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Priority threat management of invasive plant species in the Lake Eyre Basin

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Jennifer Firn, Tara Martin, Belinda Walters, John Hayes, Sam Nicol, Iadine Chades, and Josie Carwardine

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Other Authors/Contributors:	Tara Martin (CSIRO) Belinda Walters (CSIRO) John Hayes (QUT) Sam Nicol (CSIRO) Iadine Chades (CSIRO) Josie Carwardine (CSIRO) Climate Adaptation Flagship

Enquiries

Enquiries regarding this document should be addressed to:

Jennifer Firn

Queensland University of Technology

jennifer.firn@qut.edu.au

Enquiries about the Climate Adaptation Flagship or the Working Paper series should be addressed to:

Working Paper Coordinator

CSIRO Climate Adaptation Flagship

CAFworkingpapers@csiro.au

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Acknowledgments

This work represents a collaborative effort between Queensland University of Technology (QUT), CSIRO and a broad range of stakeholders (policy makers, managers, scientists, community representatives) who are collectively working for sustainable outcomes in the Lake Eyre Basin. The authors extend our most sincere thanks to these individuals who generously shared their time and expertise at a workshop and through follow up discussions during April through June 2013. These experts not only made this work possible; they are also a critical link to ensuring the work has a positive impact for decision making around weed management in the Basin.

This project was funded by the Australian Government Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC) National Environmental Research Program, to support the implementation of the Lake Eyre Basin Rivers Assessment (LEBRA). The 'LEBRA Implementation Plan 2010-2018' identified invasive species and the impacting activities associated with the establishment and spread of exotic species, including Weeds of National Significance, as one of the key pressures in the Basin. In-kind time was also provided by individuals at CSIRO, QUT and the University of Queensland. Some of the costs of running this project were shared by the sister project on prioritising invasive animal management in the Lake Eyre Basin, funded by the Invasive Animals Co-operative Research Centre.

Executive summary

This project is led by scientists in conservation decision appraisal and brings together a group of experts working across the Lake Eyre Basin (LEB). The LEB covers a sixth of Australia, with an array of globally significant natural values that are threatened by invasive plants, among other things. Managers at various levels are investing in attempts to control, contain and eradicate these invasive plant species, under severe time and resources limitations. To date there has been no basin-wide assessment of which weed management strategies and locations provide the best investments for maximising outcomes for biodiversity per unit cost. Further, there has been no assessment of the extent of ecosystem intactness that may be lost without effective invasive plant species management strategies. Given that there are insufficient resources to manage all invasive plant species everywhere, this information has the potential to improve current investment decisions.

Here, we provide a prioritisation of invasive plant management strategies in the LEB. Prioritisation was based on cost-effectiveness for biodiversity benefits. We identify the key invasive plant species to target to protect ecosystem intactness across the bioregions of the LEB, the level of investment required and the likely reduction in invasive species dominance gained per dollar spent on each strategy. Our focus is on strategies that are technically and socially feasible and reduce the likelihood that high impact invasive plant species will dominate native ecosystems, and therefore change their form and function. The outputs of this work are designed to help guide decision-making and further planning and investment in weed management for the Basin.

Experts in weed management, policy-making, community engagement, biodiversity and natural values of the Basin, attended a workshop and agreed upon 12 strategies to manage invasive plants. The strategies focused primarily on 10 weeds which were considered to have a high potential for broad, significant impacts on natural ecosystems in the next 50 years and for which feasible management strategies could be defined. Each strategy consisted of one or more supporting actions, many of which were spatially linked to IBRA (Interim Biogeographical Regionalisation of Australia) bioregions. The first strategy was an over-arching recommendation for improved mapping, information sharing, education and extension efforts in order to facilitate the more specific weed management strategies. The 10 more specific weed management strategies targeted the control and/or eradication of the following high-impact exotic plants: mesquite, parkinsonia, rubber vine, bellyache bush, cacti, mother of millions, chinee apple, athel pine and prickly acacia, as well as a separate strategy for eradicating all invasive plants from one key threatened ecological community, the GAB (Great Artesian Basin dependant) mound springs.

Experts estimated the expected biodiversity benefit of each strategy as the reduction in area that an invasive plant species is likely to dominate in over a 50-year period, where dominance was defined as more than 30% coverage at a site. Costs were estimated in present day terms over 50 years largely during follow up discussions post workshop. Cost-effectiveness was then calculated for each strategy in each bioregion by dividing the average expected benefit by the average annual costs.

Overall, the total cost of managing 12 invasive plant strategies over the next 50 years was estimated at $1.7 billion. It was estimated that implementation of these strategies would result in a reduction of invasive plant dominance by 17 million ha (a potential 32% reduction), roughly 14% of the LEB. If only targeting Weeds of National Significance (WONS), the total cost was estimated to be $113 million over the next 50 years. Over the next 50 years, $2.3 million was estimated to eradicate all invasive plant species from the Great Artesian Basin Mound Springs threatened ecological community. Prevention and awareness programs were another key strategy targeted across the Basin and estimated at $17.5 million in total over 50 years.

The cost of controlling, eradicating and containing buffel grass were the most expensive, over $1.5 billion over 50 years; this strategy was estimated to result in a reduction in buffel grass dominance of a million ha in areas where this species is identified as an environmental problem. Buffel grass has been deliberately planted across the Basin for pasture production and is by far the most widely distributed exotic species. Its management is contentious, having economic value to many graziers while posing serious threats to biodiversity and sites of high cultural and conservation interest. The strategy for containing and locally eradicating buffel grass was a challenge to cost based on expert knowledge, possibly because of the dual nature of this species as a valued pastoral grass and environmental weed. Based on our conversations with experts, it appears that control and eradication programs for this species, in conservation areas, are growing rapidly and that information on the most cost-effective strategies for this species will continue to develop over time.

The top five most cost-effective strategies for the entire LEB were for the management of: 1) parkinsonia, 2) chinee apple, 3) mesquite, 4) rubber vine and 5) bellyache bush. Chinee apple and mother of millions are not WONS and have comparatively small populations within the semi-arid bioregions of Queensland. Experts felt that there was an opportunity to eradicate these species before they had the chance to develop into high-impact species within the LEB. Prickly acacia was estimated to have one of the highest benefits, but the costs of this strategy were high, therefore it was ranked 7th overall. The buffel grass strategy was ranked the lowest (10th) in terms of cost effectiveness. The top five most cost-effective strategies within and across the bioregions were the management of: 1) parkinsonia in the Channel Country, 2) parkinsonia in the Desert Uplands, 3) mesquite in the Mitchell Grass Downs, 4) parkinsonia in the Mitchell Grass Downs, and 5) mother of millions in the Desert Uplands. Although actions for several invasive plant species like parkinsonia and prickly acacia were concentrated in the Queensland part of the LEB, the actions involved investing in containment zones to prevent the spread of these species into other states. In the NT and SA bioregions of the LEB, the management of athel pine, parkinsonia and cacti were the main strategies.

While outside the scientific research goals of study, this work highlighted a number of important incidental findings that led us to make the following recommendations for future research and implementation of weed management in the Basin:

- Ongoing stakeholder engagement, extension and participation is required to ensure this prioritisation effort has a positive impact in affecting on-ground decision making and planning.
- Short term funding for weed management was identified as a major reason for failure of current efforts, hence future funding needs to be secure and ongoing.
- Improved mapping and information sharing is essential to implement effective weed management.
- Due to uncertainties in the outcomes and impacts of management options, strategies should be implemented as part of an adaptive management program.

The information provided in this report can be used to guide investment for controlling high-impact invasive plant species for the benefits of biodiversity conservation. We do not present a final prioritisation of invasive plant strategies for the LEB, and we have not addressed the cultural, socio-economic or spatial components necessary for an implementation plan. Cost-effectiveness depends on the objectives used; in our case we used the intactness of ecosystems as a surrogate for expected biodiversity benefits, measured by the extent that each invasive plant species is likely to dominate in a bioregion. When other relevant factors for implementation are considered the priorities may change and some actions may not be appropriate in some locations. We present the costs, ecological benefits and cost-effectiveness of preventing, containing, reducing and eradicating the dominance of high impact invasive plants through realistic management actions over the next 50 years. In doing so, we are able to estimate the size of the weed management problem in the LEB and provide expert-based estimates of the likely outcomes and benefits of implementing weed management strategies. The priorities resulting from this work provide a prospectus for guiding further investment in management and in improving information availability.

