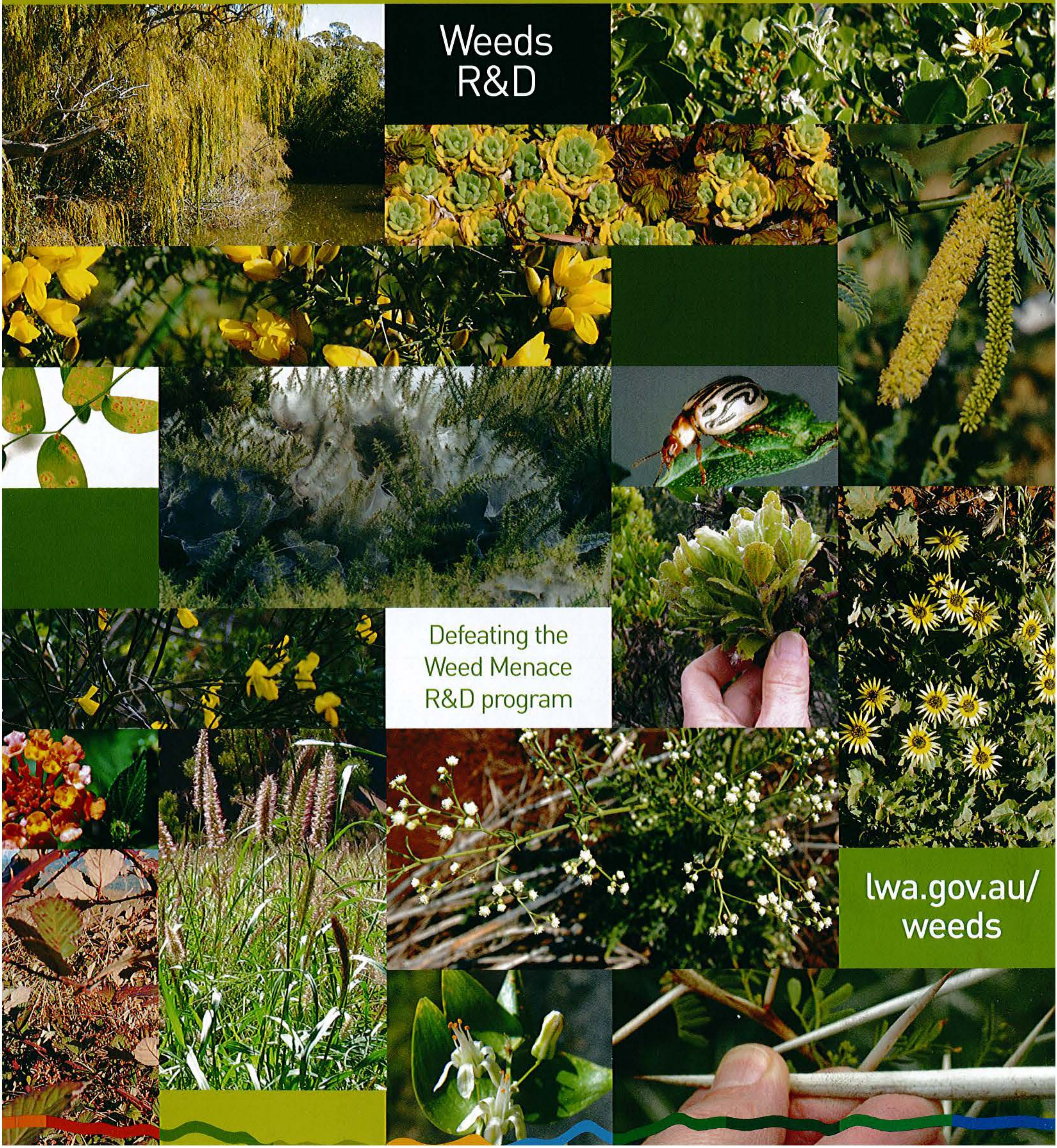
Australian Government
Land & Water Australia

Weeds R&D



Defeating the Weed Menace R&D program

lwa.gov.au/weeds

The Defeating the Weed Menace R&D program is funded by the Australian Government

Printed on Revive Silk Cover which is a FSC Mixed Source Certified, 50% recycled paper. It also contains elemental chlorine free pulp derived from sustainably managed plantation forests and non controversial sources.

Published by: Land & Water Australia
Web: www.lwa.gov.au
ISBN print: 978-1-921544-87-3
ISBN electronic: 978-1-921544-88-0

This publication can be ordered free of charge from CanPrint Communications, freecall: 1800 776 616, or e-mail: lwa@canprint.com.au and quote product code **PN30081**

Design: Angel Ink
Print: Paragon Printers, June 2009

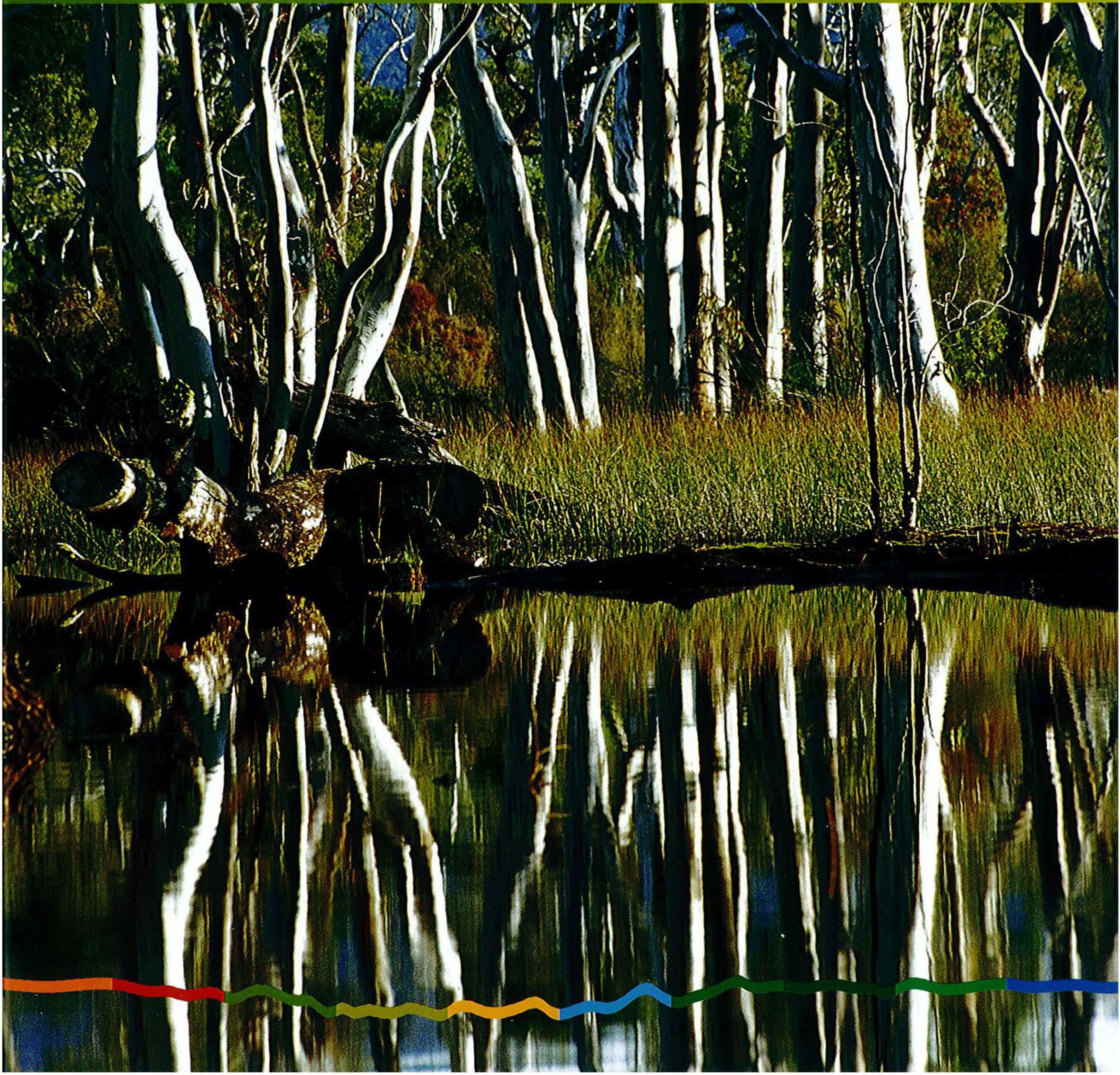
LWA project code CEN6

Australian Government
Land & Water Australia

CSIRO

Weed management on floodplains: A guide for natural resource managers

Kate Stokes and Matthew Colloff, CSIRO Entomology



Introduction

Landscapes and ecosystems are composed of complex networks of interactions; consequently the effects of management actions can be unpredictable. In dynamic floodplain systems a wide range of changes, acting through a diversity of different processes, increase the abundance of weed establishment, proliferation and spread within native plant communities (Table 1). Sustainable weed control is likely to be easiest to achieve if management actions are conducted within the scope of broader floodplain management goals. The overall goal may contain a combination of the following: to restore a particular ecosystem service, production value, functional or species diversity, community structure or conservation of a particular species of concern.

Front cover photo Alison Pouliot. Above: Floodplains support unique vegetation communities such as these river red gum forests and Moira grass plains at Barmah forest. Photo Keith Ward, Goulburn Broken Catchment Management Authority (GBCMA).

Weeds as symptoms or causes of ecosystem change?

Directly targeting invasive floodplain weeds may not lead to a shift in the ecosystem to a more desirable state for a number of reasons. Firstly, the weed species may not be a causal agent of change in the ecosystem, but instead may be a symptom of underlying processes of ecosystem degradation, such as pollution and excessive water extraction (see Table 1). Secondly, the management regime itself may promote re-invasion by the same or different species. Thirdly, recovery of native vegetation may be dependent on an ecological process, such as the supply of plant seeds to suitable germination habitat. Management objectives may not necessarily involve reduction of the population density of the invasive species directly, but instead may involve alteration of the outcomes of species interactions (e.g. competitive exclusion), or manipulation of physical factors (e.g. flood regimes), to promote suitable conditions for native plant species to germinate and reproduce.

Table 1. Human-mediated changes to riparian vegetation that potentially lead to degradation, with special emphasis on changes potentially promoting the establishment, proliferation and spread of invasive alien plant species. Adapted from Richardson et al. (2007) with permission. See glossary (page 15) for terminology.

Type of change	Processes affected	Effects favouring establishment, proliferation and spread of alien plants
River regulation	• Altered flood regime • Altered propagule dispersal regimes • Altered geomorphology	• Increased availability of recruitment sites in space and time • Changes in plant competition • Reduced dispersal of native species down rivers • Altered sediment dynamics
Water extraction	• Reduced flow • Altered flood regime • Altered propagule dispersal regimes	• Alterations in plant competition • Increased availability of recruitment sites in space and time • Reduced dispersal of native species down rivers
Agriculture	• Altered nutrient cycling • Increased soil erosion • Decreased connectivity for dispersal and migration • Reduced buffering capabilities	• Alteration of sediment dynamics • Conduit for alien species dispersal • Reduced propagule pressure (native plants) • Increased edge effects
Clearing riparian vegetation	• Altered nutrient cycling • Altered disturbance regimes • Reduced bank stability • Damaged buffering capabilities	• Altered vegetation functioning • Increased space for colonisation • Altered lateral seed dispersal potential
Planting alien species	• Altered propagule dispersal (lateral and longitudinal) • Altered nutrient cycling • Altered water use and flow regimes • Reduced buffering capabilities	• Introduction of propagules (alien species) • Alterations in plant competition • Alteration of sediment dynamics
Invasion of other alien species	• Altered ecosystem functioning and successional trajectories • Increased fire risk and intensity • Reduced buffering capabilities • Synergisms (invasional meltdown)	• Alteration of vegetative communities • Alteration of sediment dynamics • Increased facilitation of alien species invasion
Pollution	• Altered nutrient cycling • Reduced fecundity and increased mortality	• Alterations in the outcome of plant competition
Grazing and trampling (local-scale effects)	• Compaction and reduced bank stability • Reduced vegetation cover • Increased nutrient input • Reduced buffering capabilities	• Altered regeneration niches • Introduction of propagules • Increased space for regeneration • Altered plant competition
Altered fire regime	• Increased mortality of native species • Altered nutrient cycling • Reduced buffering capabilities	• Alteration of regeneration niches • Alteration of riparian structure and function
Global climate change	• Altered flow regimes • Increased amplitude of flood events	• Alteration of vegetation communities • Increased long-distance propagule dispersal

Biotic strategies of resilience and disturbance

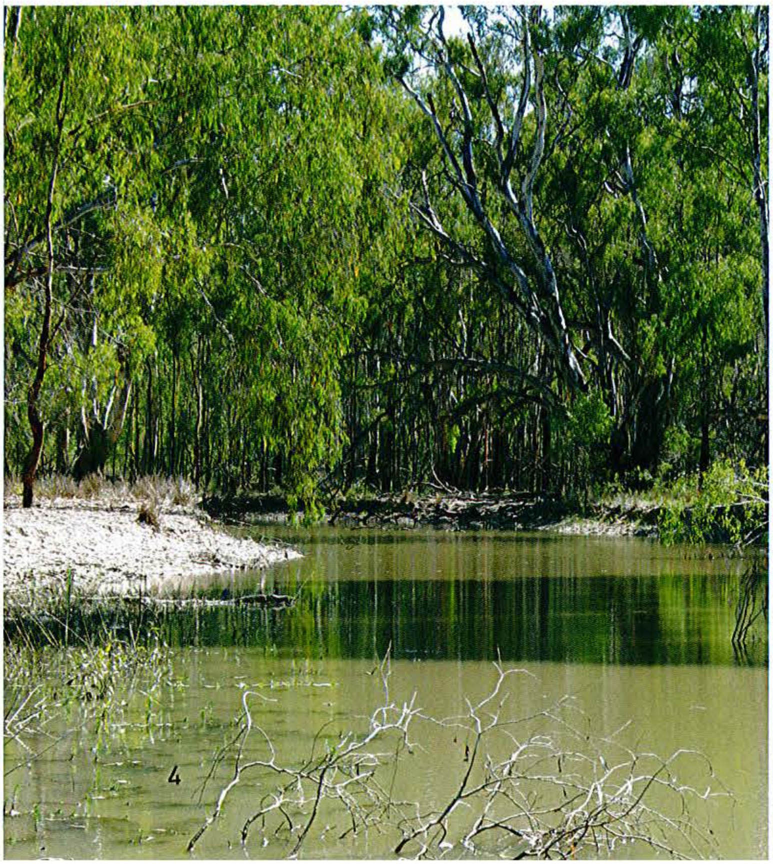
Resilience is the natural capacity of an ecosystem to recover from an alteration, or the adaptation to a regular disturbance. Disturbance is a natural or artificially imposed perturbation of the system.

Changes in the frequency, duration, depth and spatial extent of flooding are forms of disturbance that can have significant implications for wetland and aquatic habitats. Disturbance is a complex structuring mechanism, on the one hand it facilitates co-existence and maintains biodiversity by increasing opportunities for adapted natives to establish, whereas on the other hand changes to, or newly imposed disturbance, can create conditions that favour the dominance of one species over others. The effect disturbance has on species richness will vary depending on its inherent frequency, intensity, duration, timing and scale. The species that assemble after a disturbance event will also depend on the characteristics of the individual ecosystem, including the composition of the seedbank, resource availability and the outcome of species interactions.

Predicting future alterations to vegetative community composition following disturbance events, and the consequences of such alterations is a key priority for managers. Unfortunately, changes to natural flood regimes and the invasion of weeds have altered the natural pattern of species succession in floodplain communities, making prioritisation of future management plans a difficult process. In addition, climate change is predicted to alter trends in the frequency and size of future flood events in south-east Australia, with consequent effects for ecosystem functions and processes. In this context native plant species can actually become invasive under the altered conditions, as they begin to appear in areas where they have historically been absent. Understanding and forecasting changes in plant communities, ecosystem properties, and their associated services requires a mechanistic link between community shifts and modifications in ecosystem properties.

This guide describes a management protocol that aims to link the disturbance ecology of invasive weeds to management strategies, by investigating the benefits of incorporating actions that manipulate disturbance (natural or artificial) into control efforts. The factors influencing floodplain vegetation composition are discussed and conceptual models outlined, followed by a generalised framework for designing and implementing monitoring programs to assess ecological responses resulting from specific management actions, focusing on the impacts of alterations to environmental flows on floodplain weeds as an example.

Slow flows in floodplain creeks may promote colonisation by aquatic weeds such as Sagittaria. Photo Kim Pullen, CSIRO Entomology.



River channels act as dispersal conduits

Dispersal of propagules (plant seeds and vegetative units) in water is determined by the hydrological regime during seed release and transport, as well as hydrological connectivity within the landscape. River channels can act as conduits, transporting plant propagules to new locations. This is important when considering the potential success of controlling weed species, or the re-establishment of native vegetation. For example, the arrival of particular weeds in low lying catchments can sometimes be predicted from their abundance at higher elevations. This is demonstrated in Figure 1 opposite, which shows the chronological spread of *Phyla canescens* (Lippia), a low-growing plant that forms extensive mats preventing colonisation by other species. Initial records (pre-1950) show this weed had limited distribution in the north-east of Queensland and in the high elevation Alpine area on the border between Victoria and New South Wales.

Figure 1. Spatial point records of the distribution of lippia in the Murray-Darling Basin recorded over time. Photo Guy Roth.

Later records show the encroachment of the plant, southwards and westwards into the Murray system, with some early records (1951–70) occurring at the confluence of the Darling and Murray Rivers. Lippia is capable of regenerating from detached plant fragments which re-root at downstream locations following flood events. Whilst there are no records of lippia occurrence in the Darling River, it is highly probable that their absence is due to the low frequency of surveys conducted in this area, rather than true absence. The spatial patterning of the invasion over time, linked with knowledge of reproductive ability and dispersal capacity, indicate that invasion of the River Murray occurred due to the downstream transport and establishment of fragments.

The importance of hydrogeomorphic processes in creating habitat for floodplain vegetation communities

Flood disturbances can both scour substrate and deposit sediment of various sizes. Many floodplains represent a shifting mosaic of landforms created by hydrogeomorphic processes. Depending on the degree of erosion or deposition, floods can cause breakage and uprooting of plants and burial of established vegetation. This selects for plant species which can tolerate these physical conditions.

The importance of life history strategies

Plant life history strategies (e.g. growth form, seed size, dispersal mode, flowering period) determine whether, where and when a floodplain plant can colonise a site. In many floodplain communities the relative importance of sexual versus vegetative reproduction and seed banks versus seed dispersal in recruitment dynamics is poorly known. For species adapted to floodplains, opportunities for recruitment occur mostly after flood events, when new sediment is deposited or available gaps open up in the existing vegetation due to flood damage. To successfully recruit from seed in the post-flood environment, either the reproductive phenology (seasonal timing) must correspond to the flooding season, so that seeds are dispersed into a favourable germination environment, or else the species requires a propagule bank, such as a persistent soil-stored seed bank, that may be triggered following a flood or rain event.

Different types of habitat that can be expected in floodplain environments mean that plants have to be adapted to reproducing in a diverse range of hydrological conditions. Common reed photo (below) Alison Pouliot.

Post-germination fate of seedlings often explains much of the variation in species distributions. In humid areas establishment success depends on the maintenance of low water levels during germination and seedling establishment, whereas in semi-arid areas water availability and the rate of decline of the water table limit establishment. The recruitment of later successional species may be uncoupled to flood events because in these species success is contingent on life history characteristics adapted for the ability to germinate in the shade of established vegetation.

A general conceptual model to predict the organisation of plant communities on river floodplains should include the following factors and their effects on habitat characteristics and plant communities.

- the physical constraints that influence river floodplains (i.e. the scouring and depositing character of flood disturbances)
- the frequency and intensity of disturbances that limit competitive interactions and create gaps for recruitment of new individuals
- the specific life-history traits that allow plant maintenance, recruitment and colonisation in floodplains subject to differing degrees of disturbance.

Key ecological processes that potentially influence plant communities and related plant strategies are shown in Figure 2.

