALIA'S NRM REGIONS

Australian rangelands and climate change – *Cenchrus ciliaris* (buffel grass)

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Key points

- Buffel grass (*Cenchrus ciliaris*) has been shown to acclimate to higher temperatures and to maintain competitiveness and response to fire under increased CO_2, conditions expected under climate change.
- Distribution modelling and plant physiological studies indicate that the current region of buffel grass presence in Australia will remain suitable under future climates, thus maintaining or increasing (due to loss of other palatable grasses) its importance for agriculture.
- Modelling the distribution of buffel grass indicates a southward spread in Australia by 2070. This represents a particular threat to the high value nature conservation in areas such as the Great Western Woodlands, the Alinytjara Wilurara Natural Resources Management Region and the Great Victoria Desert bioregion.
- Containment strategies for buffel grass are required for high value environmental assets, given that eradication will be impossible without unsustainable resources. Likewise control is likely to be very difficult, if not impossible, in areas where the plant is already widespread. This makes containment the best strategy for new infestations, given that reinvasion is highly likely.
- There is a risk that many plant species will not survive in a future climate that is hotter and drier. If buffel grass proves to have greater resilience than other plant species then it might form the basis for a novel ecosystem. Research is needed into ways that buffel grass can be managed to maximise its value to other components of the ecosystem.
- Research is also needed into the genetic diversity in buffel grass with a view to identifying genotypes that are invasive and/or suitable for pasture improvement under climate change.

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1. Introduction

Anthropogenic climate change will lead to ecosystem changes in worldwide arid and semi-arid rangelands by the influence changed climate has on invasive plants. For example, in the western USA rangelands invasive grasses are currently transforming native ecosystems by changing fire regimes. Climate change projections for rangelands indicate that with respect to invasive plants:

- warmer conditions will favour cold-intolerant annual grasses
- changes in frequency of wet winters may alter the establishment of invasive annual grasses
- the fire season will start earlier and be longer, furthering the weed–fire invasion process (Abatzoglou and Kolden 2011)
- a reduction in precipitation in drier areas, given the low base typical of deserts, may lead to loss of grasses.

In Australia, invasive plants in the rangelands region are characterised by a wide distribution and the ability to respond to a variable climate marked by hot temperatures and extensive drought. Invasive plants are already responding to climatic extremes and consequently are likely to be pre-adapted to future climate change. Not only will rangelands invasive plants persist within the changed climate of the rangelands region, but they will spread southwards as the more southerly regions become hotter and drier. Buffel grass is a species that exemplifies this pattern.

Buffel grass (*Cenchrus ciliaris*) (Figure 1) is one of the most widespread exotic grasses in Australia. It is native to tropical Africa and Asia and has been planted widely in central, tropical and sub-tropical Australia as a pasture species. It has also naturalised throughout this range, invading areas reserved for nature conservation. This 'contentious' species presents special challenges for determining the adaptation response to climate change, because it is both a threat and a beneficial species. This case study will examine the issues related to buffel grass in the context of a changing climate.

General aspects of the reaction of weeds to climate change are covered in Module 2: Weeds and climate change of the National AdaptNRM project (https://research.csiro.au/adaptnrm/)

2. Methods

Buffel grass was chosen as the exemplar weed to show the impacts of climate change in rangelands regions because it is:

- the most widespread weed/pasture species of concern to rangelands in Australia
- a relatively well-studied species for its reaction to climate change
- important to both agriculture and the environment.

This case study takes a national approach. While buffel grass occurs throughout the Rangelands Cluster region, the implications of species movement under climate change means that neighbouring regions need to be considered also.

CLIMEX was used as the method for distribution modelling. Background to this method and explanation for the choice of model are given in the National AdaptNRM Module 2: Weeds and climate change (Scott et al. 2014). The website and associated document and data repository can be consulted for species distribution models of relevance to the Rangelands Cluster region.

3. Results

3.1 Buffel grass distribution

Buffel grass is very widespread and has the capacity to disperse further, potentially to all of Australia. Buffel grass is currently found in the Northern Territory and all Australian states except Victoria (and probably not Tasmania) (Figure 2).