Part I Lake Eyre Basin values and threats of invasive plants

1 Introduction

Often referred to as 'the heart of Australia' (Figure 1), the Lake Eyre Basin (LEB) covers around 120 million ha and spans one sixth of the Australian continent. The Basin is rich in Indigenous culture and is home to some of the rarest, least exploited ecosystems on the planet. On a global scale, the LEB is amongst the largest internally draining systems, and is drained by the most variable river systems in the world: the Georgina, Diamantina and Cooper. Lake Eyre itself is the fifth largest terminal lake in the world. The Basin spans large parts of Queensland, South Australia, Northern Territory, and a small portion of New South Wales. The rivers drain southward, with major flows from Queensland into South Australia, and from the Northern Territory into both Queensland and South Australia. The Basin is sparsely populated, with about 60,000 people overall, approximately half of whom reside in the Basin's largest urban centre, Alice Springs. The major employment sectors in the LEB are grazing and other forms of agriculture respectively (36%), which are highest in the semi-arid regions of the Basin. Government work is the second largest employment sector (11%) in the region and is concentrated around Alice Springs and the most northwestern part of South Australia. Retail (7%), health (6%) and education (6%) are the next highest employment sectors (Herr et al. 2009). The climate of the LEB drives its socio-economic and environmental conditions—the Basin is a "boom and bust" system, with unpredictable weather fluctuations characterised by long dry periods and infrequent rain to wide-scale flooding events.

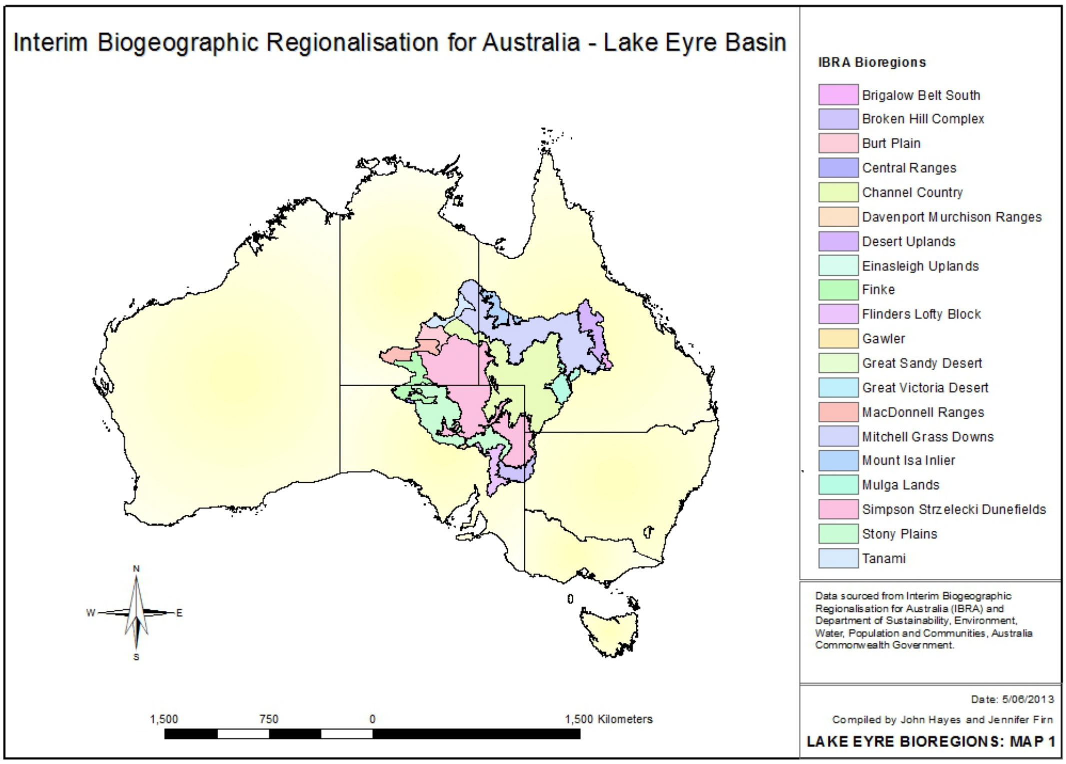

Figure 1. Map of Lake Eyre Basin showing Interim Biogeographic Regionalisation for Australia (IBRA), spanning one-six of the Australian continent

The conservation values of the LEB are immense. The LEB is one of the last unregulated wild river catchments in the world. The Basin is arid to semi-arid with the biotic and abiotic features of its ecosystems having been shaped for thousands of years of variable water flows and rainfall. National parks and conservation reserves cover around 11% of the Basin (Herr et al. 2009). The Basin supports internationally recognised wetlands such as the Ramsar listed Coongie Lakes, grasslands such as the Astrebla Downs

National Park and deserts such as the Simpson Desert National Park. The Basin is home to many rare and endangered species such as the Greater Bilby, the Kowari and Waddi Waddi trees (*Acacia peuce*), as well as one threatened ecological community, the Great Artesian Basin discharge springs wetlands that is listed as endangered under the *Commonwealth Environmental Protection and Biodiversity Conservation Act* 1999. These wetland areas of natural water seepage from the Great Artesian Basin, known commonly as mound springs, are located on the northern, western and southern margins of the Great Artesian Basin in Queensland, New South Wales and South Australia (Figure 2). The GAB mound springs support at least 13 endemic plant species and at least 65 endemic fauna species (Fensham et al. 2007).

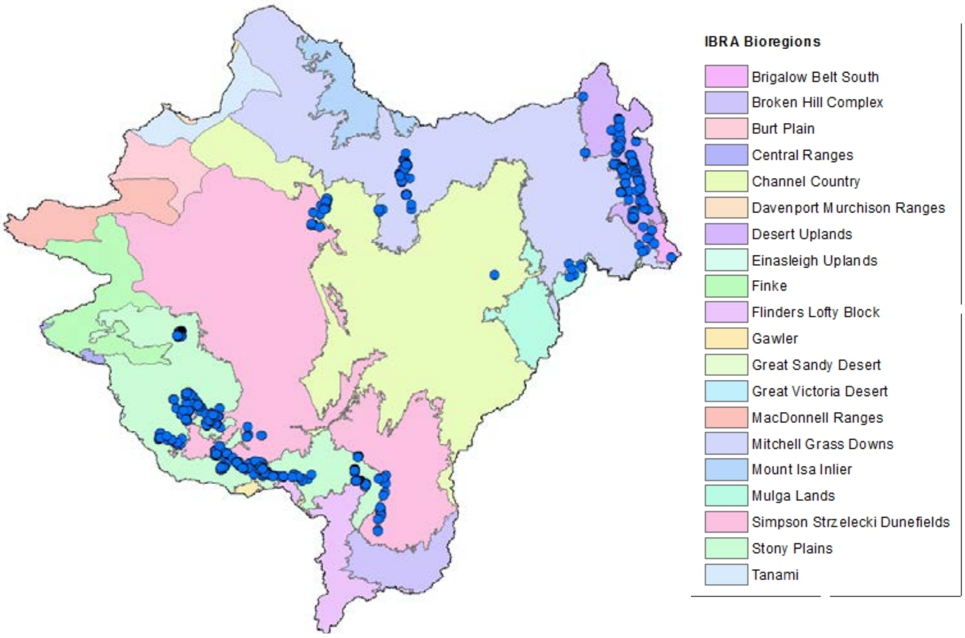

Figure 2. Map of known locations of the GAB Mound springs within each of the LEB bioregions. Data sourced from the IBRA and Department of Sustainability, Environment, Water, Population and Communities, Australia Commonwealth Government

There are significant pressures on the natural assets of the Basin that threaten the long-term sustainability of the LEB river systems. Key threatening processes include mining and petroleum extraction, irrigated agriculture, intensification of grazing, tourism and climate change as well as the establishment and spread of exotic animal and plant species. Amongst these pressures, the establishment and spread of exotic animal and plant species has been identified as priority issue for management within the Lake Eyre Basin Rivers Assessment implementation plan (LEBRA) (Kiri-ganai Research Pty Ltd 2010), a product of the Lake Eyre Basin Intergovernmental Agreement.

The LEB Intergovernmental Agreement was signed in October 2000 to increase the long-term sustainability of the LEB river systems and avoid or eliminate cross-border impacts. This agreement is a joint undertaking of the Commonwealth of Australia, South Australia, Northern Territory and Queensland governments as well the Basin community. This agreement established the LEB Ministerial Forum (decision-making body made up of relevant Ministers). The LEB Ministerial Forum established the Community Advisory Committee (to advise on implementation of the agreement and ensure community participation) and the Scientific Advisory Panel (to advise on scientific and technical issues) (Lake Eyre Basin Intergovernmental Agreement 2009).