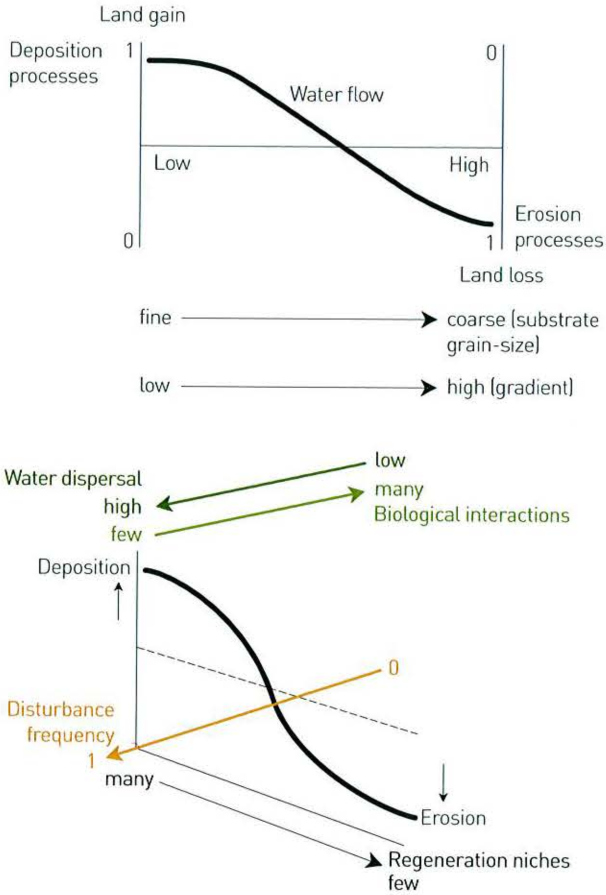
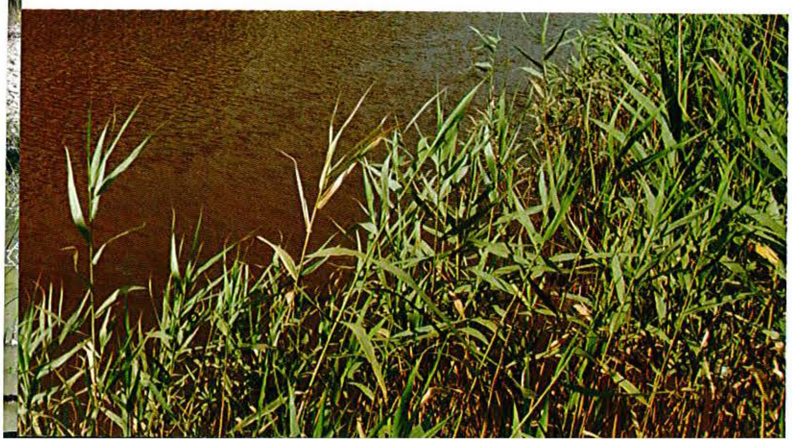


Figure 2. A conceptual model showing the hydrological and ecological processes that hypothetically control floodplain plant communities. The top figure shows deposition and erosion processes, the two main types of process that occur in floodplain landscapes. Depending on water flow, landscape gradient and grain size, land may be either lost through erosional processes, or deposited due to sediment accumulation. The bottom figure includes ecological processes resulting from the interaction of land loss or accumulation with the frequency of flooding events (disturbance frequency). During high flood frequencies dispersal of plant propagules is high, as is the potential for seeds to recruit in regeneration niches. Biological processes like plant competition are more important when the landscape is disturbed less frequently. The model is adapted from Bornette et al. (2008).



Droughts are a more frequent occurrence in recent years. Photo Alison Pouliot.

Measuring resilience in floodplain plant communities

Floodplains are dynamic systems. Measuring resilience in terms of species composition is therefore difficult in these frequently disturbed communities and is not necessarily indicative of changes underlying ecosystem structure or function. Measures of ecosystem functions themselves are expensive and time consuming to collect. Plant functional traits (PFTs) provide an alternative ecological tool indicating plant community response to variation in ecosystem attributes and processes that is largely independent of species composition. PFTs are species traits associated with reproduction, colonisation and growth. They may include factors such as flowering period, dispersal mode, seed mass, growth form, or tolerance to inundation. PFTs are not direct measures of ecosystem function, but have previously been used successfully to infer underlying ecological processes and to examine the effects of disturbance, such as fire and grazing on plant communities. Additionally, PFTs can be compared over large and disjunct geographical regions, as well as across considerable temporal scales. Finally, using a core set of PFTs allows for widespread comparisons between separate datasets and studies. The case study on the following pages illustrates how knowledge of the PFTs of floodplain plant communities both pre- and post-degradation can be used to highlight potential changes in ecosystem function, and prioritise rehabilitation efforts.

Photo Alison Pouliot.

Barmah-Millewa forest: an iconic river red gum site. Photo Keith Ward, Goulburn Broken Catchment Management Authority.

Case study: Barmah-Millewa forest

This study was conducted in the Barmah-Millewa forest, an extensive floodplain and wetland system that historically flooded in winter/spring and dried in late summer/autumn. Barmah forest is now a remnant river red gum dominated floodplain covering approximately 25,900 hectares, located between the townships of Tocumwal and Echuca. It is reserved as State Forest (72% of the area), State Park (26%) and Murray River Reserve (2%).

Barmah-Millewa forest is part of the traditional country of the Yorta Yorta people and has great conservation, heritage and amenity value. The Murray-Darling Basin Commission has identified part of the forest as a Significant Ecological Asset, and the site is listed as a Wetland of International Importance under the Ramsar Convention.

Changes in river flow at the site are due to upstream storages and releases, as well as local manipulation of regulators, all of which collectively affect floodplain inundation. Analyses (Abel et al. 2006, VEAC 2006) have identified the following:

- reduced frequency, duration and inundation area of winter-spring floods
- altered timing of flows
- increased frequency of small summer floods
- reduced variability in flood flows.

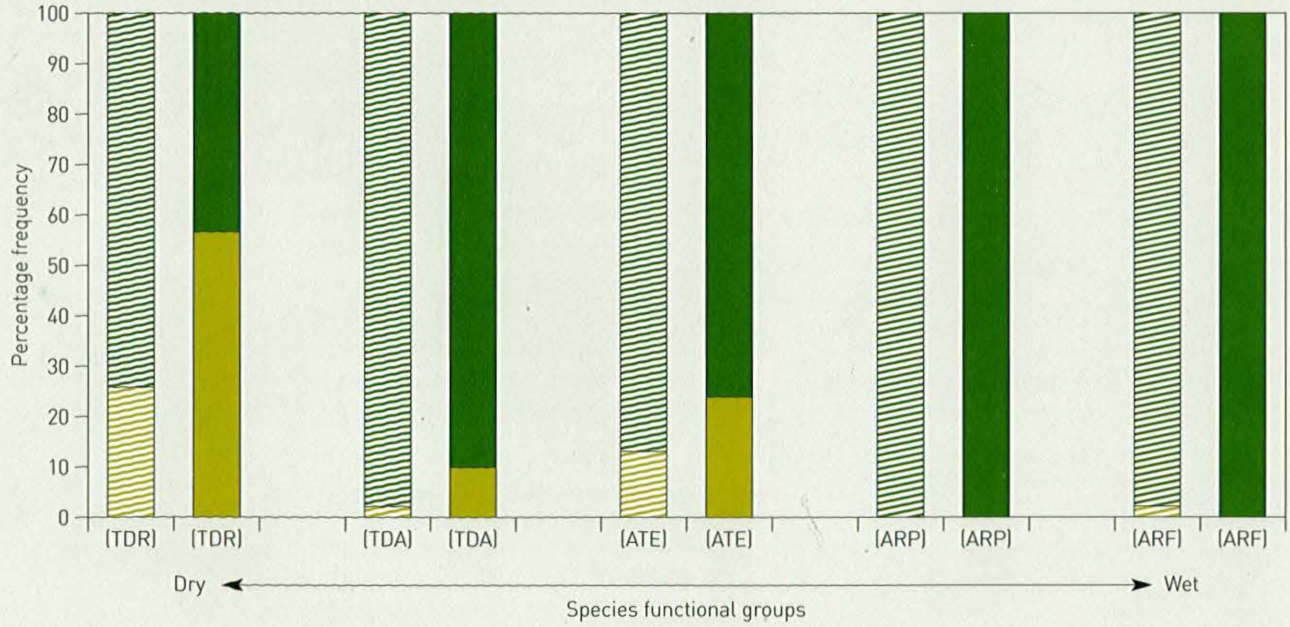
Vegetation surveys were conducted in Barmah forest in 1993/94 and 2006/07 (Ward 2007). Given that the vegetation dynamics and patterning in floodplain and wetland areas are primarily influenced by water regimes, a functional trait classification that groups species in terms of their water regime requirements for germination and establishment would be most appropriate. Ideally a vegetation classification should represent the heterogeneity of the vegetation (both species compositional and structural) at a resolution relevant to management. A hydrological classification scheme for vegetation produced by Casanova and Brock (2000) is described opposite. Exotic and native species surveyed over the 14 year time period at Barmah forest were classified under this scheme, prior to conducting statistical analyses on the results.

Results from this study indicate that a shift has occurred from native plant species in amphibious fluctuation tolerator and responder groups, which have the ability to germinate in flooded conditions and reproduce vegetatively, to exotic weed species in terrestrial dry and damp groups, which can germinate when the water table is below the surface of the soil, and mainly reproduce from seed. The ecosystem level implications of this trait shift are increased existence of durable seed banks composed of exotic species, resulting in a potentially persistent problem for site managers.

Table 2. Categories developed by Casanova and Brock (2000), from field surveys and experiments, including examples of native and exotic species found in Barmah assigned to those categories.

Primary category	Secondary category	Description	Indicative native species for Barmah
Terrestrial	Dry species (Code = TDR)	Species which germinate, grow and reproduce where there is no surface water and the water table is below the soil surface.	*Austrodanthonia setacea* Bristly or Mulga wallaby grass
Terrestrial	Damp species (Code = TDA)	Species which germinate, grow and reproduce on saturated soil.	*Amphibromus nervosus* Swamp wallaby grass
Amphibious fluctuation tolerators	Emergent species (Code = ATE)	Species which germinate in damp or flooded conditions, which tolerate variation in water level, and which grow with their basal portions underwater and reproduce out of water.	*Phragmites australis* Common reed
Amphibious fluctuation responders	Morphologically-plastic species (Code = ARP)	Species which germinate in flooded conditions, grow in both flooded and damp conditions, reproduce above the surface of the water and which have morphological plasticity (e.g. heterophylly — different types of leaves formed under dry or submerged conditions) in response to the surface of the water level.	*Myriophyllum crispatum* Curling water milfoil
Amphibious fluctuation responders	Species with floating leaves: (Code = ARF)	Species which germinate in flooded conditions, grow in both flooded and damp conditions, reproduce above the surface of the water, and which have floating leaves when inundated.	*Nymphoides crenata* Wavy marshwort

Figure 3. Mean changes in abundance (number of quadrats occupied) for five plant functional groups in Barmah forest between 1993/94 and 2006/07. Functional group codes are as in Table 2 above. Proportional frequency is represented by dashed lines in 1993/94 and solid colours for 2006/07. Exotic species are coloured in the light green and native species in the darker green.



Translating scientific knowledge to management processes

Due to the diversity of land uses in floodplain systems the management of invasive species is a frequent cause of conflict because perceptions of costs and benefits differ among stakeholder groups. Conflicting interests and perceptions make it challenging to develop and implement sustainable management practices for invasive species within an integrated natural resource management framework. As the range of environmental problems continues to grow, scientists and managers are forced to attempt prediction and management of only the most immediate problems that command their attention. A more structured response requires the adoption of a management framework that can encompass ecosystem change, and in some cases, pragmatic acceptance of invasive species as part of ecosystem dynamics. Such a management system must allow change within a range of predefined limits of acceptability, whilst also effectively highlighting where these limits are broken and action is required.

To successfully manage floodplain environments several issues will need to be addressed, including the control of feral animals, weeds, erosion, fire and salinity. However, most of these issues are closely related to delivery of environmental water. For example, flooding can be an efficient way of controlling the growth of weeds. In order to achieve appropriate flow regimes for a specific floodplain region five main requirements will have to be met.

- Delivery of a sufficient overall volume of water.
- Delivery of water at appropriate rates of flow.
- Ensuring that floods persist for appropriate periods of time.
- Delivery of water at appropriate times of year.
- Delivery of water at appropriate times between years.

Lack of scientific knowledge regarding the exact quantification of these five requirements in relation to ecological responses is one factor impeding effective water delivery. However, there are also a number of interacting physical, social, political and institutional impediments to achieving a flow regime which maintains the products, attributes and functions of floodplain wetlands. Stakeholders with an interest in water resource management will increasingly expect to see evidence of the environmental or ecological response of floodplain systems to implemented environmental flow regimes. Monitoring and assessment of controlled manipulations are therefore essential to ensure that a management program can be evaluated in relation to the goals that were originally proposed.

The flow diagrams on the following pages are intended to help better understand the relationship between management actions and ecological responses, including their inherent uncertainties.

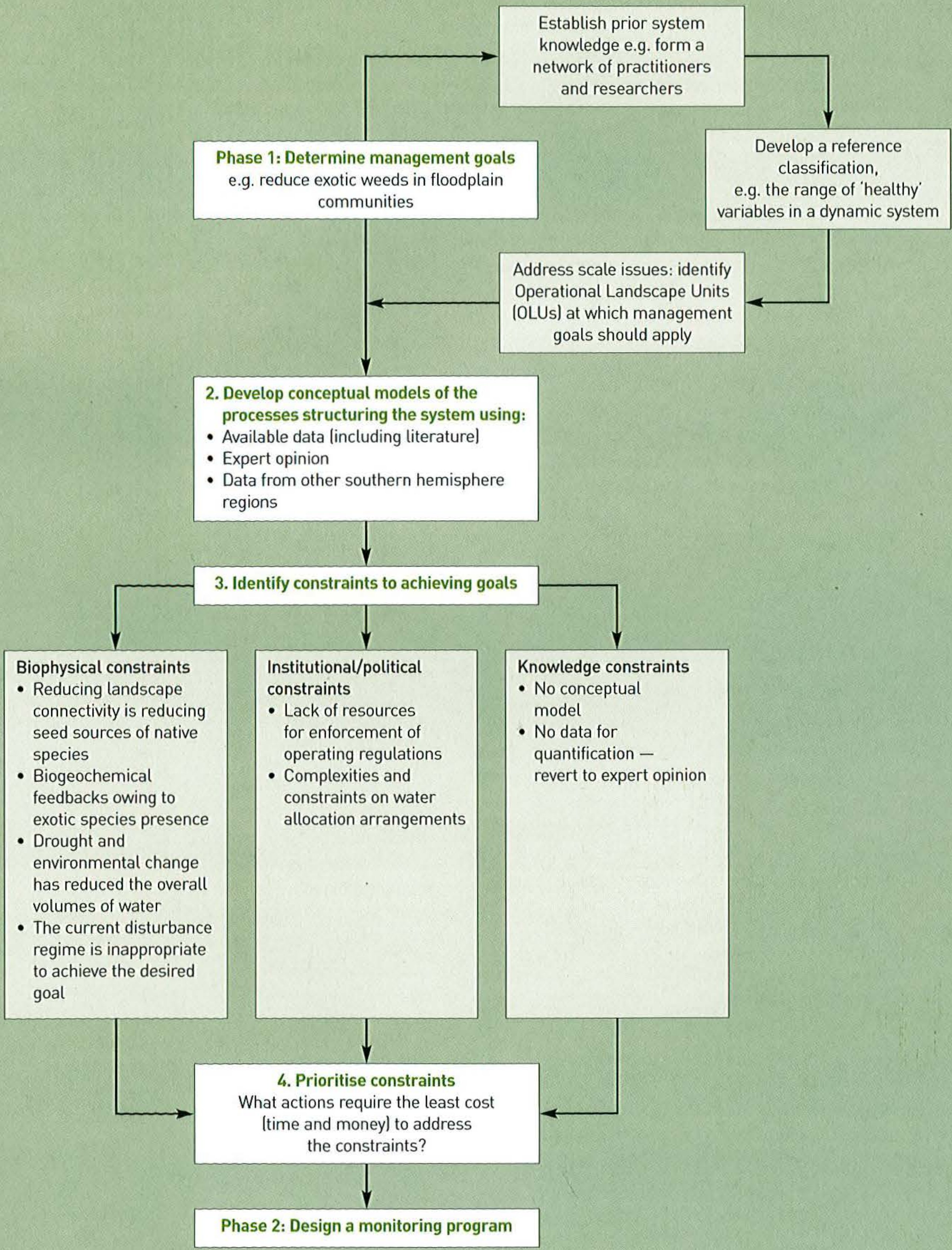
- **Phase 1** involves determining the management goals (e.g. reduction of exotic weeds) (Figure 4),
- **Phase 2** involves developing a monitoring program compatible with the study design (Figure 5).
- **Phase 3** involves characterising the changes, documenting the available evidence of success (and/or failure) of management interventions and distributing the results to stakeholders (Figure 6).

In the floodplain context, a conceptual model is of benefit to provide a reference for the range of key system variables that can be considered "healthy". This step can be initiated jointly between practitioners and researchers, in order to incorporate experiential knowledge within the context of the specific geographical regions from which the knowledge was derived. This is particularly important in cases where the implicit knowledge of managers is difficult to quantify (i.e. "it works but we don't know why it works").

Connectivity and Operational Landscape Units (OLUs)

Goal setting is not a trivial exercise and care needs to be taken to ensure that the spatial scale at which goals are to be evaluated and maintained is appropriate. One approach is to attempt to identify Operational Landscape Units (OLUs), defined as combinations of landscape patches with associated biotic and hydrogeological connections (Verhoeven et al. 2008). The aim is to combine ecological knowledge on the spatial requirements of species with the spatial distributions and connections of ecosystem processes, in order to develop more effective regional conservation strategies. An OLU then represents the totality of patches in a landscape

Figure 4. Decision tree for determining management goals (Phase 1)



mosaic over which the management strategy must be implemented. If data are available, a good variable to structure an OLU around is the degree of hydrological connectivity during flooding. Floodplain inundation models can be used to specify the geographic area which is inundated at specified river flows (e.g. see RiM-FIM model for the River Murray, Overton et al. 2006). Dispersal of plant propagules is facilitated by moving water and knowledge of the degree of landscape connectivity would indicate the spatial extent at which management has to be coordinated in order to restore seed sources for native species, or reduce upstream populations of exotics.

Once goals have been determined the factors inhibiting success must be examined. These constraints may be biophysical, political, or knowledge-based (see Figure 4). Prioritising constraints indicates which goals are feasible. Therefore the combination of landscape components into OLUs may differ for different conservation or management targets, depending on the nature of the flow component and the ecological processes.

Developing a monitoring program that evaluates the success of management actions

Floodplain interactions can be conceptualised in models developed from specific knowledge of the system, the scientific literature, or models relevant to similar types of rivers and floodplains. The different components and links in a model are likely to have varying levels of associated uncertainty. The level of uncertainty and the temporal scale of predicted ecological responses to changes in the flow regime are important to consider when developing a monitoring program (Figure 5). Monitoring programs must be flexible when selecting variables to measure the response to management actions, such as an alteration in environmental flows. Selection of relevant variables must also be sufficiently diverse to detect undesirable outcomes from the management action. This framework does not include specific instruction on variable selection but guidance can be obtained from resources such as the ANZECC and ARMCANZ (2000), and Baldwin et al. (2004).

Separating changes in ecological condition due to a direct management action (e.g. enhanced environmental flows) from other natural or human induced variability (e.g. stock grazing changes) requires an understanding of conditions both before and after environmental flows are delivered. In some situations "before" data are not available. In this case, establishing spatially replicated control sites allows "intervention" versus "control" sites to be contrasted over time (see Figure 5).

An important point to consider is determining the size of the ecological responses. This is the data that provides evidence that the management action delivered the predicted response. For example, if an environmental flow objective is to restore native plant communities, then measurable targets might include targets of abundance (e.g. 50% increase over three years), frequency of successful recruitment (e.g. annual) and spatial extent (range) over which the recruitment is expected. The smaller the likely effect size, the greater the sampling intensity and resources required to detect it. Therefore the challenge is to ensure the effect size to be measured is congruent with the resources available to measure it. Ecological responses are non-linear in nature (i.e. large responses may result from relatively small changes in flow regimes, or conversely, large changes to the flow regime may be required before an ecological response is detected). Additionally, uncertainty surrounding potential responses is likely to be high, emphasising the need for conceptual models and adaptive management processes.

The final phase of this process is to evaluate the success of the management action in terms of the original objectives (Figure 6). This may involve re-evaluating the conceptual models that form the basis of the monitoring and assessment program, or the constraints that are inhibiting progress towards goals. It is important that this learning step is undertaken in order to refine the program and improve understanding of flow-ecology relationships. A manager may need to compare the benefits of different potential actions within a continually shifting cost-benefit framework, so priorities require constant re-assessment in the light of new evidence.

Finally, shared insights should be documented and disseminated to help improve adoption and implementation.