The record in Figure 2 for the plant's presence in Tasmania does not correspond to the plant being permanently present in Tasmania and illustrates the plant's ability to disperse some distance from source

Figure 1. Buffel grass* (Cenchrus ciliaris)*.
Photo: Mark Marathon, http://en.wikipedia.org/wiki/File:Cenchrus_ciliaris.jpg.

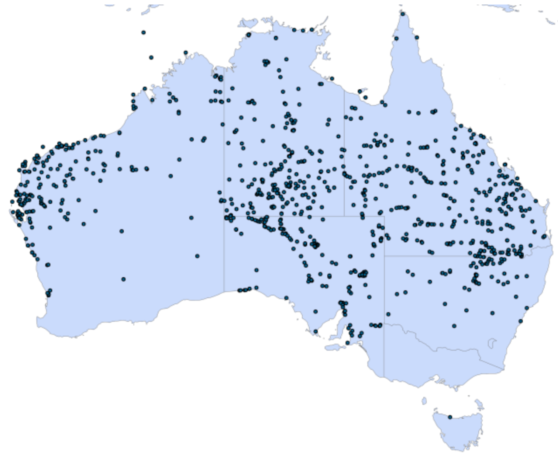

Figure 2. Distribution of buffel grass* (Cenchrus ciliaris) *(black dots) in Australia based on records in http://www.ala.org.au/.

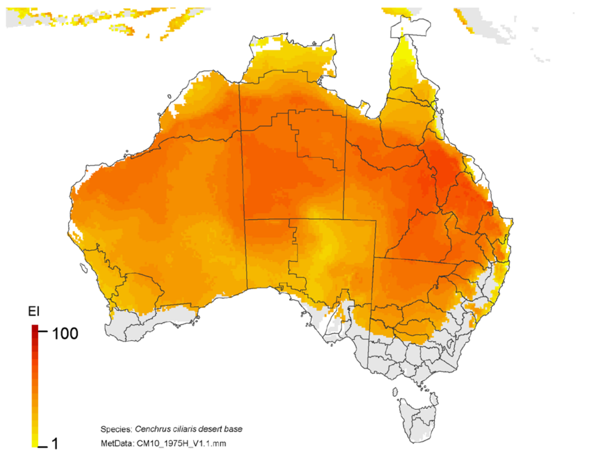

Figure 3. NRM regions and species distribution model for buffel grass* (Cenchrus ciliaris) *using CLIMEX. The higher the value for Ecoclimatic Index (EI), the more suitable is the climate for buffel grass. Values of EI = 0 (grey areas) indicate regions where populations will not persist. CLIMEX parameters for this model were modified from Lawson* et al. *(2004) and can be found at http://data.csiro.au.

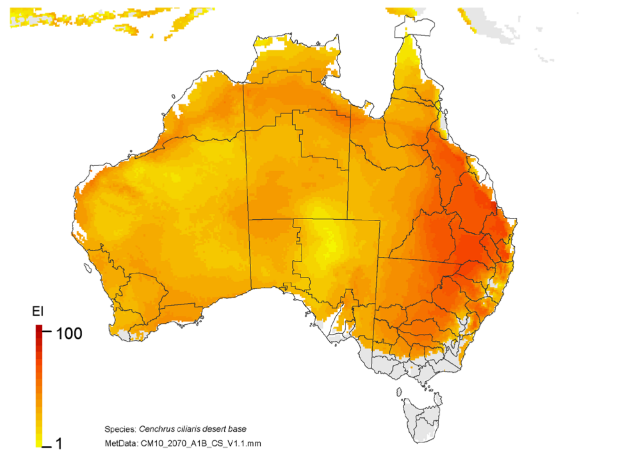

Figure 4. NRM regions and projected distribution of buffel grass in Australia as indicated by the CLIMEX Ecoclimatic Index (EI) using CSIRO Mk3 projections for 2070 based on the A1B SRES emissions scenario. The CLIMEX parameters are those used in Figure 3.

populations. However, in South Australia there are already established populations and records of the plant's presence in southern regions well south of the main buffel grass population (Biosecurity South Australia 2012).