More than 240 invasive exotic plants are recorded in the LEB, including 20 Weeds of National Significance (WONS) (Thorp and Lynch 2000, Australian Weeds Committee 2012, CSIRO and QUT 2013). Seven of these WONS current distributions are predominantly within the LEB including: *Prosopis* spp. (mesquite complex: *Prosopis glandulosa*, *Prosopis pallida*, *Prosopis velutina*), *Parkinsonia aculeata* (parkinsonia), *Tamarix aphylla* (athel pine), *Optunia* spp. and *Cylindropuntia* spp. (cacti grouping, more than 14 spp.), *Cryptostegia grandiflora* (rubber vine), *Jatropha gossypifolia* (bellyache Bush), and *Acacia nilotica* (prickly acacia). Since

2001, national strategies have been implemented to manage and reduce the distribution and spread of WONS, including a number of biocontrol programs (van Klinken and Heard 2000, van Klinken 2006). Mesquite, parkinsonia and prickly acacia are some of the highest impact weeds, invading otherwise treeless habitat, in the LEB with several initiatives being overseen by the National Prickle Bush Management Group. There is evidence that education and prevention programs have been effective, for example a recent telephone survey covering more than 2, 516, 954 ha in Western Queensland (where their distributions are the highest) found that 100% of landholders surveyed were aware of prickly acacia and 93% aware of mesquite (March 2010). There are also a number of exotic plants that are known to have high impacts in other bioregions of Australia and that at present have only limited distributions within the LEB, generally confined to the semi-arid regions within Queensland, e.g. *Ziziphus mauritiana* (chinee apple), and *Bryophyllum* spp. (mother of millions grouping: *Bryophyllum delagoense*, *Bryophyllum houghtonii* and *Bryophyllum pinnatum*). Although presently confined to one (chinee apple) or just a few (mother of millions) sites within the LEB these species have the potential to spread in agricultural areas and into gazetted national parks.

Buffel grass (*Pennisetum ciliare* L.) is the most widely distributed exotic plant species across the LEB. Buffel grass has a “dual impact” in the LEB, being of high economic value to many graziers, given that grazing is the major land-use of the LEB covering (>82% of the area) (Herr et al. 2009); and being one of the most serious threats to rangeland biodiversity (Martin et al. 2006, Friedel et al. 2009, Grice et al. 2012). Buffel grass is listed among species that are capable of continental level distributions and destroying Australian ecosystems (Humphries et al. 1991). Studies have shown its dominance can degrade refuges for threatened central Australian fauna (Griffin 1993); compete with rare plant species on cliffs and ledges (Griffin 1993); increase the intensity of natural fire regimes impacting on the habitat of native flora and fauna (Butler and Fairfax 2003, Miller et al. 2010); and directly threaten a number of plants and animals (Jackson 2005, Friedel et al. 2006).

In response to the negative impacts of invasive plant species, the National Environmental Research Program (NERP) supported the development of a priority threat management assessment of invasive plant species. This project complements a sister project developing priorities for managing the threats of invasive animals in the Basin supported by the Invasive Animals Cooperative Research Centre (IACRC).

To date many exotic plant species have been identified across the LEB but until now, no systematic decision analysis has been undertaken to prioritise which species to invest in managing to get the greatest return on investment. There are insufficient resources to manage them all, hence prioritisation is essential. This project develops an invasive plant species threat management framework to identify which species to manage in priority to get the biggest expected benefit for every dollar invested. Without such an analysis the return on investment of invasive species management within the Basin is not clear. Despite this, considerable investment is being made into the management of invasive species within the Basin including several million on various Weeds of National Significance (WONS)(Martin and van Klinken 2006) and landholders are estimated to be spending more than $6 million annually on the control of prickly acacia within the Mitchel Grass Downs bioregion with reports of only mixed success (March 2009).

Prioritising the threat management of invasive species involves assessing the expected benefit of applying each management strategy to the assets we wish to protect. These assets might include biodiversity values such as species and ecosystems, as well as sites of cultural and national significance. Cost-effectiveness approaches for prioritising threat management have recently been used to assess the priority of a range of actions for conserving wildlife in the Kimberley (Carwardine et al. 2011, Carwardine et al. 2012) and the recovery of New Zealand’s endangered species (Joseph et al. 2009). These approaches are highly flexible and suitable for situations where there are varying amounts of data availability, as they are capable of drawing on both empirical data and expert knowledge (Martin et al. 2012a). Cost-effectiveness approaches can also be used as review tools that can be update easily as more information becomes available. This work forms a potential platform for the prioritisation of invasive species management elsewhere in Australia as well as overseas.

2 Project aims and scope

2.1 Project Aims

This project aims to provide a rational framework for cost-effective investment in weed management in the LEB. The approach draws on empirical data and expert information to estimate the expected benefits and costs of weed management strategies, in order to appraise their cost-effectiveness (Possingham et al. 2002, Joseph et al. 2009, Carwardine et al. 2012, Pannell et al. 2012). We evaluate a range of weed management actions aimed at controlling, containing and eradicating a suite of invasive species in the Basin. While the management strategies discussed are not new, we provide novel insights into their cost-effectiveness by integrating their costs and expected benefits into a rational and defensible framework.

Specifically the project aims to:

- Develop a costed suite of weed management actions to address the key threats posed by invasive plant species in the Basin;
- Provide information on the amount of land area within each bioregion that can be feasibly managed for invasive species with various levels of investment and conversely, the likely area of plant invasion in the absence of various levels of investment in management;
- Provide information regarding the most cost effective management actions for reducing the spread and invasion of invasive plant species;
- Ensure the approach considers, or feed into analyses which consider, information outside that used in this analysis;
- Provide outputs and information designed to be useful to a range of decision makers, groups and individuals, including Traditional Owners.

We acknowledge that there are many threats other than invasive plant species facing the Basin. The management of invasive animal species is being investigated in a sister project managed by CSIRO. Other threats such as the increasing pressure from oil and gas exploration, irrigated agriculture and intensification of livestock grazing within the Basin also warrant rational appraisal. We recognise the great importance of the priorities of Indigenous people, but the scope of this project meant that we were unable to collect and analyse information on Indigenous knowledge, preferences, social considerations and cultural values. Full consultation with other groups (miners, pastoralists) was similarly outside the project scope. However representatives across these groups were invited to participate in the process.

Rather than presenting final decisions, this work aims to support decision makers (Traditional Owners, government agencies, pastoralists, the conservation sector and others) to plan and gain resources for implementing management strategies for minimising the negative impacts of invasive plant species in the LEB.

Part II The priority threat management approach

3 Background to the cost-effectiveness analysis approach

Substantial investment in invasive species management is occurring throughout the Basin in an effort to stem the negative impacts on natural assets and agricultural production. What is unclear is: whether the invasive species currently being targeted represent the best investment; what is the level of funding required to manage all priority species; and how best to spend funding to minimise the spread and establishment of invasive plant species?

Threat management strategies, including those for weed management, should be evaluated by estimating their cost-effectiveness for achieving pre-specified targets or goals (Vane-Wright et al. 1991, Margules and Pressey 2000, Possingham et al. 2006). The evaluation of threat management involves ranking options by their cost-effectiveness, where the expected benefits of each strategy (not measured in dollar terms) are divided by the costs (Levin and McEwan 2001, Cullen et al. 2005). The potential benefits of strategies can be measured as the improvement in species habitat protected (Carwardine et al. 2008) or improvement in species persistence (Joseph et al. 2009, Carwardine et al. 2012), and the costs are usually financial management costs and/or opportunity costs (Naidoo et al. 2006, Pannell et al. 2012). The expected benefits are often then determined based on multiplying the potential benefits by the feasibility, or the likelihood that the benefit will be achieved. Often there are additional benefits or costs associated with certain strategies. For example, in the Kimberley, targeted conservation strategies provide benefits to employment, improved livelihoods, and reduction in greenhouse gas emissions (Carwardine et al. 2012).

In many ecologically important regions, an urgent need for conservation strategies is hampered by a lack of empirical data on species distributions and likely responses to threats and management actions. A growing body of research investigates methods for undertaking conservation management appraisal and prioritisation using the knowledge of experts to complement formal scientific data (Martin et al. 2005, Kuhnert et al. 2010, Burgman et al. 2011, Martin et al. 2012a). Given the urgency of many conservation issues, evidence suggests in many cases it is better to make decisions using expert knowledge alone, rather than to avoid decisions for lack of data (Martin et al. 2012c).

Expert information has been used to evaluate the cost-effectiveness of a range of strategies for saving threatened species in Australia (Possingham et al. 2002). Priority strategies from this assessment included ending Queensland's broad scale vegetation clearing, which occurred soon after the study's release. A similar approach was used in New Zealand to prioritise projects for the recovery of threatened species (Joseph et al. 2009), using predictions (elicited from experts) of improvements in species persistence for respective projects divided by the project's cost. This approach showed that markedly higher biodiversity outcomes could be gained per dollar spent, compared with prioritising strategies by threat status or public values alone. More recently, a priority threat management appraisal to secure the future of wildlife in the Kimberley was undertaken. This study contributed to the Western Australian government's decision to invest $26 million over 5 years in the top priority conservation strategies identified by the study. These real world conservation priority assessments may have been delayed, some indefinitely, had researchers waited for additional empirical data to be collated, thus delaying the implementation of the actions they recommended.