Figure 5. Decision tree for developing a monitoring program (Phase 2)

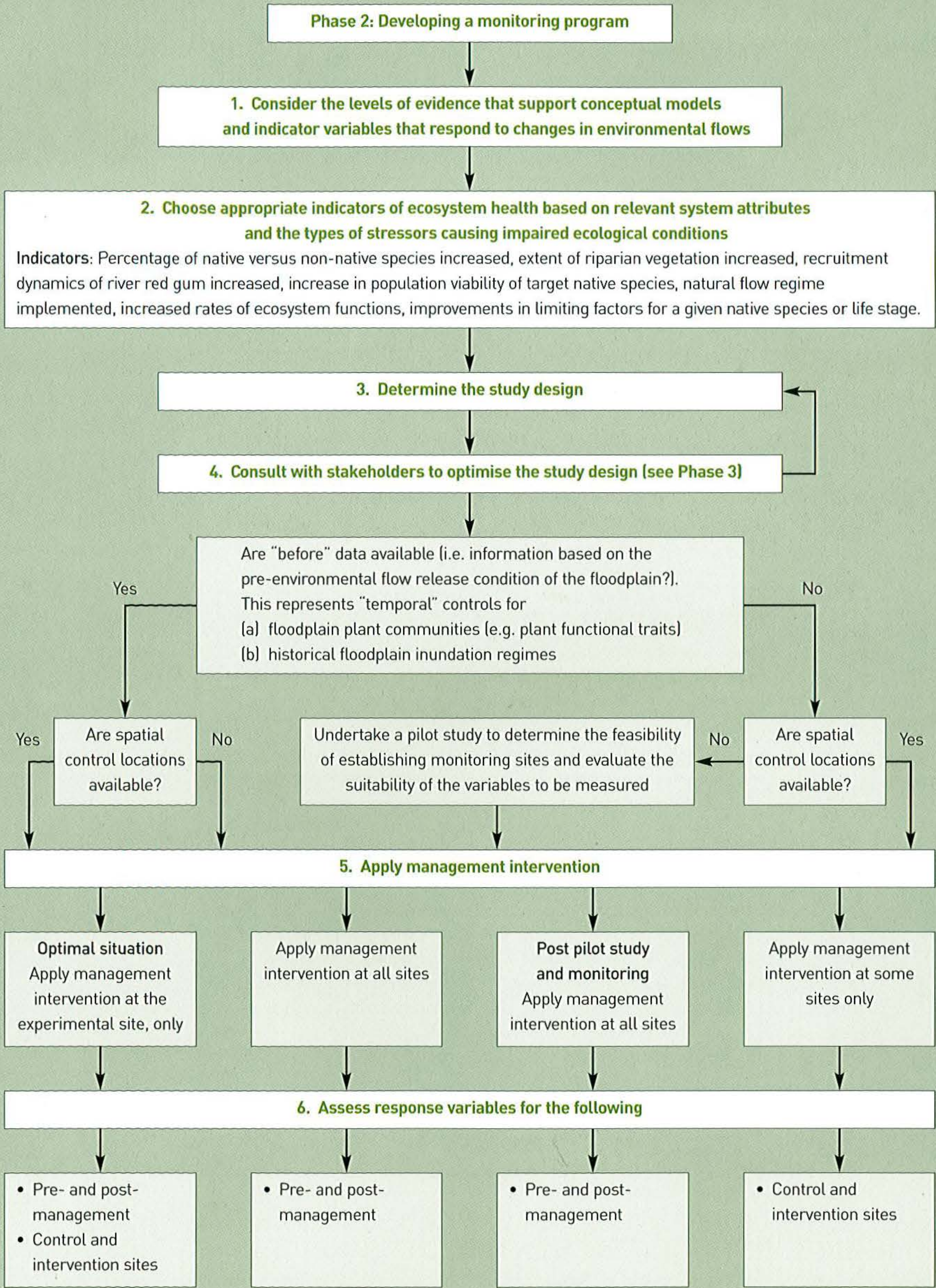


Figure 6. Decision tree for assessment of change (Phase 3)

Phase 3: Characterising the changed system

1. Consult with stakeholders to optimise the monitoring process

Agreement has to be reached within stakeholder groups on the following design specifications for evaluating the success of the management goals.

- What is the duration of the sampling design?
- What is the spatial extent of the sampling design?
- On what basis is the frequency of sampling proposed?
- Has the effect size been determined?

The effect size is the size of the ecological response to be detected by the monitoring and evaluation program. This decision will almost certainly require input from a stakeholder group because there is likely to be a high degree of uncertainty in establishing "threshold" effect sizes of importance due to limited data availability.

2. Implement the monitoring program

3. Re-evaluate constraints and goals

- Do constraints remain?
- Have new constraints emerged?
- Is the goal still feasible?
- Has the cost benefit ratio changed over time?

4. Evaluate process understanding in the context of the conceptual models

The system should require minimal on-going intervention and have the capacity to recover from natural disturbances such as floods.

- Are the effect sizes still consistent with the conceptual model framework?
- Can the conceptual models be quantified in view of the monitoring results?

Indicators: few interventions needed to maintain site, scale of repair work required is small, documentation exists that ecological indicators stay within a range consistent with reference conditions (see Phase 1) over time.

5. Document all available evidence that the management intervention has succeeded in achieving the goal

Levels of evidence will vary (see Phase 2) but documentation of preconditions and post assessment should be provided and disseminated. This helps to reduce some of the institutional constraints described in Phase 1.

6. Distribute evidence to stakeholders in appropriate formats

We thank Judy Lambert (Community Solutions) for improving the manuscript, Keith Ward (GBCMA) and Kim Pullen (CSIRO) for providing photographs, and the Land & Water Australia Defeating the Weed Menace Program team — Jim Donaldson, Judy Lambert, Nolani McColl, Teresa Oppy and Nadeem Samnakay — for their support, encouragement and collaboration.

Glossary

Buffering capability: the capacity of riparian vegetation to protect aquatic environments from excessive sedimentation, polluted surface run-off and erosion.

Edge effect: the difference in ecological attributes between the centre of an area of habitat and its margins, due to the juxtaposition with a different habitat.

Invasional meltdown: process by which a group of species facilitate one another's invasion in various ways, increasing the likelihood of survival and/or of ecological impact.

Lateral linkages: linkages between floodplains and the river channel.

Longitudinal linkages: linkages between upstream and downstream river sections.

Landscape connectivity: the degree to which the landscape facilitates or impedes movement among resource patches.

Propagule pressure: the frequency with which plant reproductive units (seeds or clonal fragments capable of regenerating and forming new individuals) arrive at recruitment sites.

Propagule dispersal: the distance that plant propagules are transported prior to recruitment.

Recruitment sites: spatial habitat areas providing physical sites for plant reproduction.

Regeneration niche: the component of the niche of a plant that is concerned with processes such as seed production and germination, and by which one mature individual is replaced by another.

Resilience: the ability of an ecosystem to return to its former state following a disturbance or stress, or the time required to return to its former state.

Riparian vegetation: vegetation that grows along the banks of rivers, lakes or watercourses.

Successional trajectories: the direction of changes in the composition or structure of an ecological community.

Further reading

Abel, N., Roberts, J., Reid, J., Overton, I. O'Connell, D., Harvey, J. & Bickford, S. 2006, *Barmah Forest: a review of its values, management objectives and knowledge base*, Report to the Goulburn-Broken Catchment Management Authority, CSIRO, Canberra, 204 pages.

ANZECC & ARMCANZ 2000, *Australian Guidelines for Water Quality Monitoring and Reporting*, Australian & New Zealand Environment and Conservation Council and the Agriculture and Resource Management Council of Australia and New Zealand.

Baldwin, D., Nielsen, D., Bowen, T. & Williams, J. 2004, *Recommended Methods for Monitoring Floodplains and Wetlands*, Murray–Darling Freshwater Research Centre report to the Murray–Darling Basin Commission, Canberra.

Bornette, G., Tabacchi, E., Hupp, C., Puijalon, S. & Rostan, J.C. 2008, 'A model of plant strategies in fluvial hydrosystems', *Freshwater Biology*, vol. 53, pp. 1692–1705.

Casanova, M.T. & Brock, M.A. 2000, 'How do depth, duration and frequency of flooding influence the establishment of wetland communities?', *Plant Ecology*, vol. 147, pp. 237–250.

Overton, I.C., McEwan, K. & Sherrah, J. 2006, *The River Murray Floodplain Inundation Model — Hume Dam to Lower Lakes*, CSIRO Water for a Healthy Country Technical Report, CSIRO, Canberra.

Palmer, M.A. et al. (20 authors) 2005, 'Standards for ecologically successful river restoration', *Journal of Applied Ecology*, vol. 42, pp. 208–217.

Richardson, D., Holmes, P.M., Elser, K.J., Galatowitsch, S.M., Stromberg, J.C., Kirkman, S.P., Pyšek, P. & Hobbs, R.J. 2007, 'Riparian vegetation: degradation, alien plant invasions, and restoration prospects', *Diversity and Distributions*, vol. 13, pp. 126–139.

VEAC 2006, 'Water Resource Use and Environmental Flows', *River Red Gum Forests Investigation Discussion Paper*, Victorian Environmental Assessment Council, Melbourne, Victoria.

Verhoeven, J.T.A., Soons, M.B., Janssen, R. & Omtzigt, T. 2008, 'An Operational Landscape Unit approach for identifying key landscape connections in wetland restoration', *Journal of Applied Ecology*, vol. 45, pp. 1496–1503.

Ward, P.A. 2007, *Monitoring understorey vegetation response to flooding in Barmah Forest: 2006/7 Final Report*, Consultant report prepared as part of the Living Murray project MD815 for the Murray–Darling Basin Commission, Canberra.

PRODUCED BY LWA'S WEEDS R&D PROGRAM. FUNDED BY THE AUSTRALIAN GOVERNMENT'S DEFEATING THE WEED MENACE PROGRAM.

For more information e-mail: Kate.Stokes@csiro.au
or see the website lwa.gov.au/weeds

This and previous page, photos Alison Pouliot.

Printed on Revive Silk which is made in Australia from elemental chlorine free pulp with 65% derived from sustainable plantation forests and 35% recovered fibre. It is PEFC Certified and Australian Paper is an ISO 14001 certified mill which utilises renewable energy sources.

Published by: Land & Water Australia
Web: www.lwa.gov.au
ISBN print: 978-1-921544-63-7
ISBN electronic: 978-1-921544-64-4

This publication can be ordered free of charge from CanPrint Communications, freecall: 1800 776 616, or e-mail: lwa@canprint.com.au and quote product code **PN22370**

Photos: Front page, Alison Pouliot
Design: Angel Ink
Print: Paragon Printers, June 2009

LWA project code CEN20

Australian Government
Land & Water Australia

CSIRO

Prevention and management of aquatic plant invasions in Australian rivers

Lauren D. Quinn, Shon S. Schooler and Rieks D. van Klinken

The issue

Australian river systems are threatened by the severe effects of drought, bank erosion, sedimentation, pollutant inputs, urban development, and invasions by exotic aquatic plant species. Invasive aquatic plants are known to increase evaporative losses, reduce dissolved oxygen availability, slow flows, degrade habitat for native flora and fauna, compete with native vegetation, and disrupt recreational activities. Their impacts may go further than we know, as aquatic plant species tend to be under-studied in Australia. For example, it is thought that mat-forming floating species, like *Salvinia molesta* (floating) or *Cabomba caroliniana* (submerged), may provide habitat for disease vectors such as mosquitoes, but this hypothesis has not yet been studied.

Pictured below: *Egeria densa* (dense water weed) and *Salvinia molesta* (giant salvinia) on an oar in a dam near Brisbane. These aquatic weeds impede recreational activities.

CSIRO researcher Lauren Quinn counts aquatic weed species in a dam near Brisbane.

Currently, five aquatic or semi-aquatic species are listed as Weeds of National Significance (WoNS), and many others are considered noxious species in one or more states. Localised and severe outbreaks of these species occur in Australian river systems, requiring costly chemical, mechanical, and biological methods of removal. Chemical control is challenged by restrictions against contamination of drinking water supplies, so the range of available herbicides is smaller than in terrestrial systems. Where allowed, herbicides can achieve effective control, but often require repeated application. Also, large quantities of biomass decomposition following herbicide application can cause secondary problems that affect native fauna. Mechanical control methods are similarly challenged. Harvesting machinery can be prohibitively expensive, and manual removal is extremely labour-intensive. Because many invasive aquatic plant species spread by vegetative propagation and display extremely rapid growth rates, mechanical control often requires repeated effort. Finally, plant invasions are often merely symptomatic of larger environmental problems and unless the underlying issues are addressed, management efforts and expenditures become ineffective in the long term.

It is imperative that we provide better solutions for prevention and control of invasive aquatic plants. For example, if we can identify the environmental factors that correlate with their presence and abundance, we can predict the locations most susceptible to invasion and manage resources to prevent and limit invasive species in those locations. In the following pages, we provide critical results from our studies and literature review, and list management recommendations based on our science.

Predicting invasions: knowing where to look

Large outbreaks of aquatic invasive plants receive high priority for management response, but some effort must be directed towards early detection of incipient invasions as well. Unfortunately, because aquatic plants tend to be patchily distributed in Australian rivers, new invasions can be difficult to detect. Because council weeds officers are often charged with monitoring large areas, it is imperative that their early detection efforts are concentrated where the risk of introduction and subsequent establishment is greatest.

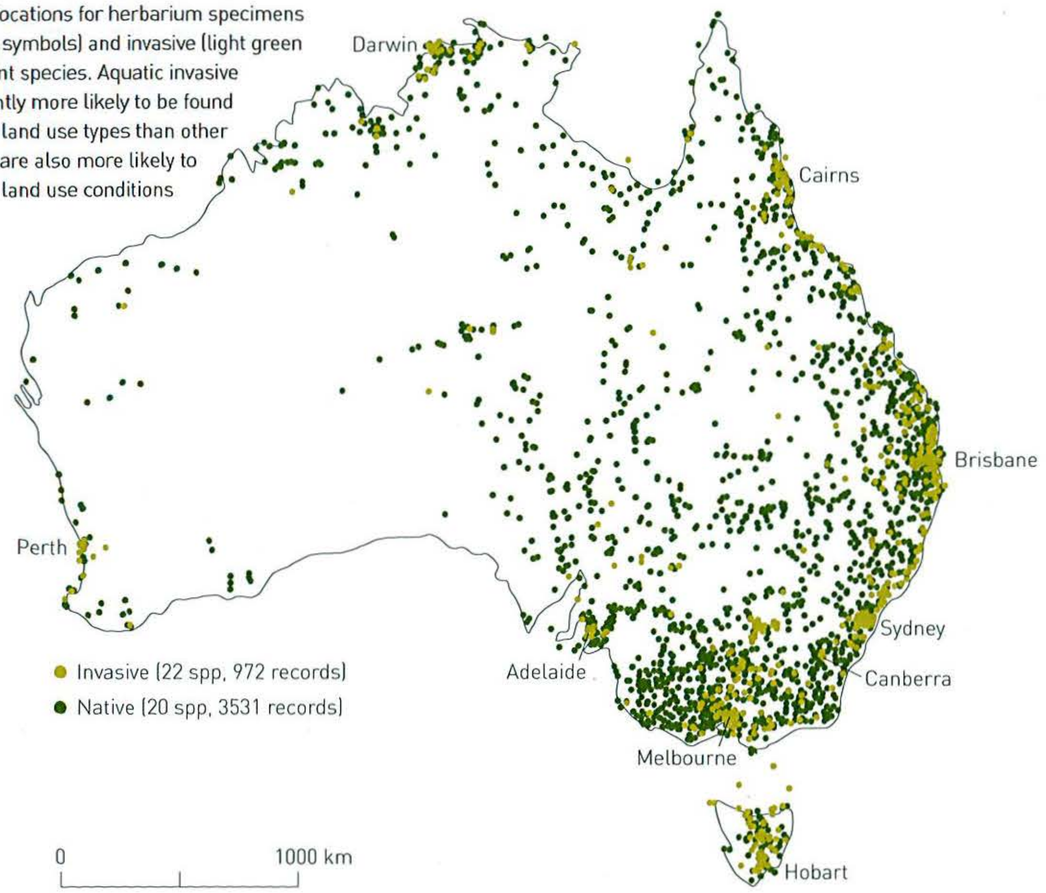


Figure 1. Collection locations for herbarium specimens of native (dark green symbols) and invasive (light green symbols) aquatic plant species. Aquatic invasive species are significantly more likely to be found in urban or intensive land use types than other land use types. They are also more likely to be found in intensive land use conditions than are natives.

Land use is relatively easy for managers to observe, and can act as a proxy for underlying environmental properties. Not surprisingly, distribution and abundance of invasive aquatic plant species is related to land use, with urban or intensive land uses hosting a greater abundance of these species. On a continental scale, most aquatic weeds can be found clustered within 10–25 km of urban city centres, and are more abundant in residential, commercial, and transport land uses (see figures 1 and 2). Aquatic weeds appear to prefer the environmental conditions typical of these intensive land use types, but it is also probable that these locations receive more propagule inputs than undisturbed areas. Invaders do, however, occasionally establish in relatively remote and undisturbed locations.

Targeting urban land use areas and selected sites in undisturbed areas in early detection programs may help limit new invasions.

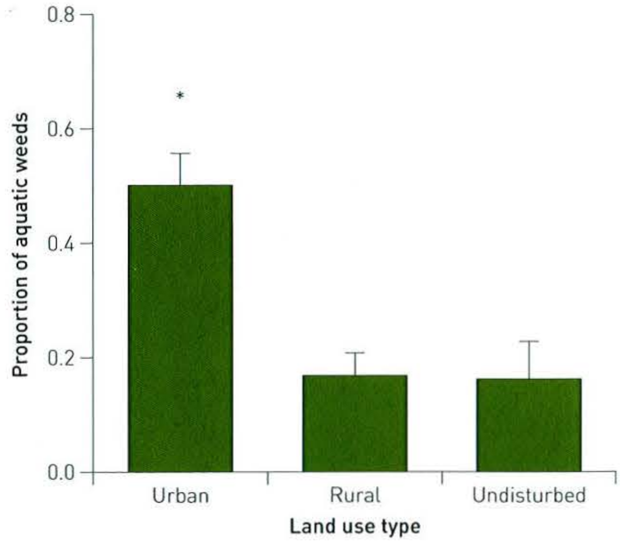


Figure 2. Proportion of the aquatic plant community that is made up of weed species. Mean values are shown for each of three land use types surveyed outside four Australian capital cities (Brisbane, Canberra, Hobart, and Melbourne). Urban sites had significantly greater proportions of weed species.

Management recommendation 1: Managers should focus early detection efforts near city centres, but remain vigilant for spread into more distant locations.

Preventing invasions: managing the environment

In addition to large-scale land use patterns, we know that invasive aquatic plant species become more abundant in response to specific environmental factors, including high light intensity, warm water temperatures, and high levels of dissolved nutrients, especially phosphorus and nitrogen. If management plans include modification or removal of factors that favour invasions, long-term control becomes more efficient and effective.

Because riparian shading appears to discourage aquatic weed growth (see figure 3), riparian restoration should be prioritised on a catchment scale. Intact riparian forests reduce light intensity and water temperatures, especially in smaller streams where channels are relatively narrow. Riparian forests provide additional large-scale ecosystem services beyond their capacity to discourage aquatic weed growth. Restoring these forests could buffer nutrient pollutant inputs into streams, stabilise streambanks to reduce sediment flows, and provide habitat for native fauna.

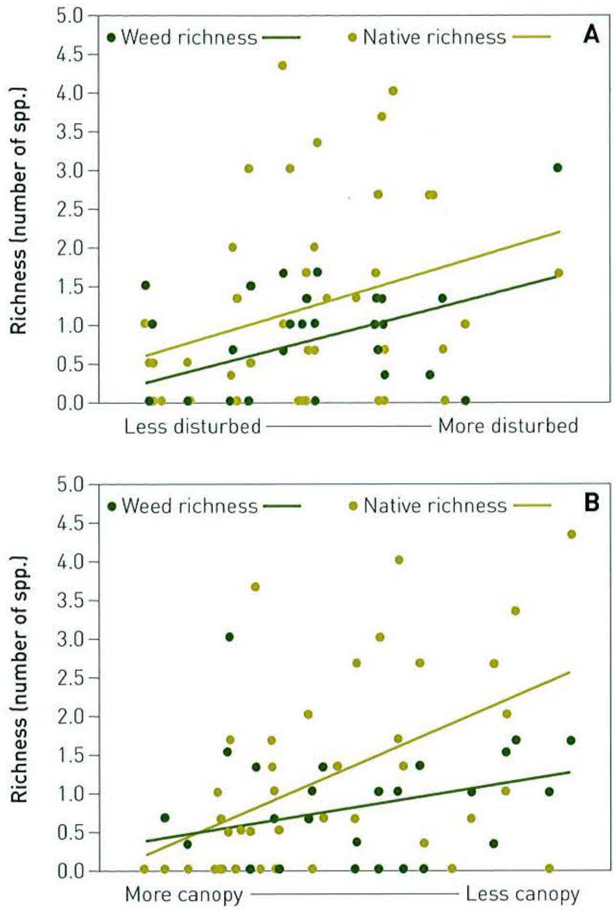


Figure 3. Aquatic plant community response to (A) anthropogenic disturbance and (B) shading from riparian canopies.

Below. A peri-urban sampling location near Melbourne. Many peri-urban sites have experienced similar reductions in riparian forest cover, which can result in proliferation of both aquatic and terrestrial invasive plant species.