The wide spread of records (Figure 2) indicates that buffel grass is able to disperse readily in addition to being deliberately planted for agricultural purposes. Its fluffy burrs are accidentally transported by humans, especially on vehicles, and by animals, both livestock and native species. This means that the plant has the ability to invade new areas, often initially establishing along roadsides before invading pasture or the natural environment.

The species distribution model (Figure 3) shows that most of Australia has a climate suitable for growth and survival of buffel grass, except for the most southerly regions (and even here there may be favourable microhabitats).

The model used here (CLIMEX) has been extensively used to model weed distributions (see https://data.csiro.au/dap/) and is based on information on the plant's temperature and moisture requirements, plus response to stress factors. Note that the climate data used in the model (Figure 3) are based on climate averages and do not cover the situation of favourable microhabitats and the effect of climate extremes. The distribution of buffel grass and its response to climate change has also been modelled for Australia by the following methods: BIOCLIM within ANUCLIM (Steel et al. 2008), BIOCLIM (Biosecurity South Australia 2012) and MaxEnt (Wilson et al. 2011, http://www.weedfutures.net/).

3.2 Growth response of buffel grass to climate change

Buffel grass is one of the few species of weed in Australia to be extensively assessed for growth response to climate change. Buffel grass has a typical plant response to increased CO_2 with increased biomass (Bhatt et al. 2007) and decreased nitrogen concentration. Leaf transpiration rates were halved at elevated CO_2 (Rudmann et al. 2001). Buffel grass has C_4 photosynthesis like many other warm climate grasses. It is generally considered that C_4 plants have an advantage in a warmer climate due to their higher CO_2 assimilation rates at higher temperatures and higher photosynthetic optima than their C_3 counterparts (Dwyer et al. 2007). Indeed, plants of buffel grass were able to acclimate to warmer temperatures (growth at 35°C versus 25°C) by adjusting the physiology of photosynthesis (Dwyer et al. 2007). Higher day/night temperatures (45/35°C) were lethal, although it is evident the plant can survive in areas such as the Sonoran Desert with air temperatures approaching 50°C (De La Barrera and Castellanos 2007).

In addition, buffel grass, along with other exotic grasses, had higher biomass when resprouting after fire than native grasses when grown under elevated CO_2 (Tooth and Leishman 2014). This indicates a mechanism – better response to fire under elevated CO_2 – which implies that buffel grass will remain, if not increase, in its ability to transform ecosystems under climate change.

3.3 Change in potential distribution

The projection for climate change up to 2070 (Figure 4) shows a declining Ecoclimatic Index (EI) in central and northern Australia, but none of these areas became completely unsuitable for growth of buffel grass. This model is based on the current plant physiology and distribution records. The evidence from the plant physiology of buffel grass in response to climate change is that it will adapt to the changed environment, and thus it may prove likely that there will not be a reduction in the invasion capacity of buffel grass in central Australia.

In common with many invasive species (see the National AdaptNRM Module 2: Weeds and climate change), buffel grass is projected to spread southwards as the climate becomes warmer (Figure 4). This is because cold temperature (temperatures at or less than 5°C, Cox et al. 1988) is the factor likely to be limiting the southern edge of the distribution in Australia. The second factor favouring buffel grass is climate with predominantly summer rainfall (Cox et al. 1988, Marshall et al. 2012). This factor may mitigate against a southward spread, although buffel grass is found across a range of rainfall patterns (Marshall et al. 2012). Another factor that could limit the southwards spread are frosts, which have already increased in frequency due to the clear skies that come with the current drying environment.

The warming of the environment can have two effects. Firstly, it will facilitate the establishment of new populations, and, secondly, it will facilitate the spread from existing populations from suitable microhabitats. Two conservation regions, the Great Western Woodlands and the arid lands of South Australia (Alinytjara Wilurara Natural Resources Management Region and the Great Victoria Desert bioregion), show why it is important to monitor and manage this southward spread or to contain infestations that are persisting in more southern regions.