4 Applying the approach to invasive plants in the Lake Eyre Basin

4.1 Collating empirical data and expert knowledge

Applying a threat management prioritisation approach to invasive plants in the LEB required extensive consultation with experts in the management and ecology of weeds and of native ecosystems and species of the region, as well as gleaning existing information from the published and grey literature. There were five major types of information that we were required to collate: (i) a background literature review and database on the invasive plants present in the Basin, their distributions and the native species and/or ecosystems they are suspected to impact upon; (ii) the definition of parameters for the prioritisation approach, which is based on prioritising management strategies by their 'ecological cost-effectiveness'; (iii) the identification of the weed management strategies; (iv) estimates of the costs and expected benefits of each of the strategies; and (v) guidance on stakeholder engagement and pathways to ensure the approach is useful to decision makers and managers on the ground. A large proportion of the information was collected during a three-day workshop (in Brisbane, April 2013), with experts participating in follow up discussions by email and phone and advising on information in existing documents.

Experts were identified at the outset of the project based on their expected ability to contribute to the range of information required, and included NRM board and local council members involved in weed management, Non-Government Organisation (Bush Heritage Australia and Australian Wildlife Conservancy) land managers working in the Basin, Indigenous rangers, park managers, Aboriginal Land Council members, Graziers, University and CSIRO scientists, employees from Agforce, Environment and Primary Industries Departments of Queensland, South Australia and Northern Territory (e.g. Queensland Department of Agriculture, Forestry and Fisheries), and the Federal Department of Sustainability, Environment, Water, Population and Communities, including several involved with the Lake Eyre Basin Scientific Panel and Community Advisory Committee. These experts were then contacted via email and phone and provided background to the project, and asked about their interest and availability to either attend the workshop or participate through other discussions. Of the 33 experts contacted, a total of 19 experts participated in some form, and 11 attended the workshop and specifically participated in the Invasive plant prioritisation project.

i. Background information

We conducted an extensive literature review on invasive plants in the LEB and on prioritisation methods for threat management. We also sourced maps of current and potential future distributions of weeds in the Basin. We developed an Excel database providing a summary of available data on invasive and threatened native plant species within the LEB, including: species name, common name, vegetative form, conservation status (for native species) and location (within bio-regions), links to distribution maps, and impacts of invasive plants on native flora and fauna. The information was collected from the Atlas of Living Australia and various other sources and was updated by experts prior to and during the workshop. This database was built on post workshop to include the information used in the analysis and the cost-effectiveness results, as described later. The papers collected during the literature review and the excel database can be accessed online at: www.dropbox.com/sh/bt9w89gqmnqq675/NDgqAOEd6f

ii. Definition of parameters for analysis

The parameters for an ecological cost-effectiveness analysis need to be tailored to each issue in each region, as outlined by Carwardine et al. (2012). While the overall goal of cost-effectiveness analysis is to maximise the expected benefit per unit cost, the parameters such as study extent, resolution, objective, time frame, benefit metric, etc., will depend on case-specific factors.

The experts agreed that the spatial extent of the study would be the original LEB boundary (Figure 1) as used in the LEB Rivers Assessment. The spatial resolution was defined as the extent of the 12 IBRA (Interim Biogeographical Regionalisation of Australia) bioregions (version 6) that fall within the LEB boundary. The group agreed that they would define a number of strategies, each with a set of supporting actions, which aim to reduce the impact of weeds across the Basin. A decision was made to use a time frame of 50 years for estimating the cost-effectiveness of each strategy. It was agreed that costs would be estimated by using existing data where possible.

Experts acknowledged that this project aims to measure the expected benefits of threat management strategies to biodiversity, but that the impact of weed management strategies on native species was not the most appropriate surrogate for measuring overall biodiversity impact in this case. One of the most difficult characteristics to measure and record about invasive plant species are their impact on biodiversity and key ecosystem functions (Levine et al. 2003, Grice 2006, Firn and Buckley 2010). On one hand, we know that the establishment and dominance of a species like prickly acacia impacts on the structure of ecosystems by converting grasslands to shrublands (Radford et al. 2001) and likely also changes key resource conditions such as light, nutrient availability and hydrological flows. On the other hand, measuring the impact on dominant native species, and threatened and endangered species from these dramatic conversions is very challenging. Experts agreed unanimously that high impact invasive plant species with the capability to dominate sites have a significant impact on native biodiversity. Evidence from scientific studies also suggests that when biodiversity is lost from plant communities, key ecosystem functions decline (Vila et al. 2011). For example, loss of biodiversity from plant communities reduces productivity (biomass accumulation) (Hector et al. 1999), nutrient cycling (Tilman et al. 1996), resilience to drought conditions (Tilman et al. 1997), capabilities of ecosystems to recover from disturbances such as fire (MacDougall et al. 2013) and the ability to sustainably provide the key ecosystem services people need (Isbell et al. 2011).

In light of these challenges, it was agreed that the most appropriate surrogate for biodiversity benefit would be the expected change in the intactness of ecosystems, measured by the extent that each weed is likely to dominate in a region, resulting from each strategy. Aiming to reduce the dominance of an invasive exotic plant will have benefits for biodiversity and the long-term sustainability of ecosystems as a whole. The objective of the analysis was therefore to identify which strategies are likely to be the most cost-effective for reducing the total area dominated by weeds in each bioregion. This required experts to quantitatively define dominance and invadable habitat. If an invasive plant was dominant at a site, experts agreed that the site should be considered dramatically altered. Dominance was defined as a level of cover exceeding 30%. The invadable habitat was assumed to be the proportion of suitable habitat for the weed in each bioregion. Because this particular measure of expected benefit already considers the likelihood of the success of the strategy, the experts did not separately estimate the likelihood of success as per previous analyses (e.g. Carwardine et al. 2012; Joseph et al. 2009).

It was collectively decided by participants that the targets for the strategy of managing the threatened ecosystem GAB mound springs would be different. The objective was to remove all invasive plant species and prevent new introductions, as it was agreed that any invasive plant presence within the Mound Springs adversely impacts this threatened ecological community. The expected benefits of this strategy were not predicted for each bioregion, rather as an overall value for the GAB mound springs.

iii. Identification of weed management strategies

The experts defined 12 strategies for species or groups of invasive plant species that are considered to have a potentially significant impact in the Basin. The experts selected these species from the total of 240 weeds currently in the Basin, as they are considered to have a much higher potential for widespread and significant ecological impact and have the potential for feasible management strategies. All of the strategies were assumed to be feasible if the funding was made available. For each strategy one or more supporting actions were defined, which would be involved in implementing the strategy. The 12 strategies and actions are:

- S1. Prevention and monitoring program for all weeds
- S2. Target mesquite
- S3. Target parkinsonia
- S4. Target rubber vine
- S5. Target buffel grass
- S6. Target bellyache bush
- S7. Target cacti (e.g. coral, harissia, devil's rope)
- S8. Target mother of millions
- S9. Target chinee apple
- S10. Target athel pine
- S11. Target prickly acacia
- S12. Target Threatened Ecological Community: Great Artesian Basin Mound Springs

Details of these strategies and their supporting actions and costs are provided in the results section (Table 1).

iv. 'Best guess' benefits and estimating costs of strategies

Experts estimated the information required for the benefit metric by taking the following steps:

- Estimating the expected proportion of invadable habitat in each bioregion that each weed (or group) will likely dominate in (>30% coverage at a site) in 50 years without implementation of any strategy
- Estimating the expected proportion of invadable habitat in each bioregion that each weed (or group) will likely dominate in (>30% coverage at a site) in 50 years with implementation of the strategy targeted to manage that weed (or group)

For each of these scenarios experts gave their best guess, upper (most optimistic) and lower (most pessimistic) bounds, and a level of confidence that the true answer lies within this range.

The expert information needed to estimate the costs of strategies was collected largely during follow up consultation with experts from the workshop and a range of other experts who were unable to attend the workshop. For the majority of strategies, experts were able to cost each action within each bioregion over 50 years as invasive plant control programs. In other cases, experts provided estimates of the annual costs/ha of managing (eradicating, containing or controlling) each weed at high and low densities where relevant, and provided time-frames for management over 50 years. In all cases the costs of undertaking each strategy i by its component actions in each bioregion j were estimated by considering the costs of previous and current management activities and spatial variants such as land tenure and remoteness. The economic cost C_{ij} was the cost in present day Australian dollars of activities associated with strategy i in bioregion j over 50 years.

v. Stakeholder engagement and pathways to adoption

During the workshop we held a discussion on the importance of stakeholder engagement and how best to carry out this project to ensure maximum relevance to real world weed management problems. The scope of the project was clarified: the project is designed to analyse the broad-scale ecological cost-effectiveness of weed management strategies and does not include funds for finer scaled priority setting nor implementation. However, the group agreed that without the appropriate involvement and communication with stakeholders, the project has the potential to be another blue-sky priority setting process that is not used for implementation. A number of stakeholders were identified aside from those present at the workshop: from government ministers to community members and landholders and land managers, both Indigenous and non-Indigenous.