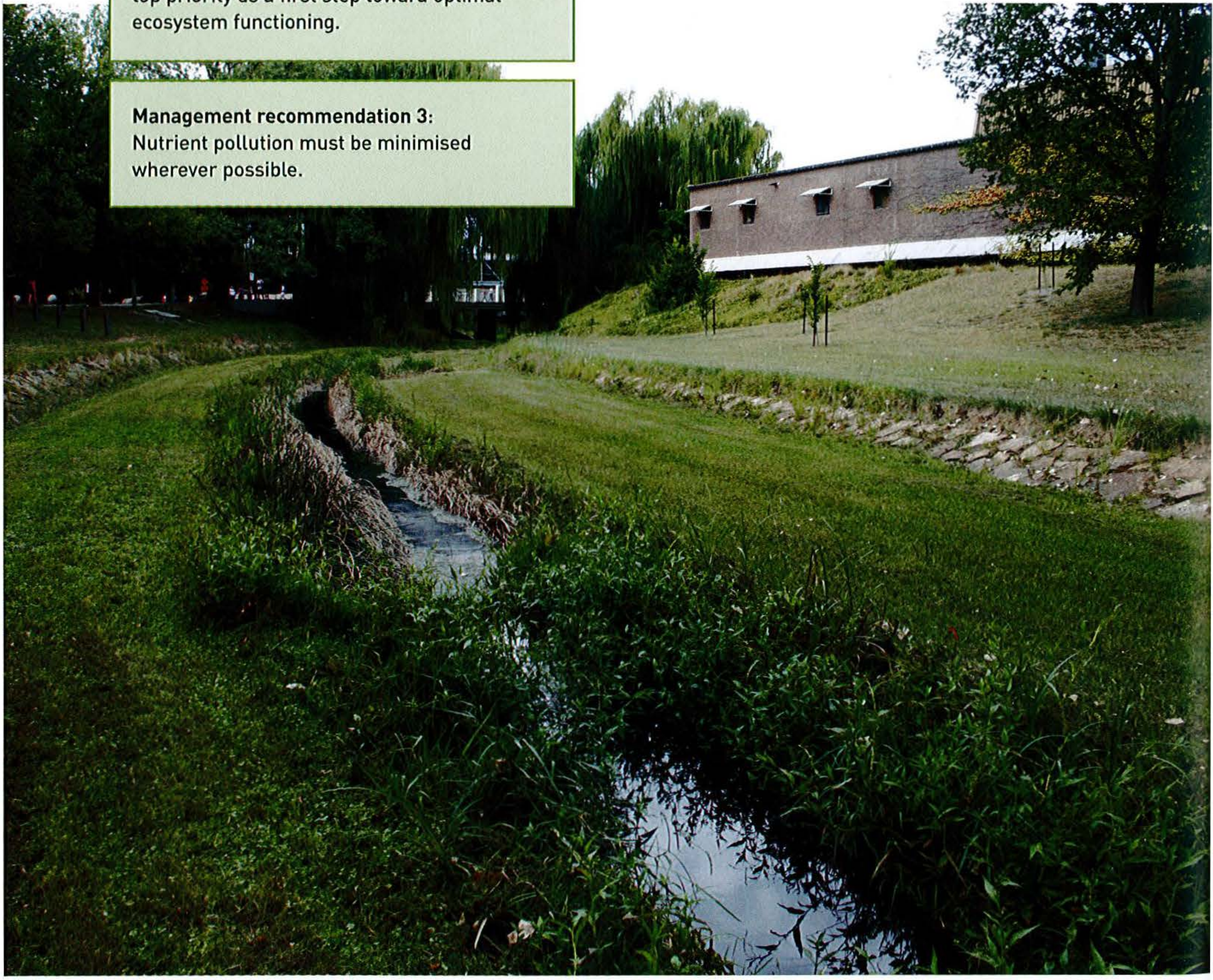
While restoration of riparian forests should result in reductions in nutrient pollutant inputs in the long term, sources of these inputs should be identified and managed in the near term. Non-point source pollution is difficult to manage, but known sources of nutrient inputs (e.g. farms, nurseries, feedlots) should be encouraged to better manage nutrient inputs and riparian erosion (e.g. more efficient fertiliser application, holding ponds for runoff, and fencing off of streambanks from stock).

Management recommendation 2:
Riparian restoration should be given top priority as a first step toward optimal ecosystem functioning.

Management recommendation 3:
Nutrient pollution must be minimised wherever possible.

Management challenges and future work

Effective river management is challenged by the flowing and interconnected nature of these systems. If aquatic weeds are not managed throughout the catchment, upstream infestations will act as sources of viable propagules to localities susceptible to invasion downstream. For this reason, it is extremely important for managers to look outside their immediate jurisdictions to consider catchment-wide issues and solutions. This will require regional prioritisation of funding for large-scale revegetation projects and setting of policy with regards to agricultural practices.



An example of an urban sampling location. Many urban waterways have been heavily modified (in this case, channelised for stormwater drainage), which can result in optimal conditions for aquatic weed invasions.

Aquatic weed management is also challenged by the continued influx of new propagules. The aquarium trade has been implicated in introductions of aquatic weeds in local waterways, often as a result of the "humane" disposal of aquarium contents by individuals, but sometimes purposefully planted in natural areas for later sale to aquarium shops. The National Aquatic Weeds Coordinator works with nurseries to voluntarily curb the trade of particularly invasive aquatic species, but further action should be taken to educate consumers about which species are invasive prior to purchase and the proper disposal of aquarium material.

Management recommendation 4:
Cooperation and coordination of management efforts should occur in adjacent council units throughout catchments. Control methods that are effective at large spatial scales (e.g. biocontrol) should be adopted wherever possible.

Management recommendation 5:
Aquatic plant retailers (nurseries, pet stores, web retailers) should be encouraged to distribute educational materials to consumers on the proper disposal of aquarium contents.

In conclusion

While invasive aquatic plants are a serious concern in Australia's waterways, we can target invasion-susceptible locations in early detection efforts and manage resources for long-term control. Because integration of effort is required on a catchment scale, coordination of policy must occur on a regional and, sometimes, interstate level. In this fact sheet we present five recommendations that will increase the effectiveness of regional management of aquatic weed species. Added benefits are improved water quality, the protection of habitat for endangered native aquatic species, increase in public amenity values, reduced risk of flooding and infrastructure damage, and possibly a reduced risk of vector borne diseases.

Small photo above Darwin Weed Management Branch.

Some aquatic plant species, like alligator weed (pictured), establish on stream banks and subsequently spread across water surfaces. Broken stem fragments can be washed downstream to establish new populations in other parts of the catchment. Photo Shon Schooler.

This fact sheet is based on the report "Effects of land use and peri-urban development on aquatic weeds" by Lauren D. Quinn, Shon S. Schooler, Rieks D. van Klinken. The full report is available from lwa.gov.au/weeds

Printed on Revive Silk which is made in Australia from elemental chlorine free pulp with 65% derived from sustainable plantation forests and 35% recovered fibre. It is PEFC Certified and Australian Paper is an ISO 14001 certified mill which utilises renewable energy sources.

Published by: Land & Water Australia
Web: www.lwa.gov.au
ISBN print: 978-1-921544-59-0
ISBN electronic: 978-1-921544-60-6

This publication can be ordered free of charge from CanPrint Communications, freecall: 1800 776 616, or e-mail: lwa@canprint.com.au and quote product code **PN22366**

Photos: Lauren Quinn unless credited otherwise
Design: Angel Ink
Print: Paragon Printers, June 2009

LWA project code CEN10

Australian Government
Land & Water Australia

CSIRO

Sleeper and alert weeds: Where will they awaken as climate changes?

Dr John K. Scott, Kathryn Batchelor, Noboru Ota and Paul Yeoh

It is now scientifically accepted that Australia's climate is changing and that these changes will continue over coming decades. Some weeds previously identified as either agricultural 'sleeper weeds' or weeds on 'environmental alert'* are likely to spread as a result of these changes in climate.

CSIRO scientist Dr John K. Scott and his colleagues have used computer modelling of both plant characteristics and global climate change to predict how 41 of the nationally recognised 'environmental alert' species and agricultural 'sleeper weeds' are likely to behave as the effects of human-induced climate change become more apparent.

Sleeper and alert species

The 'sleeper' weeds are those introduced plants that are at present limited in their distribution, but have the potential to become significant weeds impacting on Australian agriculture. A second group of introduced species, at present in their early stages of establishment, but with the potential to become a significant threat to biodiversity, are identified as 'environmental alert' species.

Each of these groups of weeds might scarcely be noticed in the landscape at present. Yet as climate changes, both have the potential to become major problems in areas where they currently do not occur.

* See www.weeds.gov.au, national weed lists for more information about sleeper and alert species.

Predicting weed behaviour using computer models

Scott and his colleagues have used CLIMEX, a computer model that uses temperature and moisture parameters to develop a growth index for plants. Various stress factors were then applied to determine an Ecoclimatic Index, indicating the suitability for survival of the various species. Information from published literature was used to determine the current distribution, phenology (natural climate-related development characteristics) and physiology of each species and to determine the parameters for the models.

For some species growth chamber experiments were used to provide extra information on the plants' growth and development.

The models were then tested against known current distribution of the species, both overseas and in Australia.

The distribution of each species under various climate change scenarios was then predicted for both high and low emission scenarios for 2030 and 2070. The models used were Echam 3 and Hadley 2. The Echam 3 model includes higher rainfall, especially in northern and north-western Australia than Hadley 2: the latter also predicting hotter climates.

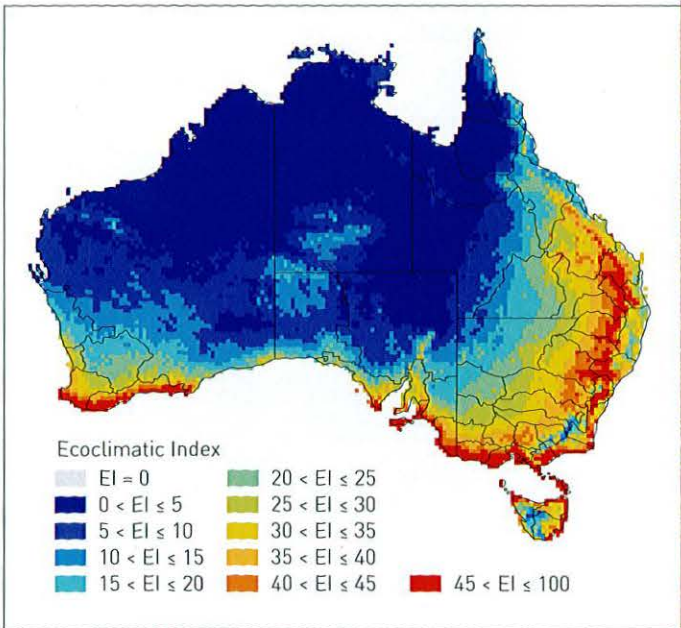


Figure 1. Average of the Ecoclimatic Indices (EIs) for 41 sleeper and alert species per quarter degree square, based on CLIMEX predictions using today's climate. Front cover and lower right: Karroo thorn. Photos D.L. Nickrent, Southern Illinois University.

Predicted shifts in weed distribution

Using either the Echam or Hadley climate model and combining it with the CLIMEX predictions of plant growth, show that the risk of environmental alert and agricultural sleeper weeds remains high in southern Australia, especially in the south-east and the south-west. Both climate models also predicted that there will be a reduced risk of establishment of these problem plants in northern Australia.

Under climate change, Scott and his colleagues predict there will be a general shift southwards for most weed species, with the shift being greatest for wet tropics species (which have the potential to move over 1000 km southward). Changes predicted for southern coastal species are much smaller, simply because they will run out of land mass on which to establish under changed climatic conditions.

Left: Yellow soldier flower (*Lachenalia reflexa*). Right: A mature White weeping broom in flower (*Retama raetam*). Photos CSIRO.

Sleeper and alert species of major concern under changed climatic conditions

Some species are predicted to show little change as a result of the impacts of climate change, while the area affected by others (including some that are currently widely distributed) will decrease.

Of greatest concern are species that will significantly increase their spread under changed climatic conditions. Scott and his colleagues identify *Acacia karroo* (karroo thorn), *Tipuana tipu* (rosewood or Tipuana tree) and *Bassia scoparia* (kochia) among the most important in terms of the increased area they are likely to affect. Some of the species are likely to become major problems under the current climate. These include *Acacia karroo*, *Retama raetam* (white weeping broom) and *Equisetum arvense* (common horsetail).

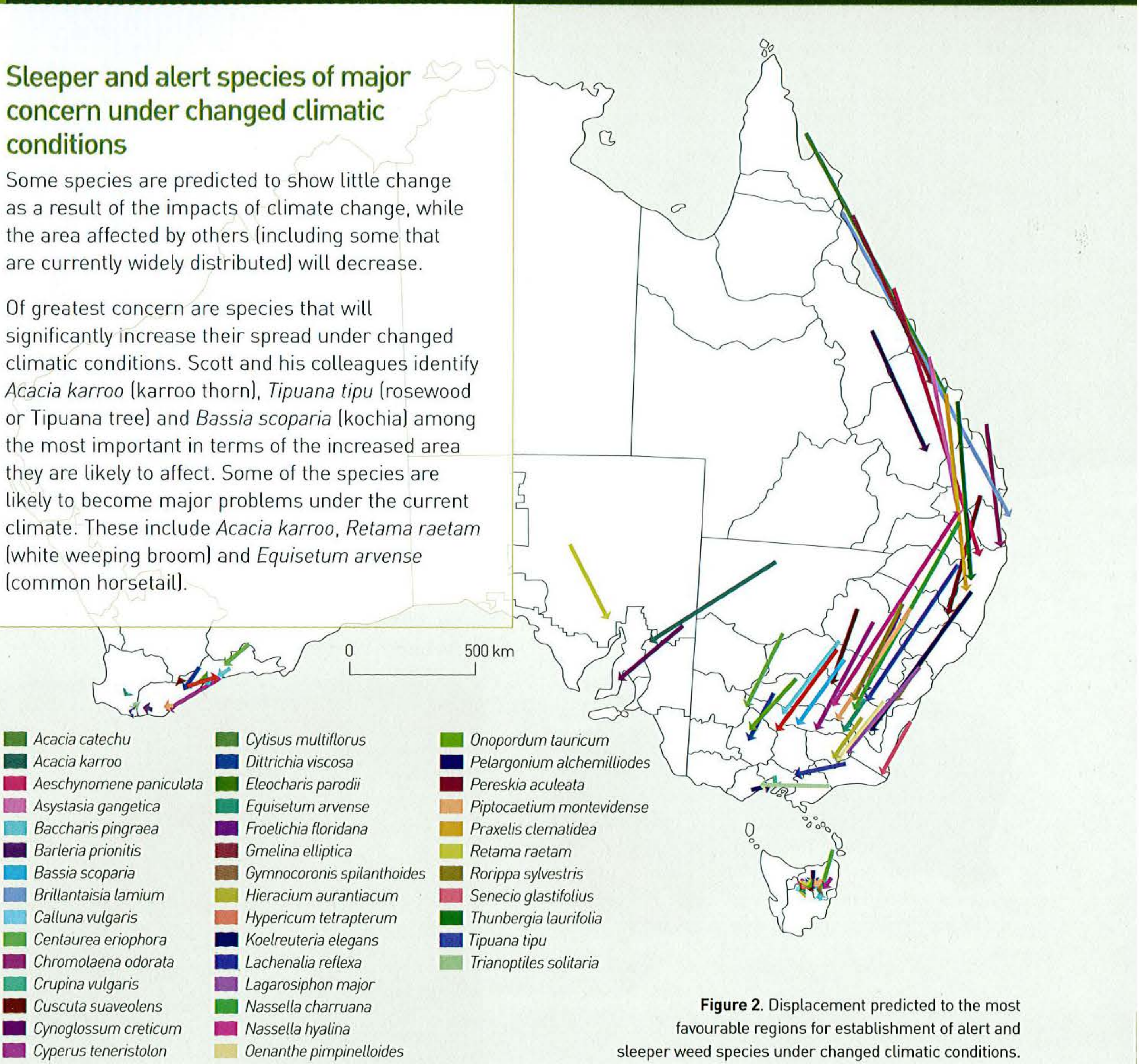


Figure 2. Displacement predicted to the most favourable regions for establishment of alert and sleeper weed species under changed climatic conditions.

Implications for NRM regions

Scott and his colleagues have analysed the threat to each of the natural resource management (NRM) regions from alert and sleeper species, under the current climatic conditions and under changed conditions predicted from the international climate models.

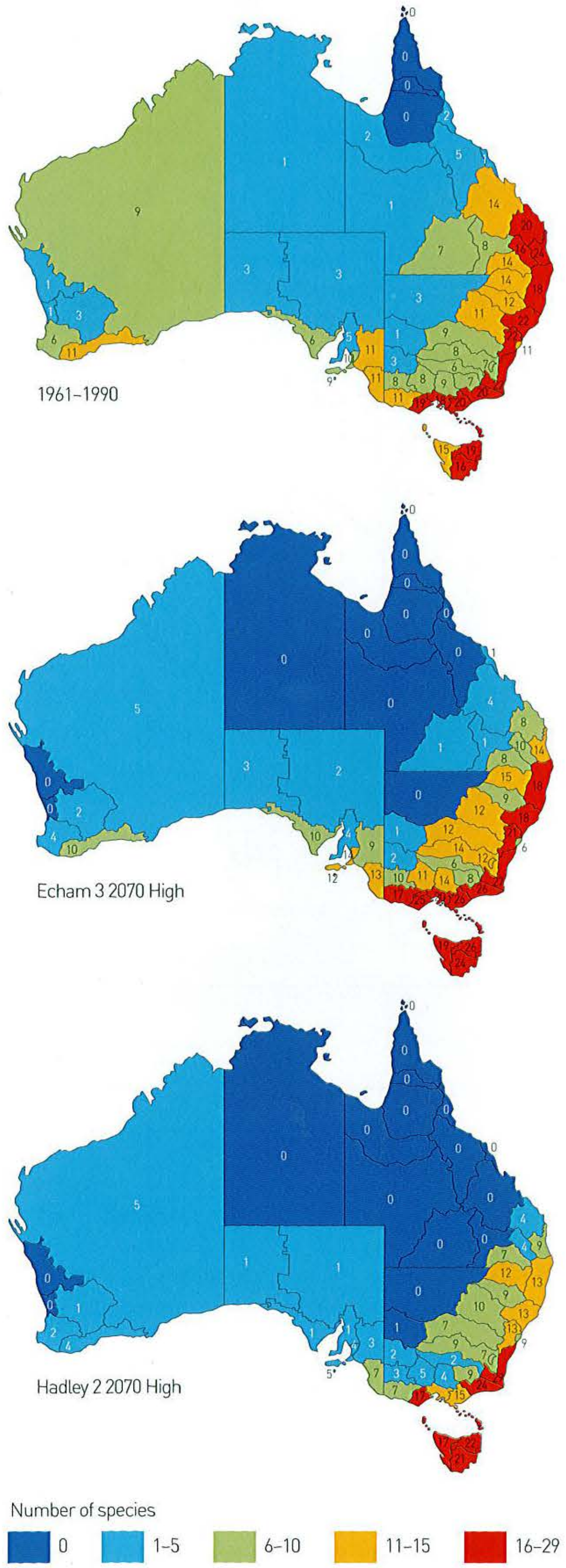
As is clear from Figure 3 (next page), NRM regions in the south-east of the continent are at greatest risk of increased numbers of sleeper and alert weeds establishing in their areas. Regions in the wheat-sheep belt of northern New South Wales to the Victoria-South Australia border are most vulnerable.

Recommendations for action

The climate modelling used in this study preceded the fourth report from the International Panel on Climate Change in 2008, and it is likely that the changes predicted are an under-estimate. This increases the importance of the recommendations that follow.

1. In order to raise awareness of the likely impacts of climate change on the spread of undesirable plants, the distribution maps developed in this project and identification photos for the key species should be made readily available on CSIRO and government websites.

Figure 3. NRM regions showing the number of sleeper and alert species with a high probability of establishment under today's climate conditions and two climate change scenarios in 2070.



2. Each of the NRM regions predicted to experience increased impacts of sleeper or alert species should take appropriate action to prevent their spread within and into each region.
3. Given that weeds frequently establish and spread from 'vacant spaces' in the landscape, and existing weeds are likely to move south as climate changes, a **new** set of sleeper and alert species needs to be identified for northern Australia.
4. Management strategies that take account of the likely impacts of climate change should be developed for each sleeper and alert species predicted to present problems in new areas. This might include both new surveillance strategies and quarantine barriers across the north-south migration route.
5. The information provided from this project should be updated using the climate predictions provided by the Independent Panel on Climate Change in its fourth report presented in 2008.