3.3.1 Great Western Woodlands

The Great Western Woodlands (GWW) in the rangelands of the south-west of Australia are the world's largest remaining Mediterranean-climate woodland. There are few (5%) exotic plant species that occur in the GWW. Perhaps the most important invasive plant threat to the GWW is the southward spread of buffel grass due to increasing winter temperatures and increased summer rain. While buffel grass impacts negatively on native flora and fauna, the most threatening aspect is the potential to provide connectivity of fire fuels, combined with increased risk of fire ignition and spread. At present, the GWW has areas bare of vegetation that limit the ability of fire to spread. Buffel grass could provide the fuel for fires to link across the vegetation. This could potentially transform both the ecosystem structure and overall landscape (Prober et al. 2012). This risk is recognised in the invasive management plans for the GWW, where at present buffel grass is mainly restricted to some roadsides (Department of Environment and Conservation Western Australia 2013).

3.3.2 South Australia

Buffel grass is now widely distributed across northern regions of South Australia as scattered populations, with extensive infestations in the far north-west of the state (Biosecurity South Australia 2012) (Figure 2). South Australia has developed a Strategic Plan with the overall aim to contain buffel grass and reduce its impact. This includes preventing the southward spread and infilling. Areas identified for the containment of buffel grass include the Alinytjara Wilurara Natural Resources Management Region and the Great Victoria Desert bioregion (Biosecurity South Australia 2012).

3.4 Response to extreme events

Examining a plant's response to extreme climatic events gives an indication to how the plant might respond under climate change. Understanding the role of extreme events also helps direct management that will be useful under current climate conditions as well as under climate change.

Buffel grass can proliferate in response to extreme events such as hot temperatures, exceptional rainfall, drought and fire, events that are also likely to increase under future climate change. Whereas buffel grass does not tolerate extended flooding, it is able to grow roots to a soil depth of 3 m, which would give it resilience in the face of extended drought.

In the USA, buffel grass is causing the transformation of fire-resistant desert dominated by cacti to flammable grassland. Buffel grass fires are more intense and frequent than fires in surrounding USA ecosystems (McDonald and McPherson 2011). In contrast, Australian ecosystems are already fire-adapted, but buffel grass will still increase the fuel loading (Miller et al. 2010) leading to increased frequency and intensity of fires.

3.5 Management

3.5.1 Beneficial aspects

Buffel grass is a valuable pasture species for rangelands areas and may become more important under a climate change scenario because of its ability to acclimate to higher temperatures, to persist and provide productive grazing. In dry areas it may become an important soil stabiliser, especially if climate change causes a reduction in other plant species. It has already been used to prevent erosion (Marshall et al. 2012).

A detailed study of the genetic variability in buffel grass, both here and overseas, is needed to enable identification of strains that will be useful to future agriculture. There is already concern that genotypes of buffel grass will be lost from its native habitat (e.g. Tunisia: Kharrat-Souissi et al. 2014) were the plant is subject to overgrazing and increased aridity.

3.5.2 Potential ecological impacts

In the rangelands area buffel grass has been implicated in decreases in native plant diversity and abundance, lessening tree recruitment and increasing fire intensity that changes woodland structure. As a consequence, the diversity is reduced of native fauna, including invertebrates, reptiles and native mammals (references in Bradshaw et al. 2013 and Marshall et al. 2012). Increased densities and infilling by buffel grass are likely to exacerbate these problems under conditions of climate change. Long-term studies (28 years) show that the decline in native biodiversity has stronger associations with competition by buffel grass than with fire and variable rainfall (Clarke et al. 2005).

A management approach could be to avoid introduction of new genetic material, to increase control efforts where the plant is sparse, perhaps including containment, and establishing quarantine barriers to prevent incursions into nature reserves (Grice et al. 2012). Better identification (Kharrat-Souissi et al. 2014) is needed of the buffel strains in Australia, which will help with understanding origins and invasion potential.