Potential influence channels were discussed, including sending out appropriately packaged information to local governments, regional groups and Indigenous communities, finding commonalities with existing initiatives, e.g. food security, and identifying supportive 'champions' from departments such as DAFF QLD, the Rangelands Alliance and NRM groups. It was also acknowledged that attendees at the workshop had an opportunity to disseminate their experience of the project through existing communication avenues. It was agreed that the researchers would present findings at the LEB conference in September 2013.

The group agreed that while the project is required to produce a scientific report, a shorter pamphlet containing the main findings in plain English would be a more easily accessible format for many stakeholders. Indicators of a good outcome were also discussed, including: broad knowledge and understanding of the project and its outcomes amongst the LEB community, particularly natural resource managers, over the next few years, and the integration of the priorities set in this project with existing local and regional scale priority setting approaches. These discussions further highlighted the importance of securing ongoing funding for implementation and finding avenues to carry out the priority strategies through the existing LEB Intergovernmental agreement.

4.2 Analyses

Once expert data collection on costs and expected benefits was complete, we used these data along with existing information to convert the costs and benefits to a suitable format for analysis.

For the expected benefit estimates, we converted the estimated proportions of invadable habitat dominated by each weed under each strategy to the total area dominated using maps of the potential distribution of each weed in each bioregion. While we acknowledge that accurate prediction of potential distribution of invasive plant species is difficult, we used the best available data to complete our analysis. The potential distributions of most invasive plant species were obtained from the Weeds of National Significance (WONS) program (Thorp and Lynch 2000). Potential distribution maps for mother of millions and chinee apple were assessed by overlaying 50km^2 squares (similar approach used in the WONS mapping) over occurrence maps downloaded from the Atlas of Living Australia website, as it was assumed that the area surrounding an existing population of a weed will have the highest likelihood of becoming invaded. For buffel grass distribution we used unpublished habitat suitability maps specifically created for this species using a number of key indicative variables e.g. soil moisture, temperature, rainfall, grazing intensity and fire frequency (Martin et al. 2012b). The expected benefit of each strategy was then estimated by the reduction in the total area (in ha) predicted to be dominated by the weed in 50 years if the strategy was implemented compared to if it was not using the average of the best guess estimates across all experts.

The estimates of individual experts for a strategy in a bioregion were aggregated by averaging the estimates. The total expected benefit, B_{ij} of strategy *i* in bioregion *j* was defined by,

$$B_{ij} = \frac{A_{ij} \sum_{k=1}^{N} (b_{jk0} - b_{ijk})}{N}$$

Where:

- A_{ij} is the total area of invadable habitat in bioregion *j* for the species managed under strategy *i*
- b_{jk0} is the proportion of invadable area dominated by the weed if no action is taken in bioregion *j* estimated by expert *k* over the time period (50 years)
- b_{jik} is the proportion of invadable area dominated by the weed under strategy *i* in bioregion *j* estimated by expert k over the time period (50 years)
- N is the number of experts who made an estimate for strategy *i* in bioregion *j*.

This process was repeated using the upper and lower bounds to analyse the sensitivity.

To determine the total cost for the strategies that were costed over whole bioregions, we summed the cost of all actions required to implement a strategy in a bioregion. For strategies with actions that were costed on a per hectare basis, we used maps of the current distribution of each weed and information on the treatment area for each strategy to convert the cost information into an average cost/year over 50 years for each bioregion. In all cases the once off costs, such as building a fence, were counted once, while ongoing annual costs, such as maintaining the fence, were summed over 50 years. The total cost for strategy *i* and bioregion *j* is denoted C_{ij}.

We created an Excel database containing the expected benefits (averaged best guess, upper, lower bounds and confidence) over 50 years and the average costs/year for each strategy over 50 years in each bioregion. The cost-effectiveness of each strategy in each bioregion was then calculated by dividing the expected benefit by the expected cost. In all cases once off costs, such as building a fence, were counted once, while on-going annual costs, such as maintaining the fence, were summed over 50 years using a discount rate of 2% per year.

The cost-effectiveness, CE_{ij}, in ecological terms, of each strategy *i* in each bioregion *j* was calculated by:

$$CEij = \frac{\mathrm{B}_{ij}}{\mathrm{C}_{ij}}$$

The strategies were then ranked across all bioregions and within each bioregion.

Part III Priority invasive plant threat management strategies and implications

5 Priority threat management strategies

5.1 Recommended actions and estimated costs for all strategies

At the workshop and in follow-up consultations participants identified one or more actions within each of the 12 strategies and costed these actions over the next 50 years (Table 1). Strategy 1, prevention and monitoring programs for all invasive plants, was not able to be quantitatively compared with strategies 2-12. However when predicting the expected benefits for reducing the dominance of the invasive plants over 50 years, experts assumed that this strategy would be implemented. Key actions within the prevention and monitoring strategy were the development of a basin-wide weed management task force or plan, continued education programs for all invasive plants, in particular mesquite, bellyache bush, chinee apple and buffel grass, and a centralised approach to mapping, monitoring and surveillance (Table 1). When collating information and data to predict the current and potential distributions of invasive plant species and even WONS, we had great difficulty in sourcing reliable data, which highlights the importance and urgency for a centralised system for analysing management options and managing invasive plants within the LEB, especially across and between the semi-arid bioregions.

The buffel grass strategy had overwhelmingly the highest cost, while the chinee apple strategy had the lowest cost overall. Actions for parkinsonia and prickly acacia, although costed for just a couple of bioregions, involve setting up containment zones to prevent the spread of these species into the southern regions of the LEB. The mesquite strategy includes the investment of funds in "periodic suppression" as based on prior experiences, land managers have found this species to build up small populations during high rainfall times that should be monitored and eradicated when they arise. The GAB mound springs strategy estimated at a total cost of $3.25 million over 50 years, with $200,000 annual expenditure recommended for the first 5 years as a targeted control program and $500,000 recommended every 10 years after. Similar to strategy 1, the mound springs strategy was costed for the entire Basin and not within bioregions.

Table 1. Estimates of the cost of actions that make up each of the specific invasive plant species strategies, including costs (discounted) for the actions over 50 years, and average annual costs over the 50 years (some actions as indicated below were not costed over 50 years, but the values are shown this way for comparison purposes).

Strategies	Description of actions	Total costs (50 years, discounted)	Average annual costs
S1. Prevention and monitoring program for all weeds	Develop weed management task/plan basin-wide	$160,729	$3,215
	Mapping, monitoring and surveillance (ground and aerial, build on weed spotters network)	$217, 651	$4,353
	Centralised information sharing for weed incursion/extents	$20,000	$400
	Secure positions: two FTEs, one FTE for mapping and centralised information sharing and one FTE for on-ground activities	$8,333,540	$166,671
	mesquite awareness campaign	$76,651	$1,533
	bellyache bush awareness campaign	$76,651	$1,533
	chinee apple awareness campaign	$76,651	$1,533
	buffel grass awareness campaign	$217,651	$4,353
S2. mesquite	Eradicate from the following bioregions: Mitchell Grass Downs (MGD), Desert Uplands (DEU), Broken Hill Complex (BHC) and the Channel Country (CHC); $800,000 investment in the first year and then $300,000 per year for next four years.	$3,028,191	$60,564
	Periodic suppression of new infestations over time; investment of $200,000 per year for the first three years and repeated every 10 years	$2,6051873	$52,118