This project was conducted by Dr John K. Scott, Kathryn Batchelor, Noboru Ota and Paul Yeoh, CSIRO Entomology.
Full report: *Modelling climate change impacts on sleeper and alert weeds.* A report prepared for Land & Water Australia. CSIRO Entomology, Wembley WA. Accessible at http://csiro.au/resources/Sleeper-Alert-Weeds.html

For more information contact John K. Scott:
Tel: (08) 9333 6647
E-mail: john.k.scott@csiro.au

Printed on Revive Silk which is made in Australia from elemental chlorine free pulp with 65% derived from sustainable plantation forests and 35% recovered fibre. It is PEFC Certified and Australian Paper is an ISO 14001 certified mill which utilises renewable energy sources.

Published by: Land & Water Australia
Web: www.lwa.gov.au
ISBN print: 978-1-921544-51-4
ISBN electronic: 978-1-921544-52-1

This publication can be ordered free of charge from CanPrint Communications, freecall: 1800 776 616, or e-mail: lwa@canprint.com.au and quote product code **PN22353**

Photos: Front page, D.L. Nickrent
Design: Angel Ink
Print: Paragon Printers, June 2009

LWA project code CEN24

Australian Government
Land & Water Australia

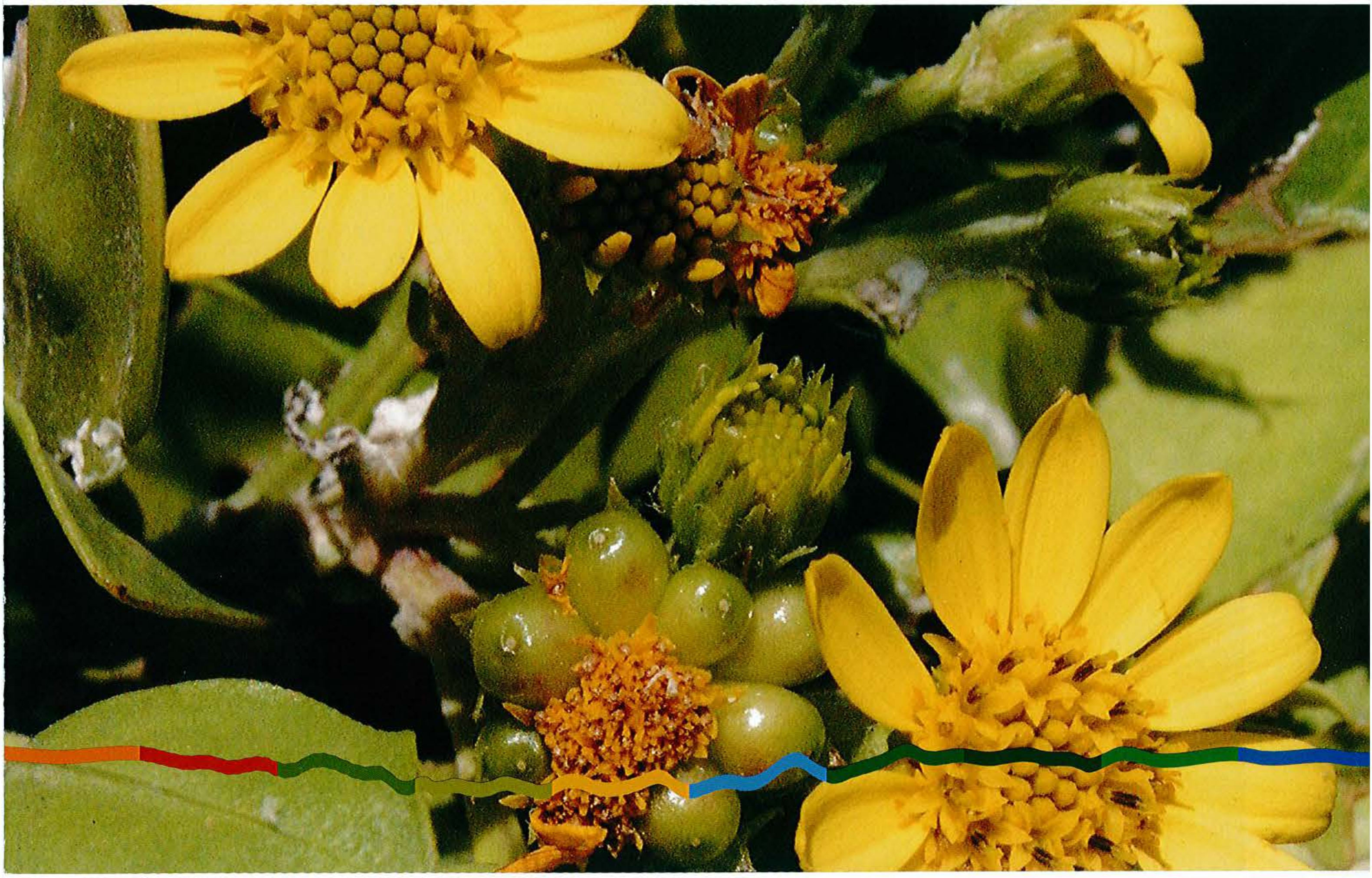
Do natural ecosystems benefit from the management of Weeds of National Significance?

Dr Adele Reid, Dr Louise Morin, Dr Paul Downey,
Associate Professor Kris French and Dr John Virtue

The issue

Weeds pose a significant threat to natural ecosystems in Australia and consequently large quantities of resources are spent each year to manage them. Amongst these, species identified as Weeds of National Significance (WoNS) are particularly important. The capacity of weed management programs to contribute to biodiversity conservation in Australia has not been comprehensively assessed.

A desktop analysis was undertaken to investigate how native ecosystems respond following weed management. The project: 1) reviewed the scientific literature for studies on management of WoNS in natural ecosystems, 2) surveyed by e-mail land managers managing WoNS in these ecosystems and 3) analysed data gathered in field experiments on two WoNS species: bridal creeper and bitou bush (pictured below).



Findings

The literature search found 94 published papers on the management of WoNS in natural ecosystems in Australia. A review of these papers revealed that the response of natural ecosystems following WoNS management was rarely monitored. Of the 17 studies that did incorporate some form of plant communities monitoring, it was found that native plant species did not necessarily recover. Moreover, in many cases the WoNS either re-invaded or was replaced by other weed species. There was also a distinct lack of information (only three studies) on the response of animal and microbial communities and ecosystem processes following the control of a WoNS.

A total of 168 replies to the land manager survey were received, with more than 50% of management programs focusing on four WoNS: blackberry, bitou bush/boneseed, bridal creeper and willows. Results from the survey revealed that although biodiversity conservation was the aim of 76% of programs, monitoring efforts focused on the response of the target weed to management and to a much lesser extent on the response of other plant species. Respondents who answered the question on changes in plant communities after management reported that the WoNS was replaced by bare ground (8%), by weed species only (including the target WoNS) (13%), by native plants only (25%) and by a combination of native and weed species (44%). Ten per cent of respondents did not record the replacement species.

The native plant species *Pimelea spicata* threatened by bridal creeper. Photo Tony Willis, CSIRO Plant Industry.

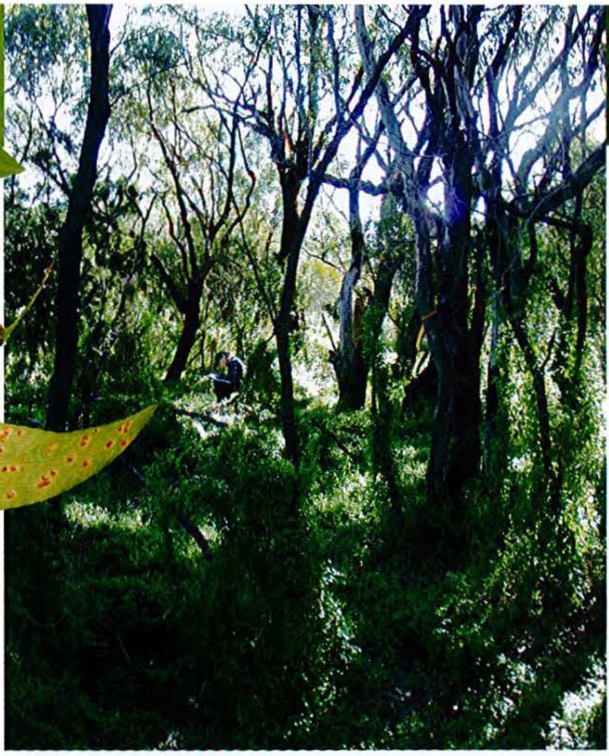
The rust fungus (*Puccinia myrsiphylli*) released in 2000 for the biocontrol of bridal creeper. Photo CSIRO Entomology.

The bridal creeper and bitou bush case studies provided examples of scientific monitoring of plant communities following management of WoNS in natural ecosystems. These studies showed that while management effectively reduced densities of bridal creeper and bitou bush, there was limited recovery of native plant species over the monitoring period. The relatively short-term nature of these studies (two to three years), which is comparable to the majority of on-ground monitoring programs, may be in part responsible for the limited recovery reported.

Discussion

Given the combined findings of the three components of this project, it is clear that management programs for WoNS and other weed species in natural ecosystems should put greater emphasis on monitoring the response of native species to the reduction or removal of target weeds. Some monitoring is essential to check whether the management methods used damaged native plants and to decide whether additional interventions are required to assist native plants recover. Microbial and animal communities, and ecosystem processes should also be monitored for a more thorough assessment of how natural ecosystems respond to weed management. However, it is unrealistic to expect most on-ground land managers to implement this type of detailed monitoring. Such monitoring is better left for trained researchers to undertake at representative sites.

A whole-system approach, integrating weed management programs with other actions (e.g. planting native species) is essential to assist the recovery of native communities and restore the structure and function of ecosystems, protecting against future weed invasion. Long-term monitoring is crucial to evaluate the effectiveness of this integrated approach for restoring ecosystems.



Evaluating the impact of a biological control agent on bridal creeper and the response of associated vegetation to a reduction in the weed population. Photo Peter Turner, CSIRO Entomology/University of Western Australia.

Recommendations

Management of weed-invaded natural ecosystems

1. Weed management programs should target sites with high conservation value, such as those containing threatened native species or ecological communities and where management and recovery are likely to succeed.

2. Weed management programs should be set into a broader context of natural ecosystem management and restoration to encourage recovery of degraded habitats and increase their capacity to resist future weed invasions.

3. Before starting weed management programs, native species at risk and other significant impacts (e.g. changes in soil nutrients) from weed invasion should be identified at a site level and carefully monitored during and after management. This would enable ongoing evaluation and implementation of additional or different management strategies, if necessary, to ensure recovery of the ecosystem.

4. Unless a WoNS (or other dominant weed species) of natural ecosystems is targeted for eradication or containment, management should target multiple weed species at a site, by combining a range of appropriate methods where necessary, and have the long-term aim of restoring native communities and ecosystem processes.

5. Active monitoring of the response of weeds and native plant communities using quantitative methods should be an integral component of weed management programs in natural ecosystems to underpin subsequent adaptive management actions and document outcomes of programs.

6. National or state/territory-based systems, such as the Threat Abatement Plans developed for bitou bush and lantana that identify native species or communities at risk from weed invasion, should be developed for other priority weeds (including WoNS) within regions to prioritise invaded sites for management in order to achieve the greatest outcomes for conservation.

Support for land managers

7. A core set of monitoring and restoration protocols (with a strong emphasis on measuring the response of plant communities to weed management) should be developed to assist land managers responsible for weed management within natural ecosystems.

8. Training should be provided to land managers in plant community monitoring (including data collection, analysis and interpretation) and restoration principles and techniques.

Funding

9. Applications for funding to support weed management programs in natural ecosystems should include details of the monitoring schedule that will be used to assess the response of native communities and outline strategies that will be implemented to restore the habitat.

10. Funding bodies should tie subsequent weed management funding to on-ground outcomes that demonstrate effectiveness of the initial management program and the response of plant communities.

11. Longer-term funding should be made available for programs that integrate weed management with native species conservation and/or habitat restoration, underpinned with sustained monitoring and reporting activities.

WoNS program

12. During the review of each of the 20 WoNS strategies, specific actions on monitoring the response of native species to weed management programs over a sufficient timeframe should be included.

13. Priority should be given to ensuring that all WoNS that invade natural ecosystems have baseline data on their impacts to native species and ecosystems.

Partnerships

14. Weed management and restoration practitioners should work more closely together to ensure better outcomes for conservation following weed management programs.

15. National and state/territory meetings of weed scientists, restoration ecologists and practitioners should be organised to establish dialogue, identify needs and develop collaborative research programs.

Research

16. While a better understanding of the impact of weeds on natural ecosystems is still required, particularly for ecosystem processes, more emphasis should be given to research investigating:

- the process by which weeds cause native species to decline and the implications for management
- the effects of reducing or removing weeds on restoration of ecosystems
- ways of overcoming persistent effects of weed invasion that prevent or delay ecosystem recovery (e.g. change in nutrient levels, residual allelopathic chemicals, slow decomposition of below-ground organs)
- long-term field comparisons of the benefits for native species and cost effectiveness of various weed management and restoration approaches
- mechanisms that increase resilience of native communities to weed invasions.

17. Research findings should be made available to practitioners in a format that allows them to adapt their management actions to a range of situations.


Willow. Photo Roger Charlton.

This project was conducted by Drs Adele Reid and Louise Morin (CSIRO Entomology), Dr Paul Downey (NSW Department of Environment and Climate Change), Associate Professor Kris French (University of Wollongong) and Dr John Virtue (South Australian Department of Water, Land and Biodiversity Conservation).

Full report: Reid, A.M., Morin, L., Downey, P.O., French, K. & Virtue, J.G. 2008, *Evaluating the environmental benefits from managing WoNS in natural ecosystems*. A report prepared for Land & Water Australia by CSIRO Entomology, Canberra.

The full report is available from lwa.gov.au/weeds
For more information contact Louise Morin:
Tel: (02) 6246 4355
E-mail: louise.morin@csiro.au

Printed on Revive Silk which is made in Australia from elemental chlorine free pulp with 65% derived from sustainable plantation forests and 35% recovered fibre. It is PEFC Certified and Australian Paper is an ISO 14001 certified mill which utilises renewable energy sources.

Published by: Land & Water Australia
Web: www.lwa.gov.au
ISBN print: 978-1-921544-53-8
ISBN electronic: 978-1-921544-54-5

This publication can be ordered free of charge from CanPrint Communications, freecall: 1800 776 616, or e-mail: lwa@canprint.com.au and quote product code **PN22357**

Photos: Front page, Hillary Cherry
Design: Angel Ink
Print: Paragon Printers, June 2009

LWA project code LNR004729

Australian Government
Land & Water Australia

Improving targeting of weed biological control projects in Australia

Quentin Paynter, Richard Hill, Stanley Bellgard and Murray Dawson

Over the years a great deal of work has been directed towards improving the selection, testing and evaluation of biological control agents for weed control. However our understanding of how to select target weeds against which biological control might become an important part of management remains limited.

Most classical biological control projects directed against weed targets have been conducted in South Africa, Australia, New Zealand, the USA and Canada. Classical biological control (or biocontrol) tends to be a public, community-level activity carried out by research institutions and government departments rather than by private enterprise.

Inset: Close-up of an adult leaf-feeding beetle (*Zygogramma bicolorata*) feeding on parthenium. Photo K. Dhileepan, DPI&F. Main: Witches' broom caused by the rust fungus *Endophyllum osteospermi* on a boneseed plant. Photo Louise Morin, CSIRO Entomology.

Considerable resources are required if a biocontrol project is to be completed well, so it is important that the weeds selected for management using this approach justify the investment. In order to properly account for this public investment it is important to have in place decision-making processes that increase the likelihood of selecting biocontrol targets that are important, biologically and ecologically feasible, and have broad social support.

In practice, the means by which target species are selected varies widely, with only limited research guiding the use of the most important criteria.

Land & Water Australia commissioned Landcare Research New Zealand to develop a decision-making system to maximise the likely effectiveness of investment in biocontrol research and to ensure this is done in ways that are transparent and repeatable.

Deciding which factors to include

Several previous studies from Canada[1], the USA[2], New Zealand[3] and Australia[4], were used to assist in determining which factors should be used to prioritise which weeds to target for biological control in the future.

The Landcare Research team identified three key dimensions influencing the priority of a weed as a target for biocontrol: Weed **Importance** and the predicted **Impact** of biological control and the **Effort** required to import, test and release biological control agents.

Importance of a particular weed takes account of a number of factors that were considered when Thorp & Lynch[5] developed the Weeds of National Significance (WoNS) list.

During the development of the prioritisation framework the ranking of each of the WoNS was used to reflect importance. However it is recognised that some species may have increased in abundance and importance during the 10 years since the WoNS species were ranked, while other species have been successfully biologically controlled and, therefore, declined in importance. The method developed since the WoNS list was developed and now used in the National Post-Border Weed Risk Management Protocol might offer a sound alternative to the WoNS ranking, as a measure of importance to be considered in further developing the prioritisation framework.

Impact of biocontrol can best be predicted by the existence of a successful precedent in another country. However where Australian weeds present novel targets not previously addressed through biocontrol experiments, the habitat, life cycle and reproduction of the plant species are important considerations, as are the native range of the species, existence of multiple forms of the plant, and competition in the growing environment.

Effort required to control a weed species using biocontrol was included as an important factor because as effort and associated costs rise, the feasibility of progressing a biocontrol project decreases.

Once developed, the framework was tested by ranking species that have been the subject of biocontrol research in the past, using reports from South Africa and the USA. It was also verified through input from state and nationally based biological control researchers and senior policy makers with a demonstrated interest in the biological control of weeds.

Applying the scoring system to assess past biological control efforts in Australia, South Africa and continental USA, biocontrol impacts were invariably major against those weeds that scored more than 70 (out of a possible score of 100). For weeds that scored between 50 and 70, impact was variable (approximately 40% successes and 60% failures), while biocontrol most often had no impact against weeds that scored less than 50.

Bellyache bush (*Jatropha gossypifolia*) is a target species for biocontrol. Photo Tim Heard.

1. McClay (1989); Peschken & McClay (1995)
2. USDA-APHIS-PPQ (2005–2006)
3. Owen (1997); Syrett (2002)
4. Palmer & Miller (1996)
5. Thorp & Lynch (2000)

For complete references, see full report.

Using the framework to assess weed priority for biocontrol development

By working through a simple series of questions in which responses receive weighted scores, the user of the framework can develop an overall score for the priority of the species as a target for biocontrol (see figure below).

Scores on each of the key factors are combined using the formula

$$\frac{\text{Total } \mathbf{Impact} \times \mathbf{Importance}}{\mathbf{Effort}}$$

Two questions, asked at the beginning of each weed assessment present Stop/Go decision points:

- Is the weed a native species and is it in its natural range?

and

- Is opposition to biocontrol likely and does the weed species have socio-economic value?

If the answer to the first question is 'Yes' then biological control is undesirable and should not proceed. For the second question biological control should also not proceed unless a cost: benefit analysis indicates that the benefit of control would outweigh any socio-economic value a weed may have.

The research team notes that by adjusting the weightings given to **Impact**, **Importance** and **Effort**, the framework can be modified to have greater relevance to either tackling the most important weeds or maximising the number of successful programs.

Using the WoNS list and weeds already identified by the Australian Weeds Committee as suitable for biological control, the research team then prepared a ranked prioritisation list of species suitable for biological control.

There remain some challenges for prioritisation of weeds for which biocontrol agents might be developed. Not least among these are:

- the lack of data available in relation to feasibility of control of many species using non-biological methods, such as herbicides
- the appropriate weightings to be given to the measures used in the framework
- ways in which emergent species such as agricultural 'sleeper' and environmental 'alert' species should be addressed, especially in the face of a changing land uses and human-induced climate change.

Excerpt from the framework for assessing priority as a target for biocontrol

Module 2: Effort required to obtain and host-test biocontrol agents

This section of the framework assesses the effort required to obtain and host-range test biocontrol agents.

Has the weed been/is it a subject of adequately resourced biocontrol program elsewhere?		Difficulty score
a. Yes, successful program	If specific agents are already known and host-range testing has already been conducted overseas, then program is likely to be cheaper	1
b. Yes, unsuccessful program	Some knowledge of agents may help, but law of diminishing returns — if the current known suite of agents is ineffective,finding new ones will be harder	15
c. Current target/too early/insufficient data to assess success elsewhere or variable success elsewhere	Potential for cost savings, but uncertainty factored into score	8
d. No, never	Program will have to bear all costs of survey work and agent testing	20

The next question addresses the ease of working in the native range.

PRODUCED BY LWA'S WEEDS R&D PROGRAM. FUNDED BY THE AUSTRALIAN GOVERNMENT'S DEFEATING THE WEED MENACE PROGRAM.

Recommendations

1. The framework, as a score-based decision-making tool, should be reviewed regularly and revised as more weed biocontrol impact data becomes available. The methods for ranking weed importance (e.g. WoNS, Weed Risk Management Protocol, and current versus incipient weeds such as agricultural 'sleeper' and environmental 'alert' weeds) should be debated and agreed between interested parties.
2. There needs to be more dialogue and engagement with those likely to be affected by the adoption of such a framework to ensure its successful implementation. A pragmatic decision-making process should always accompany the framework when deciding the portfolio of target species for biological control.
3. Research questions should be developed and addressed to improve the predictive power and to reduce the level of uncertainty in the framework.
4. Review of the framework should be simplified by developing a database to capture information about weeds and the assumptions behind the framework.