3.5.3 Novel ecosystems

Management of buffel grass as a ‘novel ecosystem’ (Belnap et al. 2012) may form the basis for survival of other species. It is clear that buffel grass is difficult to remove, and ecosystem restoration is impossible without exceptional resources. In addition, buffel grass provides valuable ecosystem services in the form of grazing for cattle and provision of erosion control. Together these drivers point to the desirability of retention of this novel ecosystem (Belnap et al. 2012).

Such a conclusion should not be accepted uncritically. There is a need to explore the options for management of buffel grass to favour species diversity and pasture production at the same time. However, the results of an ecological impact and fire study by Schlesinger et al. (2013) indicate that the novel ecosystem approach will be a challenge to achieve given the competiveness of buffel grass.

A novel ecosystem due to an increase in a weed distribution or abundance may lead to unintended consequences. A study of King Brown snakes (*Pseudechis australis*) found that the snake is associated with increased buffel grass density (McDonald and Luck 2013). The distribution of King Brown snakes in Australia is very similar to that of the current distribution of buffel grass, so a spread southward with the weed might be possible under climate change. The management option mentioned by McDonald and Luck (2013) is to remove buffel grass from near human habitation as a way of reducing the risk of snake presence. As humans are likely to be the main vector of buffel grass seeds, removing the weed near human habitation will also reduce the risk of weed spread.

3.5.4 Management plans

A selection of management and strategy guides for buffel grass are listed here:

- CRC for Australian Weed Management (2008) *Weed management guide: managing weeds for biodiversity*. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/347153/awmg_buffel-grass.pdf.
- Biosecurity South Australia (2012) *South Australia buffel grass strategic plan: a plan to reduce the weed threat of buffel grass in South Australia*. Government of South Australia. http://www.pir.sa.gov.au/__data/assets/pdf_file/0005/177656/91806_SA_Buffel_Grass_Strat_Plan_FIN_WEB.pdf.
- Northern Territory Government (no date) *Buffel grass management guide for central Australia*. http://www.lrm.nt.gov.au/__data/assets/pdf_file/0014/19211/buffel_guide_web_version.pdf.

- Moore et al. (2006) *Perennial pastures for Western Australia*. Department of Agriculture and Food Western Australia, Bulletin 4690, Perth.
- Queensland Department of Agriculture, Fisheries and Forestry (2013). *Buffel grass in south Queensland*. http://www.daff.qld.gov.au/plants/field-crops-and-pastures/pastures/buffel-grass.

4. Conclusions

Buffel grass is a contentious plant species, both beneficial and detrimental, depending on the situation (Friedel et al. 2011). Landholders generally have similar perceptions of the positive and negative impacts of buffel grass. However, the main contentious area is that of high conservation value pastures (Friedel et al. 2011), and such areas newly suitable for buffel grass after climate change should be the target of adaptation responses and planning well beforehand. Part of this planning would include understanding pastoralist perceptions towards the costs and benefits of buffel grass (Marshall et al. 2011).

Abbreviations

IN THIS REPORT	
TERM	**DEFINITION**
EI	Ecoclimatic Index
GWW	Great Western Woodlands
NRM	natural resource management

IN ALL REPORTS IN THE SERIES	
TERM	**DEFINITION**
ABS	Australian Bureau of Statistics
ACRIS	Australian Collaborative Rangelands Information System
AFCMP	Australian Feral Camel Management Project
BoM	Bureau of Meteorology
BS	bare soil
CMA	Catchment Management Authority
DKCRC	Desert Knowledge Cooperative Research Centre
DSI	Dust Storm Index
EMU	Ecosystem Management Understanding™
ENSO	El Niño Southern Oscillation
FIFO	fly in, fly out
GAB	Great Artesian Basin
GCM	General Circulation Model
GDM	Generalised Dissimilarity Modelling
GHG	greenhouse gas
GW	Groundwater
IBRA	Interim Biogeographic Regionalisation for Australia
ICLEI	International Council for Local Environmental Initiatives
IPCC	Intergovernmental Panel on Climate Change
LEB	Lake Eyre Basin
LGM	last glacial maximum
MOF	manual observation frequency
mya	million years ago
NAFI	North Australian Fire Information