Strategies	Description of actions	Total costs (50 years, discounted)	Average annual costs
S3. parkinsonia	Prevent spread into Diamantina National Park by eradicating from Springcreek and Diamantina river north of the National Park up to the western river convergence	$471,346	$9,427
	Eradicate from the following bioregions: Stony Plains, Broken Hill (STP) Complex (BHC), Flinders Lofty Block (FLB) (SA)	$343,193.00	$6,864
	Control downstream outliers and establish large-scale buffer zones in the Georgina and Thomson Rivers (downstream of Boulia and Jundah/Windorah respectively). Requires initial control program (three years) then periodic suppression every 10 years.	$716,065	$14,321
	Impact reduction through introduction and proliferation of dieback biological control agents in established infestation areas of the MGD, DEU and CHC	$503,278	$10,066
S4. rubber vine	Contain and control in DEU	$2,264776	$53,896
	Eradicate from MGD, CHC	$1,920,286	$38,406
S5. buffel grass	Contain in STP, Finke (FIN) and control in all other SA bioregions	$421,611	$8,432
	Control in MacDonnell ranges (MDR) to reduce hot burns – especially along creeks	$228,386,768	$4,567,735
	Control and locally eradicate (including rehabilitation) and prevent incursions into clean areas in gazetted conservation areas in Queensland	$1,316,135,691	$26,322,714
S6. bellyache bush	Eradicate from DEU	$319,543	$6,391
S7. cacti (e.g. coral, harissia, devil's rope)	Contain all cacti spp. in southern part of SA, eradicate to north	$3,613,715	$72,274
	Control and contain all cacti elsewhere	$46,635,538	$932,711
S8. mother of millions	Eradicate from urban areas in all areas of the Basin	$26,948	$539
	Control and contain in DEU, MGD and any other occurrences	$240,033	$4,801
S9. chinee apple	Eradicate from MGD	$89,826	$1,797
S10. athel pine	Eradicate weedy and high risk Athel pine from Queensland (e.g. MGD and CHC), and Northern Territory, except from the lower FIN	$1,358,496	$27,170
	Control in South Australia	$1,145,048	$22,900
S11. prickly acacia	Eradicate from South Australian part of CHC	$10,000	$200
	Eradicate from Northern Territory part of MGD	$20,000	$400
	Prevent further spread southwards down the three big rivers (from Stonehenge on cooper system, converging Diamantina and Western and Wokingham creek, Boulia on the Georgina)	$32,052,078	$641,042
	Containment and progressive reduction of already infested areas - DEU, MGD, CHC	$12,579,442	$251,589
S12. GAB mound springs	Eradicate all invasive plants from the mound springs	$2,253,453	$43,069

5.2 Appraisal and ranked management strategies

5.2.1 ECOLOGICAL COST-EFFECTIVENESS OF STRATEGIES ACROSS THE BASIN

The total cost of the 12 invasive plant strategies was estimated to be $1.7 billion over 50 years. This expenditure is expected to prevent dominance of invasive species across approximately 17 million ha of the LEB, roughly 14% of the entire Basin. If only targeting Weeds of National Significance, the total estimated cost is estimated to be $113 million over the next 50 years (Table 1). The costs of controlling, eradicating and containing buffel grass were the most expensive, over $1.5 billion over 50 years, and was estimated to result in a reduction in buffel dominance of over a million ha in areas where this species is not commercially used.

Table 2. Appraisal of key invasive plant management strategies across the LEB – average of estimated expected benefits (reduction in total area potentially invaded by the invasive plant species in ha over 50 years, n = 1-6 experts per estimate, based on best guess, upper benefit estimates and lower benefit estimates), average annual costs (discounted) and cost-effectiveness (CE). Average annual costs were over the 50 years (some actions as indicated below were not costed over 50 years, but the values are shown this way for comparison purposes).

Rank (CE) Best guess	Rank (CE) Upper	Rank (CE) Lower	Strategies	Average benefits (dominated area avoided, ha) Best guess (Δ upper and Δ lower)	Average annual costs (50 years)
1 (40.8)	1 (42.3)	1 (28.8)	S3. parkinsonia	1659673 (+60527, - 487660)	$40,678
2 (19.1)	2 (22.7)	3 (13.3)	S9. chinee apple	34347 (+17040, -10507)	$1,797
3 (18.8)	3 (21.04)	2(14.0)	S2. mesquite	2119147 (+251786, -546974)	$112,681
4 (13.5)	4 (14.1)	4 (10.5)	S4. rubber vine	1247167 (+50299, -277007)	$92,301
5 (11.1)	5(12.7)	5 (7.8)	S6. bellyache bush	71050 (+10350, -21420)	$6,391
6 (10.6)	6 (12.7)	7 (6.0)	S11. prickly acacia	10110333 (+1869267, -4422467)	$955,678
7 (10.1)	7 (11.5)	6 (7.2)	S8. mother of millions	53649 (+7723, -14987)	$5,340
8 (6.6)	8 (7.1)	8 (3.30)	S10. athel pine	331307 (+18159, -168827)	$50,071
9 (0.7)	9 (0.9)	9 (0.5)	S7. cacti (e.g. coral, harissia, devils rope)	713967 (+127539, -200927)	$1,004,986
10 (0.03)	10 (0.04)	10 (0.03)	S5. buffel grass	1051712 (+32378, -174906)	$30,898,881

The parkinsonia strategy was predicted to be the most cost-effective strategy, followed by chinee apple, mesquite, rubber vine, and bellyache bush (Figure 3, Table 2). The cost-effectiveness rankings remained the same for all ten strategies when calculated with the best guess and upper estimates for expected benefits (Table 2), but did vary when calculated with the lower estimates. With the lower estimates for benefits parkinsonia was the most cost-effective strategy but mesquite was the second most effective followed by chinee apple, and mother of millions changed places with pricky acacia becoming the sixth and seventh most cost-effective. Chinee apple is the only species in the top five most cost-effective strategies that are not WONS (Thorp and Lynch 2000). Chinee apple's only know location is one property within the Mitchell Grass Downs. Experts agreed that both chinee apple and mother of millions (also not a WONS) were potential concerns and are both cost-effective strategies due to their current limited distributions, and potential to invade larger areas if left untreated. The highest potential biodiversity benefits were estimated for the prickly acacia strategy, but this was strategy was comparatively expensive, hence was ranked 6th (7th with the lowest biodiversity benefit estimates) across the LEB; whereas one of the lowest expected biodiversity benefits were estimated for Bellyache bush which was relatively cheap, and then ranked 5th across the Basin.

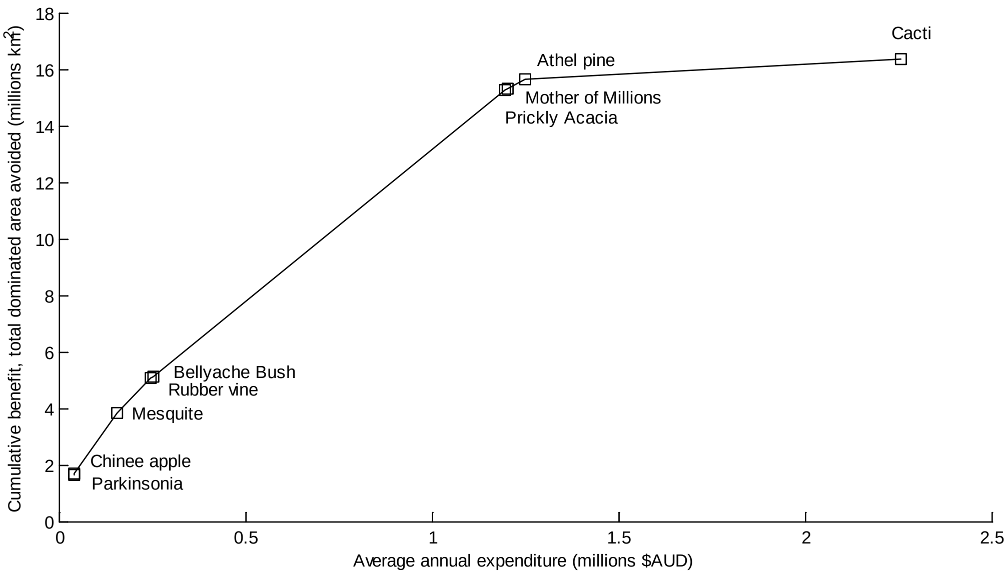

Figure 3. The cumulative amount of land area (ha) that not be dominated (>30% cover) by the top nine of the ten key invasive plant species at increasing levels of annual investment into invasive plant species control across the LEB. Buffel grass was not included in this figure because it's significantly higher cost masks the detail of benefits and costs of the other nine invasive plant strategies

The least cost-effective strategy across the LEB was investment in buffel grass, which is a reflection of the high cost of its control (estimated at $2000 per ha annually using manual and chemical measures (Friedel et al. 2009)), and the difficulty in successfully reducing the dominance of an invasive plant species with such an extensive distribution in gazetted conservation areas within Queensland and the Northern Territory where actions to control buffel grass were recommended (Table 2). There are also extensive areas of buffel grass seed sources from private properties where in many parts of the LEB it is regarded as a highly desirable pasture species (Friedel et al. 2009).