Despite the qualifications contained in these recommendations, the framework provides a sound and easily usable basis from which to develop a nationally agreed tool to assist in assigning resources to weed biological control research.

Right: Spear thistle (*Cirsium vulgare*) a target species for biocontrol, photo Roger Charlton. Below: Gorse spider mite (*Tetranychus lintearius*); a biological control of gorse, photo Peter Martin.

Full report: Paynter, Q., Hill R., Bellgard, S. & Dawson, M. 2009, *Improving targeting of weed biological control projects in Australia*. A report prepared for Land & Water Australia, by Landcare Research NZ, Auckland. The full report is available from lwa.gov.au/weeds

For more information contact Quentin Paynter:
Tel: +64 09 574 4123
E-mail: PaynterQ@landcareresearch.co.nz

Printed on Revive Silk which is made in Australia from elemental chlorine free pulp with 65% derived from sustainable plantation forests and 35% recovered fibre. It is PEFC Certified and Australian Paper is an ISO 14001 certified mill which utilises renewable energy sources.

Published by: Land & Water Australia
Web: www.lwa.gov.au
ISBN print: 978-1-921544-77-4
ISBN electronic: 978-1-921544-78-1

This publication can be ordered free of charge from CanPrint Communications, freecall: 1800 776 616, or e-mail: lwa@canprint.com.au and quote product code **PN30028**

Photos: Front page main image, Louise Morin
Design: Angel Ink
Print: Paragon Printers, June 2009

LWA project code UNE62

Australian Government
Land & Water Australia

Best practice for on-ground property weed detection

Brian Sindel and Om Jhorar (School of Environmental and Rural Science), **with Ian Reeve, Lyndal-Joy Thompson and Michael Coleman** (Institute for Rural Futures, University of New England, Armidale, NSW)

Introduction

Around 28,000 exotic plant species have been introduced into Australia since European settlement, and more than 2770 of these have become naturalised, of which around 65% are considered a problem for natural ecosystems and about 35% are considered a problem for agricultural systems.

Weedy species will continue to enter the country, while existing species will continue to expand their range within Australia through various pathways of weed spread (the subject of Defeating the Weed Menace Project UNE61 — *Pathway risk analysis for weed spread within Australia*, see: http://lwa.gov.au/programs/defeating-weed-menace-rd-program), particularly as changes in climate occur. The first step in the control of such weedy species is their detection, and the sooner after introduction that this can be achieved, the more effective management strategies are likely to be.

There have been attempts to develop guidelines for professional surveying and mapping of nationally significant weeds and in national parks, weed spotting networks, and surveillance techniques for weeds that have already been detected in Australia such as branched broomrape. However, a large proportion of Australia is privately owned or managed by farmers and graziers, and as yet no one has undertaken a comprehensive study to ascertain current weed surveillance levels and practices amongst these landholders or the noxious weeds inspectors (or their equivalents in each state) that already check properties for new and existing invasive plants.

Concerned landholders and researchers inspect paddocks on the south coast of NSW where fireweed (*Senecio madagascariensis*) is spreading.

A recent survey of graziers in southern Australia by Trotter, Reeve, Scott and Sindel, conducted for Meat & Livestock Australia (data unpublished) showed that over 80% of the 900 respondents regularly checked their paddocks for weed infestations, but only 10% either recorded those infestations on maps or marked them in-field.

Here then is an existing Australia-wide network of people interested and committed to the detection of weeds ('weed spotters') but whose rigour is assumed to be relatively low. Likewise, public officers in most states and territories have a specified inspection function for weeds but how the states compare in their effectiveness has not been explored.

Information on existing landholder and weed inspector search patterns (particularly on their best and proven techniques) and data management and use, needed to be collected before we attempted to develop and extend widely more efficient methods for surveying and eradicating emerging weeds.

The research questions to be addressed in this project, therefore, were as follows.

1. What are the current inspection patterns for weeds on Australian farms?
2. What steps do landholders and inspectors take to report and obtain correct identifications of new species?
3. Which of these inspection and reporting strategies are most effective at detecting, identifying and eradicating new invasions?

Whilst weed spotter networks have been set up in Victoria (to survey for new and emerging weeds, and State Prohibited Weeds not already in the state) and in Queensland (working with community groups, such as bush walkers, to improve the capacity to find and record new weeds in national parks and other environmental areas), much private land is inaccessible to such groups. This project therefore complements these two existing systems by expanding enormously the coverage of land (across industries and land uses) and the number of interested people involved in weed detection networks.

Indeed, new weeds have a habit of being introduced to farms in imported feed, grain, pasture seeds, on travelling machinery and by livestock. Consequently, one of the best tools for detection of new weeds is landholders' eyes in their own paddocks.

Parthenium (*Parthenium hysterophorus*) can mature and spread if juveniles such a

Supplementing landholders are noxious weed managers. The role of this latter group is different in each state and territory and it is therefore essential to collate information from all jurisdictions to obtain a complete picture of inspection patterns (for example — methods, location, frequency, seasonality, time spent, single or multiple species focus, life cycle influences) and how data are then handled for weeds across the country to be able to identify where there are gaps and weak points in on-ground surveillance and eradication efforts.

An important aspect of this inspection picture is how long a plant can be present on a farm before a landholder or weed inspector recognises it as a 'new' weed, or before he or she takes a specimen away for identification. Key to this is the ecology of the weed, how quickly it reproduces after a propagule arrives at a new site, and how quickly the weed then spreads. A further consideration is the extent to which the invading weed has a negative economic impact on the landholder.

the one pictured above (left) are not undetected. Photos Arthur Mostead.

The purpose of this research therefore, was to:

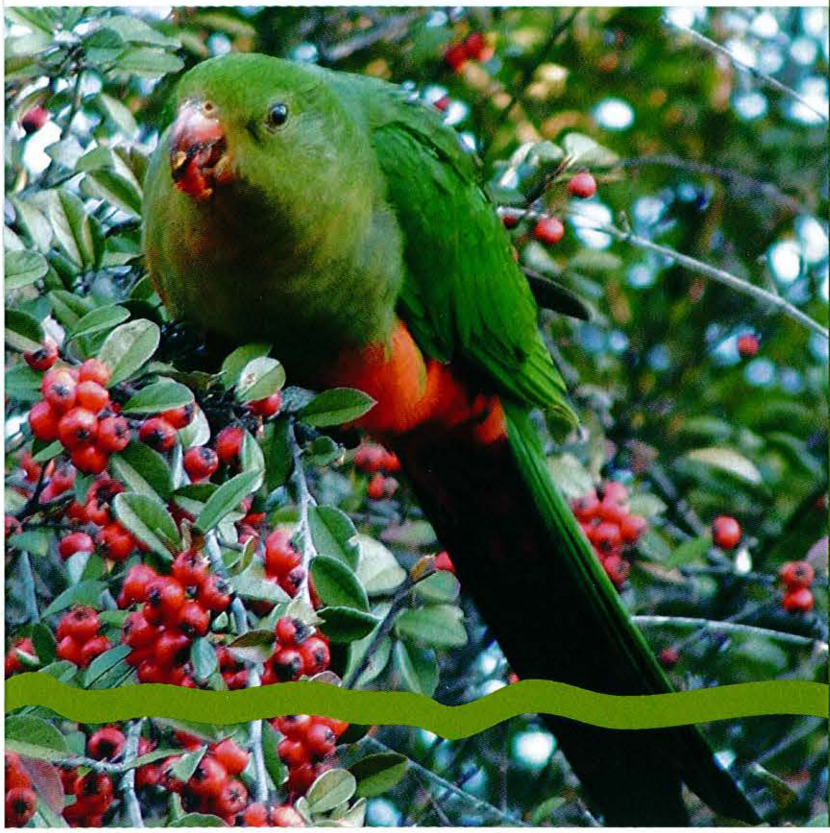
1. Assess current weed surveillance levels and practices amongst landholders and noxious weeds inspectors; and
2. Identify ways to improve weed detection by these groups on-ground.

Some results

- Over 74% of respondent weed inspectors have experienced hesitance on the part of landholders to report weeds. This is caused by the costs associated with weed control, fear of potential sanctions or enforcement, lack of interest, and insufficient knowledge.
- Inspectors consider that landholders have a moderate commitment to weed detection overall, with only just over 10% believing that landholders have a high level of commitment.
- The main incentives committing landholders to weed detection and control are believed to involve landholder knowledge, while the main impediments to landholder commitment involve various 'costs' (financial, time, staffing). The landholders assessed as least committed to weed detection are part-time farmers (absentee landholders, lifestyle farmers, and farmers with off-farm employment).
- Most inspectors (76%) believe that weed surveillance could be improved:
  - through supply of increased resources and personnel, community awareness and education, and
  - through more of their time being devoted to in-field detection work. Although less critical, improvements to weed identification would involve weed identification training for staff, landholders, volunteers and the general public, as well as dedicated weed identification resources.
- Other suggestions for improving weed detection involve the themes of training and education of staff, landholders and the general public, increased government resources and funding, improving inspection techniques, and changes to legislation.
- The great majority of farmers (84.3%) check for weeds on a regular basis though most (65.3%) do so while conducting other on-farm tasks.
- Most farmers consider that weed declaration makes no difference to checking for weeds, though it does make a difference for a small majority of Western Australian interviewees, suggesting a more effective declaration strategy and promotion in that state.
- Only 4.8% of landholders indicate that the impending visit of an inspector makes them change their weed checking activity, which is in contrast to the more favourable perception of this impending visit amongst weed inspectors surveyed.
- Farmers believe that weed authorities should focus on making sufficient information available to landholders on target plants rather than focusing on getting landholders to simply report suspicious plants to authorities, although 28.5% suggest that both strategies would be useful.

- More farmers (65.3%) than inspectors (45.8%) believe that weed distribution information on private property should be made publicly available.
- Of all property types, crop farmers have the highest checking rate overall (96.5%) and horticulturalists the lowest (86.1%).
- Approximately half of the farmers believe their surveillance strategy is 'mostly effective' while the other half said that it was 'very effective'.
- Curiosity, is the main motivation for having a weed identified. This interest influences farmer behaviour to a greater degree than concerns about spread, and possible economic losses.
- When finding a new weed, 42.1% of farmers will mark the site in the paddock with a stick or pole, while 36.8% will record it in a diary or notebook.
- The majority of farmers believe that impediments to reporting new weed discoveries include the cost of eradication, threat or fear of legal action, and concern over what other landholders might think.
- Over half of all farmers rate the level of government commitment to weed control as 'low'. However, this percentage varies between states. For example, while 72.4% of Victorian interviewees and 68.2% of those from Tasmania rate the level of commitment as 'low', only 41.9% of interviewees from South Australia do so.

Birds, such as this King Parrot, are believed by farmers and weeds inspectors to be a major pathway for the spread of weeds such as this cotoneaster. Photo Brian Sindel.



Conclusion

On the whole, this research project showed that Australian farmers are alert to new weeds, and have a reasonably high level of commitment to their detection and control. As a group, farmers therefore need to be encouraged, and equipped to be vigilant and effective weed spotters. This may be achieved through training opportunities, greater extension and educational activities, increased resources devoted to weed detection, and greater cooperation between landholders and weeds authorities.

There was often considerable variation between states and territories, and property types in relation to weed spread detection and reporting. Some states and territories, and landholder types were considered as performing better than others, though geographic and climatic differences, as well as enterprise differences, accounted for some of the variability. Research and extension programs aimed at improving weed detection strategies will need to take into account such variation and target specific groups appropriately.

Overall, there was seen to be a low level of government commitment to weed detection. Given the high environmental, social and economic impact of weeds, this situation needs to be remedied, since early detection is much more cost-effective than a later cure.

For more information contact Brian Sindel
Tel: (02) 6773 3747
E-mail: bsindel@une.edu.au

Printed on Revive Silk which is made in Australia from elemental chlorine free pulp with 65% derived from sustainable plantation forests and 35% recovered fibre. It is PEFC Certified and Australian Paper is an ISO 14001 certified mill which utilises renewable energy sources.

Published by: Land & Water Australia
Web: www.lwa.gov.au
ISBN print: 978-1-921544-91-0
ISBN electronic: 978-1-921544-92-7

This publication can be ordered free of charge from CanPrint Communications, freecall: 1800 776 616, or e-mail: lwa@canprint.com.au and quote product code **PN30083**

Photos: Front page, Brian Sindel
Design: Angel Ink
Print: Paragon Printers, June 2009

LWA project code CAU006966

Australian Government
Land & Water Australia

A national information system for weeds: What do end-users need?

Christopher Auricht and Graham Yapp

Invasive species — weeds in particular — are one of the major threats to the sustainable management of natural resources. Weed control costs Australian farmers approximately $1.5 billion per year, with lost agricultural production estimated at more than $2 billion. These estimates do not account for environmental costs such as the effects of long-term degradation of vegetation and impacts on biodiversity and waterways, or impacts on health, safety, amenity, infrastructure, tourism and the general quality of life.

The Australian Government for some time has been working with state and territory governments to develop a 'National Invasive Species Information System'. Such a system is directed primarily to ensuring ongoing monitoring and evaluation of invasive species. This needs to be done in ways that enable ongoing reporting at different levels across different jurisdictions.

Paterson's curse (*Echium plantagineum*). Photo Jon Dodd.

Land & Water Australia (LWA) is a research broker committed to generating new knowledge for the sustainable management and use of Australia's natural resources. As such, LWA recognises that information tools (e.g. identification aids) and access to accurate weeds related data and information are key elements in the successful management of natural resources. Where available in a timely fashion and in a format that is readily available to interpret, such tools, data and information help reduce uncertainty in planning and clarify issues for further analysis. Strategies to overcome the complex challenges of weed management may then be developed and the results monitored as part of an overall system.

As part of the Defeating the Weed Menace (DWM) R&D program, LWA commissioned a project to assess the potential end-users of a national information system for weeds, and to determine their needs and priorities. The number of potential end-users of weeds information is large and they have an appetite for a wide range of data and information.

To be effective, a national information system must meet the diverse needs of its end-users.

What the project team did

The project team used a literature review, site visits to state and territory government agencies, and focus group sessions to develop a user survey to determine who might use a national information system for weeds, and to what uses they would put that information. A questionnaire was widely distributed on-line and 385 responses were received from a wide cross-section of the natural resource management (NRM) community, including Australian, state and territory governments, research organisations, NRM regional bodies, local government, non-government organisations (NGOs), educational and tertiary institutions, landholders, industry, community based groups and the media. The survey information was supplemented by targeted in-depth interviews.

Generic components of an invasive weeds information system

Foundations

Governance
- Legislation
- Regulations
- Policies and programs
- Targets
- Investments
- Research priorities

Knowledge base / resource library
- Biology / dispersal methods
- Distribution / density
- Research results / risk assessments
- Manager support / toolkits
  - Best practice manuals
  - Control methods
  - Hygiene
  - Identification tools

Strategies, actions and outputs

Information services and advice
(Farmers, gardeners, NGOs, industries, other interests)
- Awareness raising
- Skill development
- Sources of finance and expertise
- On-ground advisory services (methods etc.)
  - Risk
  - Control
  - Eradication
  - Hygiene
  - Monitoring, evaluation and reporting

Surveillance
- Weed Watch etc.

Reporting
- On-ground action
- Costs
- Effectiveness
  - Speed of response
  - Impact reduction
  - Removal of threat
  - Re-infestation
  - Replacement

Outcomes

Feedback and enhancement

Who would use a national information system for weeds?

The results of the user needs assessment reveal that the key users of a national information system for weeds would be the Australian, state and territory governments, regional bodies, local government, researchers, community groups/NGOs and industry. Most of these users are involved in program management, policy development or on-ground NRM activities. Interestingly, the nursery and landscape industries and gardeners also stated that they would get considerable value from a national information system — especially as it relates to plant identification.

The box below (using results from survey question 5) summarises the stated requirements for weed information.

5. For what purpose do you require weeds related data or information? (Please check all that apply)

	Response per cent	Response count
Natural resource management —aquatic	48.4%	177
Natural resource management — terrestrial	**80.3%**	**294**
Policy or program development	54.4%	199
Monitoring, evaluation or reporting	66.7%	244
Regulatory	33.9%	124
Input to scientific analysis	23.5%	86
Teaching	26.2%	96
Identification	65.6%	240
Other (please specify)		19
Answered question		366
Skipped question		19

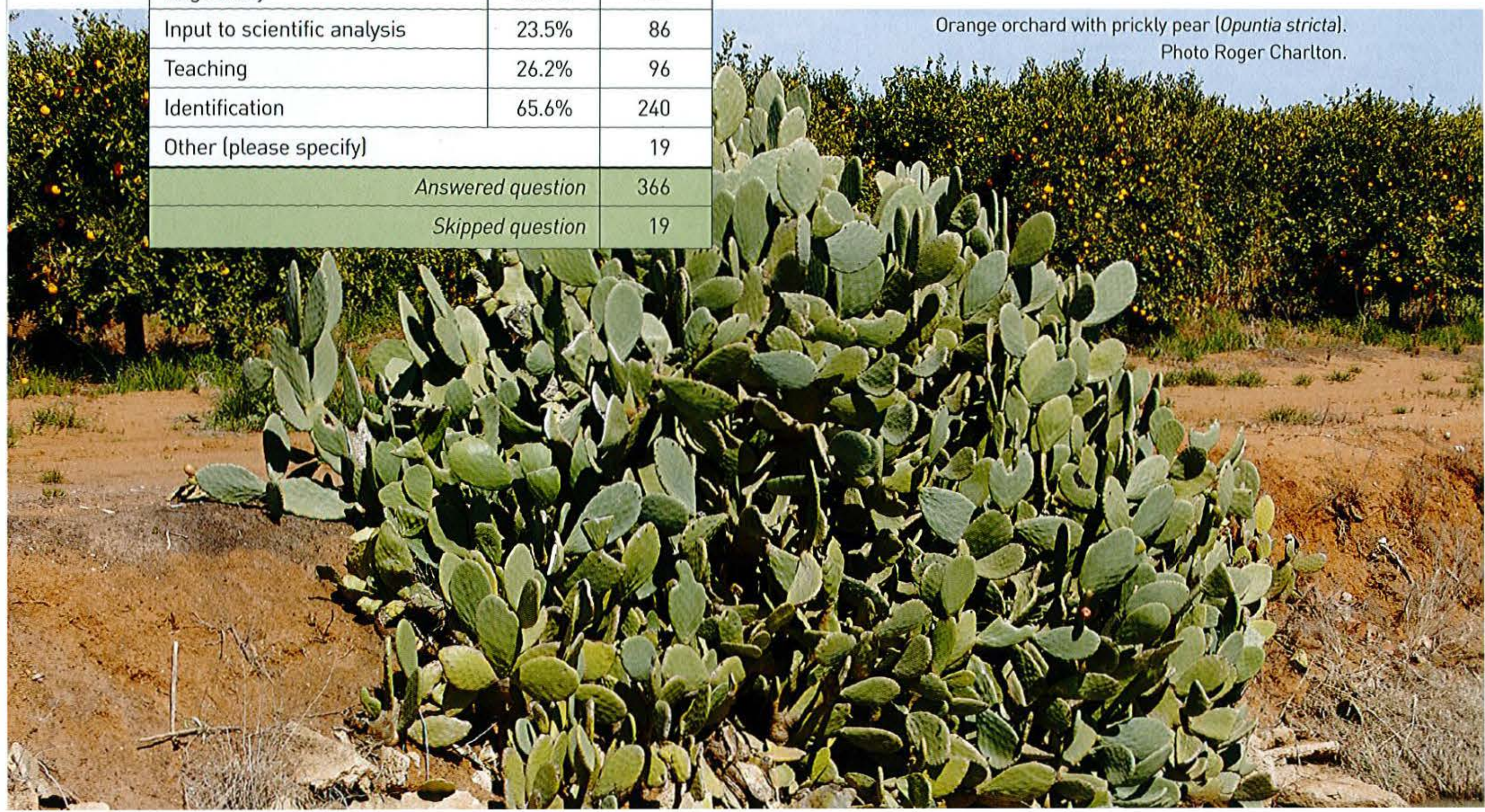
The drivers for seeking national information in weeds

The lists that follow present a generic summary of drivers for seeking weed-related information.

National, state and territory governments

Ministers, government agencies, ministerial councils and their standing committees require data and information about weeds to:

- underpin assessments of the status and trends in condition of Australia's resources at scales that allow broad priorities to be set and outcomes to be measured against those priorities;
- guide policy and program development;
- evaluate regional plans in the context of partnership initiatives (e.g. the Natural Heritage Trust and the National Action Plan for Salinity and Water Quality), to ensure the plans are robust and address priority issues in the region;
- monitor compliance with legislation;
- track progress in initiatives — such as the Defeating the Weeds Menace (DWM), Caring for our Country, and Weeds of National Significance (WoNS) programs, and assess their impacts and effectiveness; and
- meet regional, national and international reporting obligations.