IN ALL REPORTS IN THE SERIES	
TERM	**DEFINITION**
NCCARF	National Climate Change Adaptation Research Facility
NPV	non-photosynthetic vegetation: senescent pasture and litter
OH&S	occupational health and safety
PV	photosynthetic vegetation: green
RCP	Representative Concentration Pathways
SAAL	South Australia Arid Lands
SDM	species distribution modelling
SW	Surface water
TGP	total grazing pressure
TM	Thematic Mapper
Western CMA	Western Catchment Management Authority
Western LLS	Western Local Land Service

Glossary

IN THIS REPORT	
TERM	**DEFINITION**
C_3 and C_4 plants	The different methods plants use to convert carbon dioxide from air into organic compounds through the process of photosynthesis. All plants use C_3 processes; some plants, such as buffel grass and many other warm climate grasses, also use C_4 processes. C_4 plants have an advantage in a warmer climate due to their higher CO_2 assimilation rates at higher temperatures and higher photosynthetic optima than their C_3 counterparts
Contentious species	A species that presents special challenges for determining the adaptation response to climate change, because it is both a threat and a beneficial species (Friedel et al. 2011, Grice et al. 2012)
Novel ecosystem	Species occurring in combinations and relative abundances that have not occurred previously within a given biome (Hobbs et al. 2006)

IN ALL REPORTS IN THE SERIES	
TERM	**DEFINITION**
Adaptive capacity	The ability to change and therefore reduce gross vulnerability; includes issues such as mobility, financial resources and education
Bioregion	A large, geographically distinct area of land that has groups of ecosystems forming recognisable patterns within the landscape
Dust Storm Index (DSI)	The Dust Storm Index is based on visibility records made by Bureau of Meteorology (BoM) observers. The DSI provides a measure of the frequency and intensity of wind erosion activity at continental scale. It is a composite measure of the contributions of local dust events, moderate dust storms and severe dust storms using weightings for each event type, based upon dust concentrations inferred from reduced visibility during each of these event types.
DustWatch	DustWatch is a community program that monitors and reports on the extent and severity of wind erosion across Australia and raises awareness of the effects of wind erosion on the landscape and the impacts of dust on the community.
Ecological refugia	Refugia defined according to the water requirements of the species they protect. The conservation significance of ecological refugia, and the priority assigned to their conservation, depends on the level of knowledge available for the species they support.
Evolutionary refugia	Those waterbodies that contain *short-range endemics* or *vicariant relics*. Evolutionary refugia are most likely to persist into the future and should be accorded the highest priority in NRM adaptation planning.
Generalised Dissimilarity Modelling (GDM)	A method of modelling based on compositional turnover of a group of species at a location; it considers whole biological groups rather than individual species
Gross vulnerability of a system	The combination of exposure and sensitivity of system
Heatwave	Continuous period beyond a week when a particular threshold temperature is exceeded
Hyporheic water flows	Below-surface flows
Indicators of exposure	Factors such as days above a certain temperature, days without rainfall, population density
Indicators of sensitivity	How sensitive a system is to hazards; indicators include the types of dwellings people live in and the percentage of the population with certain health characteristics
'No regrets' strategies	These strategies yield benefits even if there is not a change in climate
Rainfall event	One or more closely spaced rainfalls that are large enough to produce a significant vegetation response

IN ALL REPORTS IN THE SERIES	
TERM	**DEFINITION**
Refugia	Habitats that biota retreat to, persist in and potentially expand from under changing environmental conditions
Return period	The number of days from the end of one rainfall event to the start of the next
Reversible strategies	Flexible strategies that can be changed if predictions about climate change are incorrect
Safety margin strategies	Strategies that reduce vulnerability at little or no cost
Species Distribution Modelling (SDM)	A species-specific approach whereby observational records are used to model the current potential distribution of a species
Short-range endemics	Species that occur only within a very small geographical area
Soft strategies	Strategies that involve the use of institutional, educational or financial tools to reduce species vulnerability to climatic change
Species invasiveness	A species that causes environmental or socioeconomic impacts, is non-native to an ecosystem or rapidly colonises and spreads (see Ricciardi and Cohen 2007). In the Invasive animals report it refers to non-native species (that is, those introduced to Australia post-1788) that have caused significant environmental or agricultural changes to the ecosystem or that are believed to present such a risk.
Strategies that reduce time horizons	Strategies that reduce the lifetime of particular investments
Vicariant relicts	Species with ancestral characteristics that have become geographically isolated over time