5.2.2 ECOLOGICAL COST-EFFECTIVENESS OF STRATEGIES WITHIN AND ACROSS BIOREGIONS

The top ten ranked strategies for cost-effectiveness across bioregions involved investment in invasive plant strategies in just three of the bioregions, i.e. Mitchell Grass Downs, Channel Country and the Desert Uplands. Overall the benefit per dollar of investing in parkinsonia actions in the Channel Country was expected to be the highest across the LEB bioregions, followed by parkinsonia in the Desert Uplands, and mesquite in the Mitchell Grass Downs (Table 3). Parkinsonia was the most cost-effective strategy in three of the bioregions, Desert Uplands, Channel Country and Broken Hill Complex. The prickly acacia strategy had the highest overall expected benefits in the Mitchell Grass Downs but was ranked 7th because of the high costs of the strategy and 9th (of a possible 34 strategies) when compared across bioregions. Athel pine had the highest expected benefit per dollar of investment in the Simpson Strzelecki Desert, Finke, MacDonnell Ranges and Stony Plains, but athel pine was the only strategy appraised in all of these bioregions, except the Stony Plains. Cacti strategies were estimated to have high costs and only moderate expected benefits and consequently were consistently the lowest ranked for cost-effectiveness within and across bioregions (Table 3).

We did not appraise the buffel grass strategy at the bioregion level, because of differences in how we were able to elicit costs. Experts were more comfortable estimating costs at the lower resolutions (e.g. state level or entire Basin) for buffel grass and not between bioregions.

Table 3. Appraisal of key invasive plant management strategy in each of the bioregions of the LEB – estimated average expected benefits (reduction in total area potentially invaded by the invasive plant species), average costs (discounted) and cost-effectiveness (CE). Not all strategies were costed within all bioregions, as not all invasive plant species can become established within each of the LEB bioregions, because of low and unpredictable rainfall and low nutrient edaphic conditions. Strategies were ranked based on their cost-effectiveness within each of the bioregions and also across all bioregions. The buffel grass strategy was not included in the bioregion level analyses.

Bioregions	Strategies	Rank CE within bioregion	Rank CE across LEB	Average benefits between experts over 50 years (ha)	Average Annual costs	CE
Mitchell Grass Downs	S2. mesquite	1	3	1536480	$43,226	35.5
	S3. parkinsonia	2	4	931200	$27,103	34.4
	S10. athel pine	3	6	32640	$1,712	19.1
	S9. chinee apple	4	8	23680	$1,797	13.2
	S11. prickly acacia	7	9	9600000	$829,783	11.6
	S4. rubber vine	5	11	187500	$19,203	9.8
	S8. mother of millions	6	22	1350	$3,968	0.3
	S7. cacti	8	33	175500	$811,090	0.2
Desert Uplands	S3. parkinsonia	1	2	162000	$3,355	48.3
	S8. mother of millions	2	5	28000	$1,372	20.4
	S6. bellyache Bush	3	12	61750	$6,800	9.1
	S4. rubber vine	4	13	400000	$53,896	7.40
	S2. mesquite	5	14	79800	$13,114	6.1
	S7. cacti	6	26	41000	$14,189	2.9
Channel Country	S3. parkinsonia	1	1	450000	$3,355	134.1
	S10. athel pine	2	7	104800	$6,292	16.70
	S4. rubber vine	3	10	196000	$19,203	10.20
	S2. mesquite	4	18	197333	$43,226	4.6
	S11. prickly acacia	5	25	373333	$125,894	3.00
	S7. cacti	6	34	14400	$107,431	0.1
Broken Hill Complex	S3. parkinsonia	1	21	8400	$2,288	3.7
	S10. athel pine	2	27	13067	$4,580	2.9
	S7. cacti	3	30	50667	$31,424	1.6
	S2. mesquite	4	32	20000	$13,114	1.53
Stony Plains	S10. athel pine	1	17	21067	$4,580	4.6
	S3. parkinsonia	2	20	8667	$2,288	3.8
	S7. cacti	3	23	3000	$9,427	0.3
Flinders Lofty Block	S3. parkinsonia	1	15	13600	$2,288	5.9
	S10. athel pine	2	24	14400	$4,580	3.1
	S7. cacti	3	31	48000	$31,423	1.5
Simpson Strzelecki Dunefields	S10. athel pine	1	28	11866	$4,580	2.6
Finke	S10. athel pine	1	19	32667	$7,915	4.1
MacDonnell Ranges	S10. athel pine	1	16	40000	$7,915	5.1
Burt plains	S10. athel pine	1	29	14000	$7,915	1.8
Tanami						
Mt Isa Inlier	S1 prevention and control programs for all invasive plants					

It was suggested that the majority of spending be invested in the semi-arid regions of the LEB, i.e. Mitchell Grass Downs, followed by the Desert Uplands and the Channel Country (Table 4). Cacti, athel pine and parkinsonia are the strategies with actions identified in the majority of the bioregions, and the majority of expenditure in the South Australian parts of the LEB.

Table 4. Summary of the average annual expenditure on each of the Invasive plant species strategies and the proportion spent on strategies in each of the bioregions.

MGD = Mitchell Grass Downs, DEU=Desert Uplands, CHC= Channel Country, BHC=Broken Hill Complex, STP= Stony Plains, FLB= Flinders Lofty Block, MCR= MacDonnell Ranges, SSD= Simpson Strzelecki Dunefields, FIN= Finke, BTP= Burt Plains, Tanami =Tan, MII = Mount Isa Inlier

Strategy	Proportional allocation to each bioregion (%)										
	MGD	DEU	CHC	BHC	STP	FLB	MCR	SSD	FIN	BTP	Tan, MII
S3. parkinsonia	67%	8%	8%	6%	6%	6%	-	-	-		S1 prevention and control programs for all invasive plants
S9. chinee apple	100%	-	-	-	-	-	-	-	-		
S2. mesquite	38%	12%	38%	12%	-	-	-	-	-		
S4. rubber vine	21%	58%	21%	-	-	-	-	-	-		
S6. bellyache bush	-	100%	-	-	-	-	-	-	-		
S11. prickly acacia	87%	-	13%	-	-	-	-	-	-		
S8. mother of millions	74%	26%	-	-	-	-	-	-	-		
S10. athel pine	3%	-	13%	9%	9%	9%	16%	9%	16%	16%	
S7. cacti (e.g. coral, harissia, devil's rope)	81%	1%	11%	3%	<1%	3%	-	-	-	-	

Strategy 12 was the eradication of all weeds in the GAB Mound Springs (Table 1). It was agreed by the workshop participants that to protect biodiversity within the LEB, a key strategy was to have zero tolerance for invasive plant establishment in the threatened ecological community, GAB mound springs, where endemic flora and fauna species diversity it at its highest and most endangered within the LEB (Fensham et al. 2007). Eradicating all invasive plant species including Date Palms from the GAB mound springs was predicted to reduce invasive plant dominance by 42% over 50 years, an estimate of approximately 420 ha of the 1000 ha of the GAB mound springs. We were unable to collect estimates of costs and expected benefits for this strategy within each bioregion and as it had a different objective, this strategy was not directly comparable to strategies 2-11.

5.3 Other co-benefits of strategies

Invasive plant species eradication, control and containment has the potential to contribute to a range of benefits other than our metric of reducing the land area dominated (>30%) by the invasive plant for biodiversity benefits. Grazing is the major land-use in the LEB at 82% of the land area (Herr et al. 2009). Weed control is estimated to cost more than $300 million per year in Australian livestock industries, but despite this substantial expenditure yield losses attributed to weeds continue to be more than $1.5 billion in this industry (Sinden et al. 2004). Therefore, investing in invasive plant control for biodiversity benefits will also have co-benefits for the livestock industry. Collectively five of the WONS identified as key strategies in the LEB, i.e. parkinsonia, mesquite, rubber vine, prickly acacia and athel pine make up more than 28% of the costs of weed control per year in Australia (Sinden et al. 2004). Another major benefit is the opportunity for Indigenous employment, often through Indigenous rangers, for weed control.

Important objectives in the LEB include the conservation of plants, animals, the integrity of vegetation communities, the achievement of more sustainable pastoral production for pastoralists, more sustainable tourism industries, improved carbon sequestration and conservation and land management goals by Indigenous people (these may diverge from those we use due to different knowledge and value systems, many of which may be location specific) (Kiri-ganai Research Pty Ltd 2010).

Increasing evidence is showing that reducing the dominance of an invasive plant species and increasing native species diversity can have added benefits for many key ecosystem services (Isbell et al. 2011) including nutrient cycling , carbon sequestration, drought tolerance, hydrological flows and resilience to changing perturbations such as the ability of a plant community to recover after fire (MacDougall et al. 2013). Recent research has shown that high species numbers are needed to maintain all of these ecosystem functions and services over the long-term and that monocultures of species are less resilient.