Orange orchard with prickly pear (*Opuntia stricta*). Photo Roger Charlton.

Vineyard with spear thistle (*Cirsium vulgare*). Photo Roger Charlton.

Regional communities and organisations

Regional communities and organisations require data and information about weeds to:

- underpin community participation in preparing, implementing and evaluating natural resource management and invasive species eradication plans;
- help provide an understanding of the geographic distribution of problems and their implications across the region;
- track improvements in the condition of the environment and progress towards meeting targets and agreed outcomes in regional plans;
- assess the effectiveness of land conservation activities; and
- improve awareness of landscape processes.

Private sector

The private sector requires better information on weeds to:

- target investment; and
- implement environmental management systems.

Scientific community

The scientific community requires improved weeds related information to:

- better understand biophysical processes;
- create improved landscape management tools (e.g. better simulation models);
- assess the environmental impact of farming systems;
- develop and test improvements in management practices; and
- develop improved natural resource management systems.

What type of information is most important?

Issues such as biodiversity conservation, sustainable agriculture and the social and economic impacts of weeds pose questions such as:

- How big is the current problem? (i.e. extent and distribution)
- What is it affecting? (i.e. impacts on various themes e.g. agriculture, biodiversity etc.)
- What is being done about it? (i.e. extent of active management)
- How big could the problem get? (i.e. potential distribution and climate change influences)
- What would be the potential impact?

What is currently available?

A significant number of tools already exist to assist in collecting, collating and presenting information about invasive species, for example:

i) at state/territory Level: Weed Watcher in Western Australia; the Integrated Pest Management System (IPMS), and Environment Information System, in Victoria; Pest 2000+ in South Australia; and PestInfo and Annual Pest Distribution Survey (APDS), in Queensland, and

ii) at the national level: the National Land & Water Resources Audit (NLWRA) Atlas, Map Maker, Data Library and Australian Resources Online (ARO).

However, the the survey results indicate that, while several of the needs of diverse user groups are met by these tools, there are important gaps in coverage and capability.

What is needed?

As illustrated in response to a key question in the user needs survey (see box below), a variety of data is needed in order to answer the earlier questions. Respondents clearly have a high level of need for information to guide and assist weed prevention and control, early detection and eradication, integrated weed management and ongoing maintenance. Other questions elicited strong support for information on extent and distribution, including potential distribution, of weeds — but with some reservations about the quality and reliability of currently available maps and modelled distributions.

Referring specifically to weed management, survey respondents identified a number of information needs, as shown in the box below (responses to question 9 in the survey).

More detailed analysis of the general needs identified provides a wealth of information that will assist in designing a national information system that can meet the needs of the diversity of potential users.

To this end, investment in invasive species data and information must ensure that data are:

- relevant — providing factual social, economic, and environmental information that meet requirements of users with different perspectives, interests and values;
- accessible — presented in a way that is easy to understand and readily available; and
- consistent and comparable — able to be integrated with other data to analyse trends in the state of natural resources.

9. Weed management: A range of specific weed management type of information is potentially available. Do you think information on the following would be useful?

	Strongly agree	Agree	Not sure	Disagree	Strongly disagree	Response count
Weed prevention	**70.5% (237)**	26.5% (89)	2.4% (8)	0.3% (1)	0.3% (1)	336
Early detection and eradication	**77.6% (263)**	20.4% (69)	1.8% (6)	0.0% (0)	0.3% (1)	339
Biological control	**54.2% (182)**	38.1% (128)	5.1% (17)	2.1% (7)	0.6% (2)	336
Physical control	**58.3% (197)**	37.9% (128)	3.0% (10)	0.6% (2)	0.3% (1)	338
Chemical control	**55.9% (189)**	37.9% (128)	3.8% (13)	1.8% (6)	0.6% (2)	338
Cultural control	**51.8% (174)**	36.3% (122)	10.4% (35)	1.2% (4)	0.3% (1)	336
Integrated weed management	**69.3% (232)**	26.9% (90)	3.3% (11)	0.3% (1)	0.3% (1)	335
Ongoing maintenance	**65.6% (221)**	31.2% (105)	2.7% (9)	0.3% (1)	0.3% (1)	337
Additional comments						37
					Answered question	340
					Skipped question	45

Searching for natural enemies of cabomba (*Cabomba caroliniana*) in its natural habitat. Photo Ricardo Segura, CSIRO Entomology.

Can BioSIRT be adapted to meet national weeds information needs?

BioSIRT (Biosecurity Surveillance Incident Response and Tracing) is a spatial and textual web based software application being developed to enable better management of information and resources in emergency responses across animal or plant diseases, pests and incursions. BioSIRT will be used by each jurisdiction for managing emergency and routine incidents. When planning the end-user needs project, it was anticipated that new modules may be able to be designed to adapt BioSIRT to other user needs. Where possible it is highly recommended that such systems utilise the standards developed for BioSIRT as part of a national set of core attributes[1], to facilitate interoperability[2] and linkage with BioSIRT.

After consultation with BioSIRT domain experts and BioSIRT state-based administrators it was decided that in its current form BioSIRT is not suited to the capture, collation, storage and mapping of invasive species information for use by the general public. Existing web-based mapping programs such as Weed Watcher with simple user interfaces and functionality are considered more practical for this purpose.

In this respect, consideration should be given to making such systems cover all of Australia. Where possible it is highly recommended that such systems utilise the standards developed for BioSIRT to facilitate interoperability and linkage with BioSIRT.

Conclusions

Based on the findings of the current project a number of important issues have been identified. Key among these are that:

- To date, there is no nationally agreed information system in place for the collection, collation, storage and management of invasive species data and information and many believe there is a need for such a system to be introduced. Significant improvements have been obtained in recent years, though further work is required before a national system can be put in place.
- Most jurisdictions and organisations (e.g. local governments) have disparate datasets on existing distribution, while existing datasets on potential distribution are considered to be poor.
- Most users require a national system to include a range of data and information including management and policy, legislation, identification, access to research results and reporting tools. Streamlining access to such data and information has been identified as a high priority.
- Enhanced coordination is required to improve efficiencies and remove duplication.

Overall, it is clear that there are great efficiencies to be gained when data and information are acquired, processed and disseminated based on agreed standards and within a collaborative framework involving all levels of data providers and users.

The results of the current project provide a valuable basis from which to pursue the development of a national information system for weeds.

1. Thackway, R., McNaught, I. & Cunningham, D. 2004, 'A national set of core attributes for surveying, mapping and monitoring weeds of national significance', in B.M. Sindel & S.B. Johnson (eds), *Weed management: balancing people, planet, profit,* Papers and proceedings of the 14th Australian Weeds Conference, Wagga Wagga, New South Wales, Australia, 6–9 September 2004.
2. Interoperability is defined as the capability to communicate, execute programs, or transfer data among various functional units in a manner that requires the user to have little or no knowledge of the unique characteristics of those units (ISO 2382-1). Interoperability of spatial information means direct, on-demand access to distributed web-services that support business processes.

This paper is based on the report 'Assessing end-user needs of a national information system for weeds' by Christopher Auricht and Graham Yapp.
The full report is available at lwa.gov.au/weeds

Printed on Revive Silk which is made in Australia from elemental chlorine free pulp with 65% derived from sustainable plantation forests and 35% recovered fibre. It is PEFC Certified and Australian Paper is an ISO 14001 certified mill which utilises renewable energy sources.

Published by: Land & Water Australia
Web: www.lwa.gov.au
ISBN print: 978-1-921544-93-4
ISBN electronic: 978-1-921544-94-1

This publication can be ordered free of charge from CanPrint Communications, freecall: 1800 776 616, or e-mail: lwa@canprint.com.au and quote product code **PN30084**

Photos: This page, Roger Charlton
Design: Angel Ink
Print: Paragon Printers, June 2009

LWA project code DEH9

Australian Government
Land & Water Australia

Government of South Australia
Department for Environment and Heritage

The Environmental Weed Management Action Tool (EWeed MAT) — a new tool for regional environmental weed planning

Melissa Herpich and Dr Andrea Lindsay

Environmental weeds, those species of plant which can successfully invade and reproduce in bushland areas, are a recognised threat to the biodiversity of remnant vegetation across Australia.

Growing recognition of the risk has seen the proliferation, in recent years, of a multitude of weed plans and strategies across all levels and scales of government and natural resource management planning. While these are designed to guide efforts against weeds in a strategic manner most plans fail to include practical considerations, such as where the weeds are, or are at a scale which fails to influence on-ground management.

The move towards regional natural resource management (NRM) planning has created the opportunity for environmental weeds to be tackled in a more effective way. It has created easy avenues for local knowledge on environmental weeds and their spread to be incorporated into planning processes and allows environmental weed management to be integrated with complementary activities such as the restoration, management and monitoring of natural areas. The existing mechanism for disbursement of NRM funds through the regions is also a logical way to direct funds towards weed management.

PRODUCED BY LWA'S WEEDS R&D PROGRAM. FUNDED BY THE AUSTRALIAN GOVERNMENT'S DEFEATING THE WEED MENACE PROGRAM.

In recognition of the advantages of regional environmental weed action, the South Australian Department for Environment and Heritage, in the South East Natural Resources Management Region of South Australia, has developed a planning tool to help prioritise on ground environmental weed actions at the regional scale. The result of this process is a model called the Environmental Weed Management Action Tool (EWeed MAT). This 'tool' was designed to be practical, providing regionally specific support for decision making for investment of weed management funds in on-ground works. Through the process of development EWeedMAt has been tested and refined in two NRM regions.

A risk management approach was used as the basis of the 'tool'. This produces an Environmental Weed Management Priority Index for each substantial patch of remnant vegetation within a region based on its biodiversity values and the threat of weeds to that biodiversity. The larger the Environmental Weed Management Priority Index the higher the priority of vegetation patches for weed management.

The biological attributes identified in EWeedMAT as important for the targeted NRM regions include well recognised indicators of remnant vegetation health and significance, specifically the presence of threatened ecological communities and species and measures of vegetation diversity. Physical values of each patch which affect invasion risk (shape, size and management factors) are also included in the calculation.

The weed threat values incorporated into the 'tool' include a numerical representation of the invasiveness and potential impact of major weed species present. These figures are combined with an infestation score representing the infestation level for each weed found in a patch of bush. It should be noted that the 'tool' incorporates measures of actual weed infestation at each patch of remnant vegetation considered, that is, it is not predictive.

EWeed MAT has proven to be an effective tool for encouraging strategic management of weeds across the landscape in the regions to which it has been applied. It has broad application to the temperate regions of Australia and could easily be adapted to incorporate other threats, or values relevant to management of natural areas. The tool is relatively simple to use, it runs through a spreadsheet rather than specialised software and can easily be adapted.

The Environmental Weed Management Action Tool was developed and published by the South Australian Department for Environment and Heritage and the South East NRM Board using funding from the Australian government. Results are now being used in the two NRM regions in South Australia where it was developed and tested.

For more information
on the EWeedMAT please contact:
Melissa Herpich
SA Department of Environment and Heritage
Tel: (08) 8735 1205
Herpich.Melissa@saugov.sa.gov.au

Printed on Revive Silk which is made in Australia from elemental chlorine free pulp with 65% derived from sustainable plantation forests and 35% recovered fibre. It is PEFC Certified and Australian Paper is an ISO 14001 certified mill which utilises renewable energy sources.

Published by: Land & Water Australia
Web: www.lwa.gov.au
ISBN print: 978-1-921544-95-8
ISBN electronic: 978-1-921544-96-5

This publication can be ordered free of charge from CanPrint Communications, freecall: 1800 776 616, or e-mail: lwa@canprint.com.au and quote product code **PN21608**

Photos: Front page, Melissa Herpich
Design: Angel Ink
Print: Paragon Printers, June 2009

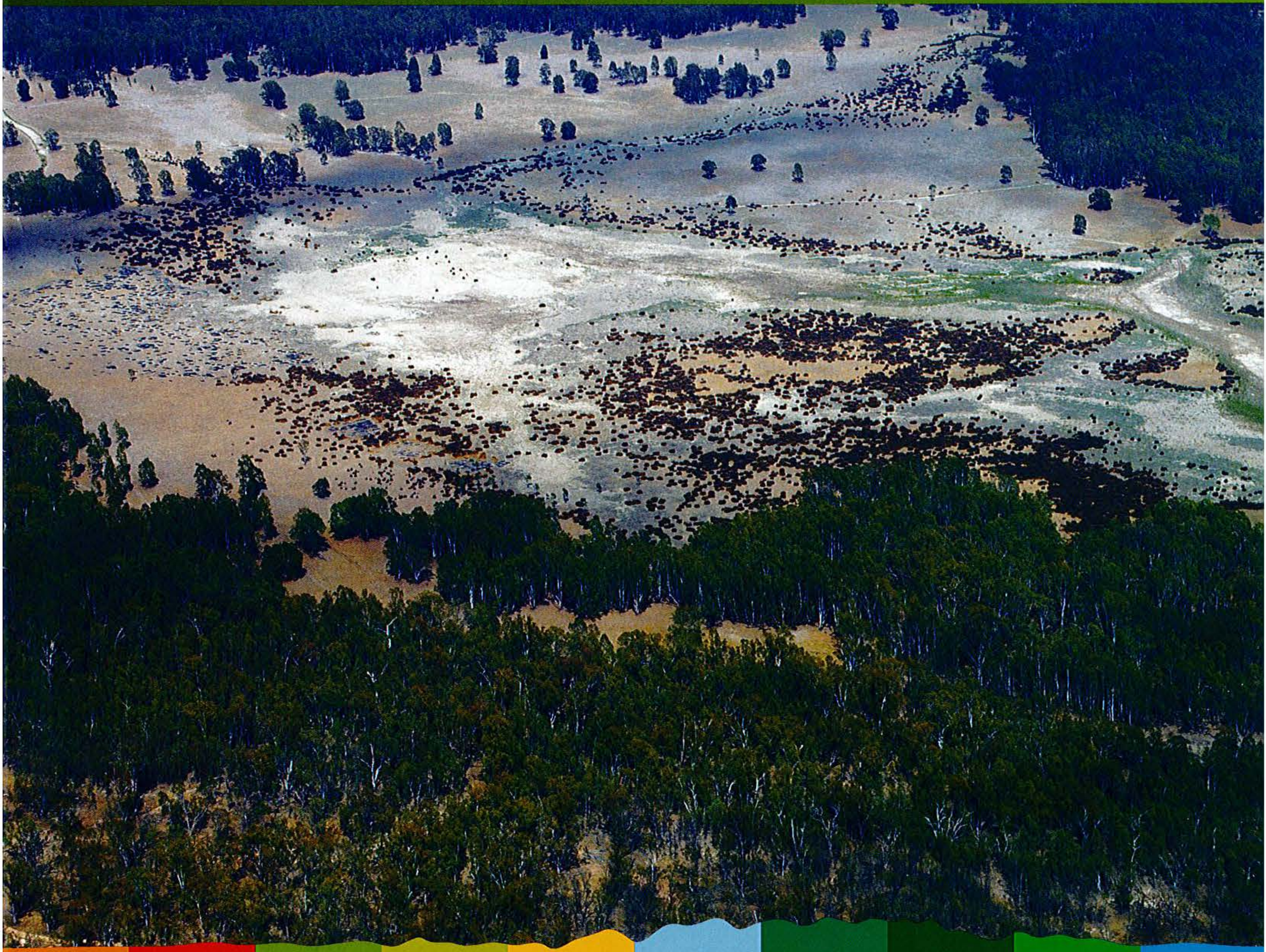
Australian Government
Land & Water Australia

CSIRO

State Government Victoria Department of Primary Industries

Control of environmental weeds: An integrated framework for natural resource management

Matthew Colloff[1], Fiona Ede[2], Louise Morin[1], Elizabeth Lindsay[1] and Kate Stokes[1]



Author's affiliations: 1) CSIRO Entomology, Canberra, ACT and 2) Department of Primary Industries, Frankston, Victoria.

Front cover: Aerial view of the extent of giant rush (*Juncus ingens*) invasion of a Moira grass-dominated temporary wetland at Barmah Forest, Victoria. Photo Keith Ward, Goulburn Broken Catchment Management Authority (GBCMA).

Summary

The integration of environmental weed control within a broader natural resource management framework is an important component of a whole-of-systems approach to conservation and management of our ecological assets. This approach is driven by increased awareness of the dynamic, interactive properties of ecosystems, and of the inter-connectedness of biodiversity, the delivery of ecosystem functions and services, and of threatening processes. Invasive plants represent one of the most significant threats to Australian ecosystems, and it is logical, timely and practical to take a unified approach to their management. Adopting a whole-of-system approach to ecosystem management allows the development of synergistic, cooperative, complementary interactions between biophysical, social and institutional frameworks, resulting in sets of management actions that have multiple ecological benefits across different parts of ecosystems. The realisation of multiple benefits is more likely if ecosystems are managed holistically than if their component parts (water, vegetation health, biodiversity, invasive species and soils) represent separate targets for management intervention.

This document outlines a conceptual framework for integration of environmental weeds management within a broader context of management for biodiversity outcomes and ecosystem functions and services. Its primary audience is natural resource management practitioners, scientists, and policy makers.

Introduction

Environmental weeds are invasive native or exotic plant species that often have detrimental effects on natural ecosystems. Their adverse impact may be on plant communities, invertebrate and vertebrate species, entire biotic assemblages and their food webs, or on ecosystem processes like nutrient cycling, hydrology, fire and flood regimes. Collectively, these effects can lead to a loss of ecosystem character and resilience, and a change to an undesirable ecological state which requires restoration. For these reasons, substantial resources are allocated for the control of environmental weeds.

A common belief is that weed control alone is all that is required to hasten the recovery of an invaded ecosystem. However, the responses of native plant and animal communities and ecosystem processes following weed control are often not monitored, which means there is no clear assessment of recovery. There are several documented examples indicating weed removal was followed not by a resurgence of native plants but by invasion of another weed, or by the original weed growing back. Re-establishment of native plants may also be hindered by the damaging effects of the weed control method (be it mechanical or chemical) or by a lack of natural regeneration due to depletion of the seedbank, or lack of other propagules. Such outcomes can have a devastating impact on the morale and sense of purpose of practitioners, especially members of volunteer natural resource management groups.

Gorse (*Ulex europaeus*) is now one of the worst agricultural weeds in temperate Australia and it is increasingly threatening native ecosystems.

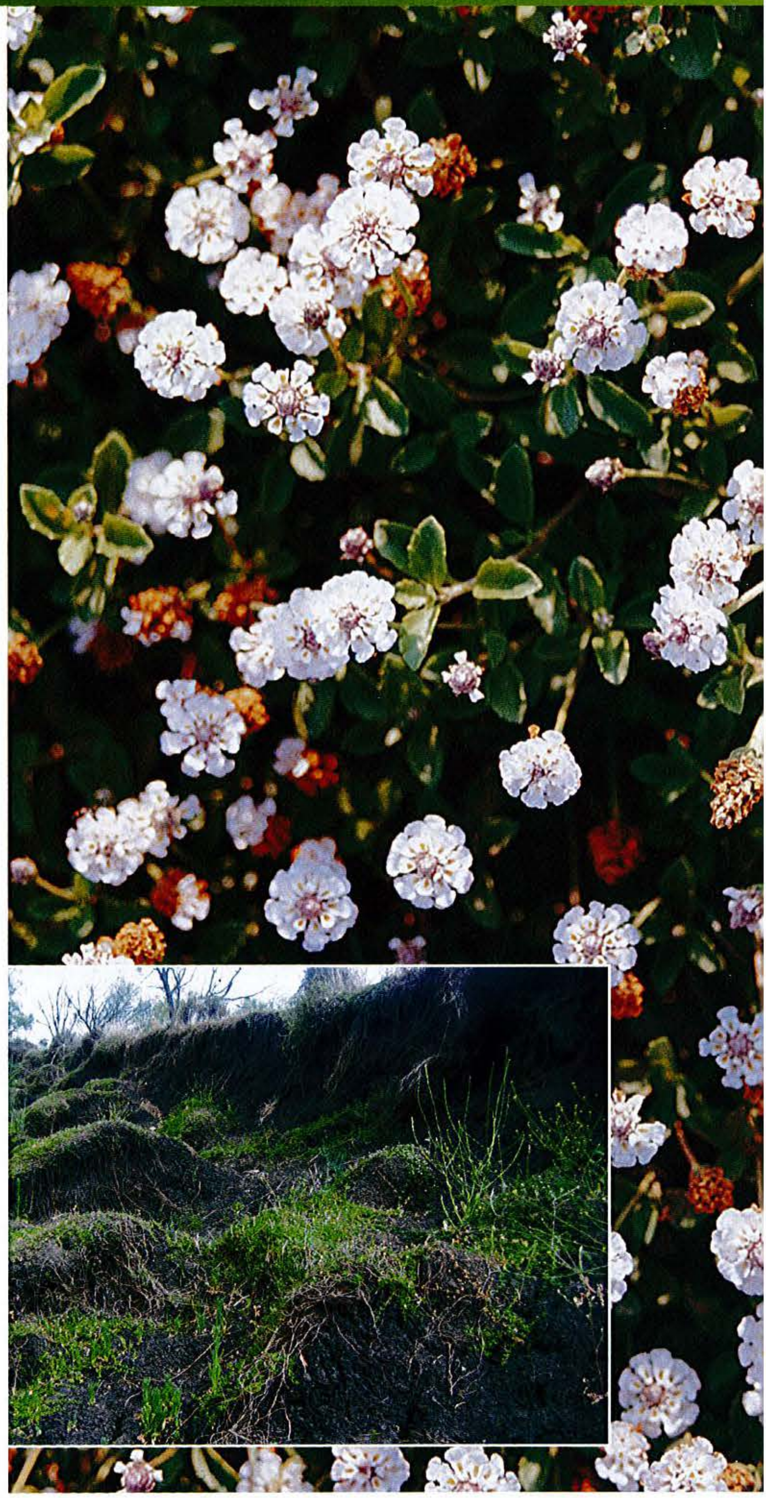
Photo Roger Charlton.