References

Abatzoglou JT and Kolden CA (2011) Climate change in western US deserts: Potential for increased wildfire and invasive annual grasses. *Rangeland Ecology and Management* 64(5), 471–478.

Belnap J, Ludwig JA, Wilcox BP, Betancourt JL, Dean WRJ, Hoffmann BD and Milton SJ (2012) Introduced and invasive species in novel rangeland ecosystems: Friends or foes? *Rangeland Ecology & Management* 65(6), 569–578.

Bhatt RK, Baig MJ and Tiwari HS (2007) Growth, biomass production, and assimilatory characters in *Cenchrus ciliaris* L. under elevated CO_2 condition. *Photosynthetica* 45(2), 296–298.

Biosecurity South Australia (2012) *South Australia buffel grass strategic plan: a plan to reduce the weed threat of buffel grass in South Australia*. Government of South Australia, Adelaide.

Bradshaw CJA, Bowman DMJS, Bond NR, Murphy BP, Moore AD, Fordham DA, Thackway R, Lawes MJ, McCallum H, Gregory SD, Dalal RC, Boer MM, Lynch AJJ, Bradstock RA, Brook BW, Henry BK, Hunt LP, Fisher DO, Hunter D, Johnson CN, Keith DA, Lefroy EC, Penman TD, Meyer WS, Thomson JR, Thornton CM, VanDerWal J, Williams RJ, Keniger L and Specht A (2013) Brave new green world – Consequences of a carbon economy for the conservation of Australian biodiversity. *Biological Conservation* 161, 71–90.

Clarke PJ, Latz PK and Albrecht DE (2005) Long-term changes in semi-arid vegetation: Invasion of an exotic perennial grass has larger effects than rainfall variability. *Journal of Vegetation Science* 16(2), 237–248.

Cox JR, Martin-R MH, Ibarra-F FA, Fourie JH, Rethman NFG and Wilcox DG (1988) The influence of climate and soils on the distribution of four African grasses. *Journal of Range Management* 41(2), 127–139.

CRC for Australian Weed Management (2008) *Weed management guide: managing weeds for biodiversity*. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/347153/awmg_buffel-grass.pdf.

De La Barrera E and Castellanos AE (2007) High temperature effects on gas exchange for the invasive buffel grass (*Pennisetum ciliare* [L.] Link). *Weed Biology and Management* 7, 128–131.

Department of Environment and Conservation Western Australia (2013) *Great Western Woodlands Draft Strategic Weed and Feral Animal Management Plan*. Department of Environment and Conservation, Perth, Western Australia.

Dwyer SA, Ghannoum O, Nicotra A and von Caemmerer S (2007) High temperature acclimation of C_4 photosynthesis is linked to changes in photosynthetic biochemistry. *Plant, Cell and Environment* 30(1), 53–66.

Friedel MH, Grice AC, Marshall NA and van Klinken RD (2011) Reducing contention amongst organisations dealing with commercially valuable but invasive plants: The case of buffel grass. *Environmental Science & Policy* 14(8), 1205–1218.

Grice AC, Friedel MH, Marshall NA and van Klinken RD (2012) Tackling contentious invasive plant species: A case study of buffel grass in Australia. *Environmental Management* 49(2), 285–294.

Hobbs RJ, Arico S, Aronson J, Baron JS, Bridgewater P, Cramer VA, Epstein PR, Ewel JJ, Klink CA, Lugo AE, Norton D, Ojima D, Richardson DM, Sanderson EW, Valladares F, Vila M, Zamora R and Zobel M (2006) Novel ecosystems: theoretical and management aspects of the new ecological world order. *Global Ecology and Biogeography* 15(1), 1–7.