5.4 Recommendations for implementation and monitoring

This project was unable to quantitatively consider the effectiveness of current or future management delivery models, although this is a crucial component of successful invasive species control and eradication for biodiversity benefits. Through discussions with experts, it was highlighted that a useful outcome of this work would be to establish pathways to integrate the process, and the priorities that resulted from the process, into further planning and prioritisation approaches, especially at more regional and local scales. In particular, the Lake Eyre Basin Intergovernmental Agreement was highlighted as being a critical avenue for the adoption of weed management implementation strategies. As part of the Agreement, the Ministerial Forum has the power to adopt management plans prepared by the States if those are consistent with the Agreement and with Policies developed or adopted by the Ministerial Forum. A strategy adopted by the Ministerial Forum under its 'Water and Related Natural Resources Policy' is to "(i)identify opportunities for improved coordination and consistency of approaches to aquatic and terrestrial weed and feral animal management activities". The Lake Eyre Basin Rivers Assessment (LEBRA) also forms an important component for integrating the information discovered in this project. The information collection and monitoring required and recommended as part of these weed management strategies could be implemented through the LEBRA, which aims to assess the condition of catchments across the Basin under the Agreement. At regional scales, further important avenues for integrating this research include the state, local government, NRM region, catchment and even property level planning that is undertaken at various levels of governments, NGOs, landholders and management groups.

Strategy one recommended a prevention and monitoring program for all weeds that included mapping, monitoring and surveillance (ground and aerial) and centralised information sharing for weed incursions/extents (without identifying properties). During the course of this study, we found sourcing data on the current and potential distributions of the invasive plant species difficult, even at the coarse spatial-scale of bioregion. The reliability of these data was identified as an issue by several participating experts. On one hand this is a caveat and on the other an important outcome of the study and suggests that additional workshops be held to elicit from experts the distributions of invasive plants in their local areas. Based on our discussions with experts during and following the workshop, we found information on current and potential distributions was known personally by land managers for respective localities and it would be highly valuable to record this information with the aim of making it centrally available. Because invasive plant infestations change over time, increasing and decreasing in size, it may also be valuable to produce an interactive tool that provides opportunities for managers to update this information as populations change in their local areas. Because many of these invasive plant species have the capacity to spread across catchments, along roads and via animal movements, it seems imperative that having reliable data on the locations of invasive plants is essential to be able to prioritise management across the LEB.

We also recommend that additional information be tested and collected on optimal control and eradication strategies for buffel grass. Buffel grass is the most widely distributed exotic species across the LEB and for rangelands it is considered a valuable species, but in conservation areas it can have serious negative impacts on biodiversity (Griffin 1993, Friedel et al. 2006, Grice et al. 2012). The strategy for containing and locally eradicating buffel grass was a challenge to cost based on expert knowledge, possibly because of the dual nature of this species as a valued pastoral grass and environmental weed. Based on our conversations with experts, it appears that control and eradication programs for this species, in conservation areas, are growing rapidly and that information on the most cost-effect strategies for this species will continue to develop over time. Given improved methods for controlling buffel grass, and improved knowledge of its impacts, buffel grass management may become a more cost-effective option in the future.

Because uncertainty exists about most conservation strategies including the best measures to control and eradicate invasive plant species, an adaptive management framework is essential. This is a "learning whilst doing" approach, where actions are monitored and strategically altered as the responses of the system to management becomes better understood (McCarthy and Possingham 2007). Working with a variety of landholders and land managers will be necessary to achieve invasive plant species control for the benefits of native plants and animals. A well-coordinated implementation strategy will also increase the likelihood of producing broader benefits and opportunities arising from carrying out the various invasive plant species strategies. We recommend that an implementation strategy and adaptive management framework be developed in collaboration with stakeholders.

5.5 Caveats

It was necessary to make a range of assumptions and generalisations for these analyses. These include simplifications for the analysis and caveats on the best available data, as follows:

- We assumed that dominance of habitat by one weed has an equal impact to dominance by another and that a cover of greater than 30% of each weed was a threshold to indicate that the weed has dominated an ecosystem and had a biodiversity impact. In reality a variable range of impacts would occur prior to and beyond this binary threshold, depending upon weed type, ecosystem type, existing dominant and threatened species, and other threats.
- Our analysis assumed that all strategies have an equal chance of being implemented, provided the resources were available. Experts chose strategies that would be implemented, resource-permitting, with a few exceptions: for example an organic farmer may be reluctant to spray a weed and lose their certification. In these cases, the cost-effectiveness of the weed management strategies that are less likely to be implemented may have been over-estimated.
- We were unable to include in our analysis the potential interactions between strategies in terms of changing the expected benefits and costs of strategies. In many cases weed management would be carried out for more than one weed at a time. In these cases the cost-effectiveness of carrying out weed management strategies that can be done in tandem would be under-estimated.
- Although we used the best data available on the current and potential distributions of invasive plants in each of the LEB bioregions, these data were most often based on simple occurrence values over coarse resolutions. It was generally acknowledged by all participating experts that knowledge of the distributions of invasive plant species is patchy and unreliable, evidenced by the recommendation of strategy 1 that included the centralisation of mapping, monitoring and surveillance (ground and aerial) building on the weed spotters network and information sharing for weed incursions/extents.
- The strategies focus mainly on the current invasive plant species problems within the LEB, with the exception of chinee apple and mother of millions (comparatively small populations exist presently with the LEB) were identified as future potential future problems. Over a 50 year time period, other invasive plant species may become issues, which again makes strategy 1 key for responding quickly and anticipating future problem plant species.
- Most of the information used in these analyses is based on the knowledge of experts that may or may not include beliefs formed on the basis of published, peer-reviewed scientific research.
- For many of the actions, costs were uncertain and real costs may prove to be higher or lower than predicted.
- The 'without strategy' scenario is theoretical as there is management currently occurring in some of the actions we identify and additional actions may be planned, however the goal of our analysis was to demonstrate potential cost-effectiveness of strategies compared with not implementing strategies, to enable their relative values to be assessed.
- We assumed strategies could be funded or not funded and there may be relationships between cost-effectiveness and increased funds to up-scale management intervention (as more funds are put into an action, the probability of success and expected benefits of the action may also increase, which make change the cost-effectiveness ranking).

- We have assessed only 12 strategies, which focus on 10 weed species; however there are a number of other weeds and a range of other non-weed related threats that we were unable to consider, which are also impacting in the Basin and may interact with weed management.
- There are many uncertainties in future conditions for undertaking invasive plant species control and eradication in the LEB, such as the consequences of climate change and future developments not considered in the analysis, which would likely compound existing threats. A precautionary approach suggests that we should increase investment early, monitor and review the effectiveness of actions and be aware of emerging threats.

Our analyses are likely to be robust in terms of the relative cost-effectiveness for the reduction of dominance for the 10 invasive plant species included in the analyses. The cost-effectiveness ranks were robust to experts' uncertainty in their expected benefit estimates. Our method is explicit, systematic, knowledge-based, and can be updated as improved information on the costs and expected benefits for invasive plant management become available.

6 Concluding remarks

Invasive plant species establishment, dominance and spread is a serious concern across the LEB, being identified as a priority issue for management within the Lake Eyre Basin Rivers Assessment implementation plan (Kiri-ganai Research Pty Ltd 2010). Ecologically, the high impact of invasive plant species within the LEB is surprising given its highly unpredictable "boom and bust" climate. Despite these severe climatic constraints, many exotic plant species have been able to colonise and successfully build up dominant populations particularly within the semi-arid bioregions of the LEB (> 240 species and 20 WONS; CSIRO and QUT 2013). Because of the difficult terrain and remoteness of the majority of the LEB, invasive plant species eradication, control, containment and monitoring is difficult and expensive. Despite this challenge, the experts participating in this study felt it was imperative that we protect the LEB from invasive plant species, as it is comprised of some of the rarest, and least exploited ecosystems on the planet.

The science we present is designed to support decision-makers and to add to existing initiatives to manage invasive plant species such as the Weeds of National Significance program (Australian Weeds Committee 2012). The results are intended to provide a basis for securing ongoing funds to manage weeds in accordance with the final priorities that will be set by the LEB stakeholders. The intention is also to help guide further information collection, in particular for implementing the Lake Eyre Basin Rivers Assessment, in terms of monitoring the condition of catchments within the Basin.

We intentionally provide a flexible approach that can be updated as more information becomes available or as situations change, so that the priorities identified can be integrated with existing and future priority setting approaches, including the planning carried out at national down to property scales, by federal and state governments, natural resource managers, conservation organisations, Traditional Owners and other land managers.

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CONTACT US

t 1300 363 400
+61 3 9545 2176
e enquiries@csiro.au
w www.csiro.au

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FOR FURTHER INFORMATION

Queensland University of Technology
Jennifer Firn
t +61 7 31389016
e jennifer.firn@qut.edu.au
w www.qut.edu.au

CSIRO Ecosystem Sciences
Josie Carwardine
t +61 7 38335682
e josie.carwardine@csiro.au
w www.csiro.au/people/Josie.Carwardine.html