Kharrat-Souissi A, Siljak-Yakovlev S, Brown SC, Baumel A, Torre F and Chaieb M (2014) The polyploid nature of *Cenchrus ciliaris* L. (Poaceae) has been overlooked: new insights for the conservation and invasion biology of this species – a review. *The Rangeland Journal* 36(1), 11–23.

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

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

Marshall VM, Lewis MM and Ostendorf B (2012) Buffel grass (*Cenchrus ciliaris*) as an invader and threat to biodiversity in arid environments: A review. *Journal of Arid Environments* 78, 1–12.

McDonald CJ and McPherson GR (2011) Fire behavior characteristics of buffelgrass-fueled fires and native plant community composition in invaded patches. *Journal of Arid Environments* 75(11), 1147–1154.

McDonald PJ and Luck GW (2013) Density of an environmental weed predicts the occurrence of the king brown snake (*Pseudechis australis*) in central Australia. *Herpetological Journal* 23(3), 161–165.

Miller G, Friedel M, Adam P and Chewings V (2010) Ecological impacts of buffel grass (*Cenchrus ciliaris* L.) invasion in central Australia – does field evidence support a fire-invasion feedback? *The Rangeland Journal* 32(4), 353–365.

Moore G, Sanford P and Wiley T (2006) *Perennial pastures for Western Australia*. Department of Agriculture and Food Western Australia, Bulletin 4690, Perth.

Northern Territory Government (no date) *Buffel grass management guide for central Australia*. http://www.lrm.nt.gov.au/__data/assets/pdf_file/0014/19211/buffel_guide_web_version.pdf.

Prober SM, Thiele KR, Rundel PW, Byrne M, Christidis L, Gosper CR, O'Connor MH, Grierson PF, Macfarlane C, Recher HF, Scott JK, Standish RJ, Stock WD, van Etten EJB, Wardell-Johnson GW, Watson A and Yates CJ (2012) Climate adaptation in intact landscapes: a framework for managing change and resilience applied to the world's largest Mediterranean-climate woodland. *Climatic Change* 110(1–2), 227–248.

Queensland Department of Agriculture, Fisheries and Forestry (2013). *Buffel grass in south Queensland*. Brisbane. http://www.daff.qld.gov.au/plants/field-crops-and-pastures/pastures/buffel-grass.

Rudmann SG, Milham PJ and Conroy JP (2001) Influence of high CO_2 partial pressure on nitrogen use efficiency of the C_4 grasses *Panicum coloratum* and *Cenchrus ciliaris*. *Annals of Botany* 88, 571–577.

Schlesinger C, White S and Muldoon S (2013) Spatial pattern and severity of fire in areas with and without buffel grass (*Cenchrus ciliaris*) and effects on native vegetation in central Australia. *Austral Ecology* 38(7), 831–840.

Scott JK, Webber BL, Murphy H, Ota N, Kriticos DJ and Loechel B (2014) *AdaptNRM Weeds and climate change: supporting weed management adaptation.* Available at: https://research.csiro.au/adaptnrm/ (accessed 20 August 2014).

Steel J, Kohout M and Newell G (2008) *Climate change and potential distribution of weeds. Whither the weeds under climate change?* Available at: http://www.climatechange.vic.gov.au/__data/assets/pdf_file/0007/73249/Whithertheweedsunderclimatechange2008v1.pdf (accessed 23 July 2012).

Tooth IM and Leishman MR (2014) Elevated carbon dioxide and fire reduce biomass of native grass species when grown in competition with invasive exotic grasses in a savanna experimental system. *Biological Invasions* 16, 257–268.

Wilson PD, Downey PO, Gallagher RV, O'Donnell J, Leishman MR and Hughes L (2011) *Modelling climate suitability for exotic plants in Australia under future climate. Final Report on the potential impact of climate change on the distribution of national priority weeds in Australia*, Macquarie University and New South Wales Office of Environment and Heritage, Sydney, Australia.

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