Whilst managers implement control programs for environmental weeds, considerable time and money is also devoted to managing and restoring other components of ecosystems, such as native biodiversity, soils and water resources. A whole-of-system approach, integrating weed management programs with other actions to assist the recovery of native communities, is generally the best way to restore structure and function of ecosystems and protect against future weed invasion. The challenge for managers and scientists is to develop cost-effective, integrated approaches to manage all key components of natural ecosystems in a way that builds on the inherent connectivity within natural ecosystems. Long-term monitoring becomes a vital component for evaluation of the effectiveness of these restoration approaches.

The key to this ecosystem-focused management approach is the identification, at the outset, of the desired ecological objectives and outcomes. Appropriate interventions can then be designed. At site scale, they may or may not include weed management, depending on the characteristics of the site.

The options available to managers for addressing ecosystem disturbance, change and variability are: 1) to passively accept these phenomena and try and adapt accordingly; 2) to actively attempt to stabilise, control and restore ecosystems to a pre-disturbance equilibrium, or 3) to anticipate that disturbance and change are inevitable, and to manipulate the system where possible to minimise harmful effects. An integrated, adaptive framework is about adopting the latter option and recognising that command-and-control approaches aimed at maintaining or restoring stability will almost always fail. Such an integrated framework helps managers identify cause-and-effect processes, understand that ecosystems are dynamic, and prioritise for interventions based on the likelihood of achieving the objectives. Resources are saved by not attempting activities with a low chance of success.

In circumstances where weed invasion is found to be a symptom of an underlying driver of ecosystem degradation, the appropriate strategy is to address the cause of the degradation, not just the weeds. These ideas are at the core of resilience-based approaches to adaptive natural resource management.



Lippia (*Phyla canescens*). Photo Guy Roth. Inset: Slumping of a creek bank due to cover of Lippia. Photo Rieks van Klinken, CSIRO.

The aim of this document is to outline a conceptual approach for integration of environmental weeds management within a broader context of management for delivery of ecosystem processes and services. Its primary audience is natural resource management practitioners, scientists, and policy makers.

Why do we have weed problems in natural ecosystems?

The role of disturbance and renewal

One view of ecosystems, evoked by tropical rainforests and coral reefs, for example, is that of complexity and stability due to high biodiversity and many intricate species interactions. The resilience of such high-biodiversity systems, i.e. their capacity to absorb disturbance, renew themselves and remain in the same state, is thought to be a function of the buffering capacity, or insurance value, of many species doing similar functional jobs (functional redundancy). When disturbance events knock some species out, others take their place. Another view is of ecosystems typified by relatively few keystone species, with little functional redundancy amongst them, and where heterogeneity and change are driven by strong, episodic, abiotic disturbance events like floods, fires and drought. Such systems include those of floodplains, rangelands, estuaries, temperate forests in medium rainfall zones and grassy woodlands.

Ecosystem disturbance is a complex restructuring mechanism. It expedites the maintenance of biodiversity by creating biotic and abiotic variation that emerge from ecosystem recovery and renewal. Heterogeneity of resources and habitats across ecosystems provides niche space, and opportunities for animals and plants, including weeds, to colonise and establish. Disturbance is critical for the very existence of particular ecosystems.

One approach to restoration is based on attempts to re-establish the natural patterns of flood and fire events, where these have been altered by human intervention. There are several examples where decreased fire frequency has changed plant community composition. One of these is the increase in range of sweet pittosporum (*Pittosporum undulatum*), from the rainforests of eastern Victoria into bushland areas much further west, as fire frequencies in these latter areas have decreased. This species can dominate bushland and the dense shade created by invasive stands makes it difficult for native species to recruit.

Controlled burning of giant rush (*Juncus ingens*), an invasive native species that has taken over temporary wetland plains of Moira grass (*Pseudoraphis spinescens*) at Barmah Forest, Victoria, due to reduced flood frequency and soil moisture content. Photo Kim Pullen, CSIRO.

But disturbance can also initiate conditions that favour the dominance of one species, and the effects of disturbance vary according to frequency, intensity, duration, timing and scale, and on the prior condition of the ecosystem. The ecological impact of disturbance can be difficult to predict, especially where either the disturbance regime or the ecosystem itself has undergone human modification. Predicting and managing the effects of such changes on our native ecosystems represents the main objective and the greatest challenge facing natural resource management practitioners, scientists, and policy makers in Australia today.

Weeds as symptoms or causes of ecosystem change

One reason that environmental weed control alone may not lead to desirable ecological outcomes is because weeds may not be the primary driver of ecosystem change. Instead, weed invasion often represents a symptom of underlying ecosystem degradation, due to nutrient enrichment, overgrazing, changed flood or fire regimes; habitat fragmentation, or the combined, often synergistic effects of such processes.

An increase in plant-available soil nitrogen and phosphorus due to fertiliser drift, sediment deposition or nitrogen fixation by weedy legumes will have direct, detrimental effects on native plant communities not adapted to high nutrient levels. Weeds may thrive under such conditions. Another example of how external drivers of ecosystem change relate to invasibility is stream flow, a strong determinant of riparian vegetation structure. Changes in stream flow, or alteration in flood regimes due to river regulation (dams, weirs and locks), affect both the recharge of groundwater and the water content of riparian and floodplain soils. Lowered soil moisture content due to decreased frequency of flood events may favour more terrestrially-adapted weeds over flood-dependent native vegetation.

These examples highlight a major challenge: the need to improve our understanding of how cause-and-effect relationships operate in natural ecosystems. A weed invasion may be a consequence of ecosystem disturbance, but once established, some species can be important causes of further ecosystem degradation, as witnessed by the damaging ecosystem engineering effects of Lippia and giant rush (see photographs). Determining whether weeds are drivers of ecosystem change or 'passengers' — taking advantage of habitat modification — is an important issue for managers. It is likely that both situations occur depending on weed species, ecosystems and their degrading processes. With the 'passenger' scenario, management efforts need to address both the control of the weed and the underlying degrading process.

Why control environmental weeds? Impacts on biodiversity and ecosystem processes

Environmental weeds affect ecosystem processes by disrupting the functional roles that native biodiversity contributes to the maintenance of ecosystem character and integrity. Effects include those on native vegetation composition and structure; invertebrate and vertebrate communities, including habitat provision and maintenance of food webs; decomposition and soil nutrient cycling; disturbance regimes including fire; hydrological processes including water quality and availability, stream channel morphology and sediment dynamics; and changes in temperature and light levels. Knowing what effects weeds have on these processes better enables us to plan our management actions. There are few such studies, and more are needed. Some weeds may have relatively little impact, while others like willows, legumes, pasture grasses and climbers may be transformer species, or ecosystem engineers, that simultaneously affect one or more processes or assets of interest.

An aggressive invader of native bush, the blue morning glory (*Ipomoea indica*) vine can climb so high that it blankets trees up to 30 metres and so wide that it creates a dense mat up to a kilometre across. Photo Jeanette Nobes.

Native vegetation community composition and habitat provision

Weed invasion can result in reduced cover of native plants, especially when the weed dominates large areas and occupies the same habitat. Several of the photographs illustrate this effect. Plant and animal species may become locally extinct following invasion because weeds out-compete other plants for resources. The abundance of a weed is not necessarily an indicator of the decline in native species cover or community diversity, as the impact a weed has on native vegetation can vary according to the community it invades. The disturbance history of a site can strongly influence community response to invasion, and not all sites invaded by the same weed species should necessarily be managed in the same way.

Weed invasion can simplify native vegetation structure. This loss of structural diversity further decreases the diversity of plants and animals within a site. Managing weeds to restore spatial heterogeneity, and thus create niche opportunities for components of the original community, can also promote the coexistence of weeds and native vegetation. The damage of weed invasion to fauna may be significant if the weed has a different life cycle, phenology, or represents a substantially different set of food or habitat resources from the native plants it displaces; like where an invasive shrub replaces grasses and herbs, or an annual weed replaces perennial natives. Effects can be especially severe for animals that rely on native plants for food. For example, where, a plant bearing palatable, fleshy fruit is replaced by a weed with large hard seeds.

Environmental weed control can become a complex issue if the weed has been present for long enough to provide alternative resources for native animals. The shrubby weed lantana (*Lantana camara*) provides habitat and food for native birds and protection against the aggressive noisy miner (*Manorina melanocephala*) which is abundant in adjacent open areas. Lantana appears to be associated with higher native bird diversity. This is a good example of an ecological trade-off scenario, where our viewpoint is dependent on the conceptual boundaries we draw around the system. From one perspective, a Weed of National Significance may be providing a habitat benefit to native birds. But alternatively, at a pristine site, or one revegetated after lantana removal, a well-developed native understorey will provide benefits not only to native birds, but to other species and to natural ecosystem processes. The trade-off we make is whether to leave the lantana in place and impart a perceived biodiversity benefit, remove it and reduce bird diversity (with likely knock-on effects, such as avian control of pest insects), or remove it and revegetate with native plants. These sorts of decisions force us to re-think how we manage weeds in a whole-of-systems framework. In such circumstances weed control has to be linked to restoration and provision of alternative native habitat and resources. Weed control and restoration may have to be done in a mosaic fashion in several stages.

Blackberry thickets infest about 9 million hectares of temperate Australia and are difficult and costly to control. Photo Roger Charlton.

Soil nutrient cycling

The availability of essential nutrients affects the productivity, composition and interactions between populations of plants, animals and microbes. While some weed invasions are more successful on nutrient-enriched soil, other plants can directly or indirectly alter soil nutrient levels. Soil fertility is based on parent material and the processes of plant and animal matter decomposition and nutrient cycling. Weed invasion can change the cycling time of nutrients from soils to plants and back to soils. This can be via changes in the invertebrate and microbial community and the development of plant-soil-microbial feedbacks that can slow or hasten nutrient cycling.

Many post-invasion changes to the decomposer community are due to the leaves of the weed being of different quality or being added to the litter layer at a different rate to those of the native vegetation. A change in the amount of leaf litter can also affect the environment in which native plants germinate and establish. Alteration of soil nutrient concentrations and decomposer communities by weeds may facilitate weed persistence and lead to problems with re-establishment of native plants after weed eradication. Positive feedback loops such as these are very hard to manage because the underlying conditions (e.g. soil nutrients) must be modified before the original vegetation can compete effectively with the weed species.

Australian native sclerophyll species are particularly sensitive to changes in soil nitrogen and phosphorus, and their symbiotic fungi and bacteria may be lost from the system after long-term disturbance, hindering native plant re-introduction.

One example of how weeds can directly increase soil nutrients is through the fixation of atmospheric nitrogen. Many weeds do this, including Acacias, gorse (*Ulex europaeus*) and English broom (*Cytisus scoparius*). These plants produce nitrogen rich leaf litter which adds to the soil nitrogen pool as the litter decomposes.

Impacts on aquatic systems

Willows (*Salix* species) have major impacts on stream flow and water availability through altering the structure of banks and stream beds, as well as changing sediment deposition and channel direction. Differences in the seasonal timing of life cycle events between natives and exotics can have consequences for native communities. Willows and river red gum (*Eucalyptus camaldulensis*) both occur in riparian zones but deciduous willows shed all their leaves in the Autumn, whereas evergreen red gums shed far fewer leaves throughout the year. These events result in different levels of river shade and litter decomposition rates. This results in changes in abundance, diversity and composition of terrestrial and aquatic invertebrates, with potential consequences for associated riparian fauna and food webs.

Willow on the Ovens River, Victoria, showing accumulation of coarse woody debris in the channel and alteration in stream flow.
Photo Trevor Hunt, Department of Primary Industries, Victoria.

In relation to water quality, the effect of certain aquatic weeds with emergent or floating leaves is likely to shade out submerged native species. Where floating-leaved plants have replaced submerged vegetation the result can be significant oxygen depletion in the water, because these plants vent oxygen to the atmosphere, not into the water. This has cascading effects on freshwater food webs, typically depletion of fish and invertebrate populations.

Loss of genetic diversity — implications for ecosystem resilience

High genetic variability is important for development and maintenance of diverse community structure and resilience, as genetically variable populations of organisms are likely to better withstand and recover from perturbation. Weed invasions can decrease the genetic diversity of native plants by reducing their population size. This characteristic is measurable but may easily be overlooked if sites are assessed only on the basis of species diversity of native plants.

A second mechanism whereby weed infestations can narrow the genetic variability of native species relates to those weeds which reproduce primarily by vegetative means. For these weeds, their populations at a site are genetically homogeneous — they are all clones of the parent plant. There is some evidence that invertebrate diversity is strongly linked to the genetic diversity of their host plants. Were this phenomenon found to be significant and widespread, it follows that clonal populations of environmental weeds would be likely to host depauperate invertebrate communities, with detrimental consequences for food web structure and other ecosystem properties and processes.

A consequence of the need for awareness of threats to genetic diversity relates to our restoration activities. It may be better to mix genetic resources of species at restoration sites, rather than strictly using seeds of local provenance. This is particularly relevant if we are seeking to establish sites which are resilient to climate change, whereby broad genetic diversity of each species may give the best chance of the ecosystem persisting over the long term.

Salvinia (*Salvinia molesta*) covering a lake at Kakadu, Northern Territory. With such dense coverage, light and oxygen levels in the water are greatly reduced. Photo Shon Schooler, CSIRO.

Small scale herbicide control of bitou bush (pictured in inset) on fore dunes in New South Wales. Both photos Kris French, University of Wollongong.

Managing weed-invaded natural ecosystems — protecting our natural assets

Management of our natural resources requires articulation of clear, explicit outcomes. There is a need for natural resource managers to critically examine, on a case-by-case basis, exactly why they are embarking upon weed control and other management actions and what outcomes they are seeking to achieve. Weed management should be a means to an end of ecosystem management, not an end in itself. This requires definition of the assets that will be protected and enhanced by all management activities. These assets may be physical ones, such as water quality and availability, stabilisation and integrity of soils and river banks, soil nutrient status and structure. Or, they may be biological ones, such as aquatic and terrestrial vegetation communities, threatened species, assemblages of vertebrates and invertebrates, or indeed the combination of habitat and community types that give a particular ecosystem its defining characteristics. Assets also incorporate biotic and abiotic interactions, which manifest as ecological functions and processes, and they include assets defined by society on the aesthetic, cultural, recreational and spiritual values of ecosystems.

An integrated framework for restoration and threat abatement

Control programs set within the broader context of natural ecosystem management and restoration are likely to have a better chance of success for ecological, institutional and operational reasons. In an integrated restoration plan, economies of scale can be achieved through bringing together the resources of a broader group of stakeholders than those interested primarily in weed control. Greater capacity to influence underlying drivers of ecosystem degradation is also possible, especially where these relate to cross-jurisdictional land and water use policies and practices.

Integrated approaches to managing environmental weeds in natural ecosystems are not new. For example, re-establishment of native vegetation has been identified as a key component in the management guides of some Weeds of National Significance including lantana, willow, boneseed, mimosa, Chilean needle grass, pond apple, serrated tussock and blackberry. For others (bridal creeper, gorse, prickly acacia, parthenium weed, mesquite, tamarisk, and parkinsonia), the emphasis on integrated approaches is not so strong, and there may be sound logistical reasons for this. Nevertheless, there is considerable scope to build on the promising beginnings of more integrated approaches.

Cattle in an unfenced riparian zone, Surry River, Victoria. Riparian zones are particularly susceptible to stock damage due to trampling, nutrient enrichment from urine and dung and transport of weed propagules. Photo Trevor Hunt, DPI Victoria.

Recovery, restoration and revegetation — weed management for ecological benefits

The identification of multiple ecological benefits from relatively few highly-targeted actions is of immense value in natural resource management, but there are few examples that have been put into practice on a large scale. One of the more important is the restoration of native vegetation: either natural regeneration by encouraging natural recruitment processes, or revegetation with tubestock or direct seeding. Revegetation with trees and shrubs requires investment in weed control for site preparation and during the growth and establishment phase. The simple act of stock exclusion by fencing areas targeted for regeneration has the benefits of encouraging recruitment through eliminating grazing on young trees and shrubs, reducing soil compaction and erosion from trampling and stock camps, as well as halting the accumulation in soil of excess nutrients from dung and urine.

There is a need for follow-up activities such as stimulating seedbank germination (for example through judicious use of fire), adding local native seeds or transplanting seedlings combined with sustained removal of new weed recruits in order to assist the recovery of native communities following control of the dominant weed species. Nonetheless, any possible underlying causes of the initial weed invasion will need to be identified and addressed before native plant communities can successfully be restored over the long term.

The adverse effects on remnant woodlands of grazing pressure, nutrient enrichment from wind drift and environmental weeds are inextricably linked and there may be conflicts of use for land managers, such as the value of remnants for stock shelter, but a desire to improve native plant diversity as part of a LandCare program. Short periods of so-called 'strategic grazing' are one possible method for removing weeds and the nutrients they have accumulated from the soil, thus creating conditions more conducive for native vegetation. Yet the deposition of dung and urine from grazing stock may add to nutrient levels. Thus at farm-scale, strictly controlling grazing access to remnants, combined with planting shelter belts to intercept windborne nutrients and adopting conservation tillage to retain nutrients in cropping areas goes some way to satisfying both production and conservation objectives. Novel restoration approaches, such as redressing soil carbon-nitrogen ratios are more likely to emerge from adopting whole-of-systems frameworks.

The importance of monitoring

Monitoring is an essential part of any natural resource management activity, including weed control, yet there is a belief that it is unnecessary and diverts resources from what is seen as the main task. Without monitoring, not only is there no proof that the desired outcome was achieved, but it is impossible to undertake an adaptive approach to management and determine whether additional interventions are required to assist the recovery of native plant communities. Monitoring includes both the reduction of the weed populations and the subsequent responses of native species. This means there is a need to sustain monitoring efforts over timeframes that are consistent with the rate of ecological recovery. Short-term programs represent a serious mismatch between monitoring needs for weed control and broader natural resource management outcomes.

Given the importance of differentiating whether weed invasion is a cause of ecosystem degradation or an effect of other degrading processes, there are significant knowledge gaps of how an effective monitoring program could be designed and implemented by on-ground land managers without significant input from researchers trained in sampling design and data analysis. Another concern is the collection of monitoring data without any framework for its assessment and use. Active monitoring of the response of weeds and native plant communities using quantitative methods should be an integral component of weed control programs in natural ecosystems, to underpin subsequent adaptive management actions and document outcomes of programs. Such methodologies can be integrated into broader evaluations, such as the Monitoring, Evaluation, Reporting and Improvement (MERI) framework. This is a modification of the widely-used principles of adaptive management and has been adopted as a generic basis for evaluation of natural resource management programs in Australia (http://www.nrm.gov.au/publications/frameworks).

The importance of environmental stewardship

Environmental stewardship programs involve paying private landholders for managing environmental assets on their land. This is a particularly important issue because over 70% of land in Australia is under private management, either as leasehold or freehold. Such programs provide both an opportunity to manage ecological assets on private land in a holistic way using valuable local knowledge, but also represent a considerable challenge for stewards in terms of knowledge transfer of systems-based understanding, setting realistic goals and targets, and the monitoring and assessment of outcomes. Development of partnerships with agency-based natural resource managers and scientists can help overcome this challenge in part, but can be time-consuming and resource-intensive.

Possibly the most valuable aspect of environmental stewardship programs is they are designed to be long term, providing the ideal opportunity for ongoing monitoring. The recognition that ecosystems do not operate on three-year funding cycles is a major step forward in natural resource management policy in Australia. A broadening of this recognition to allow for management and restoration of natural ecosystems within a realistic ecological timeframe can only improve the likelihood of successful outcomes.

Setting up permanent transects in a blackberry infestation to facilitate monitoring following implementation of control program.

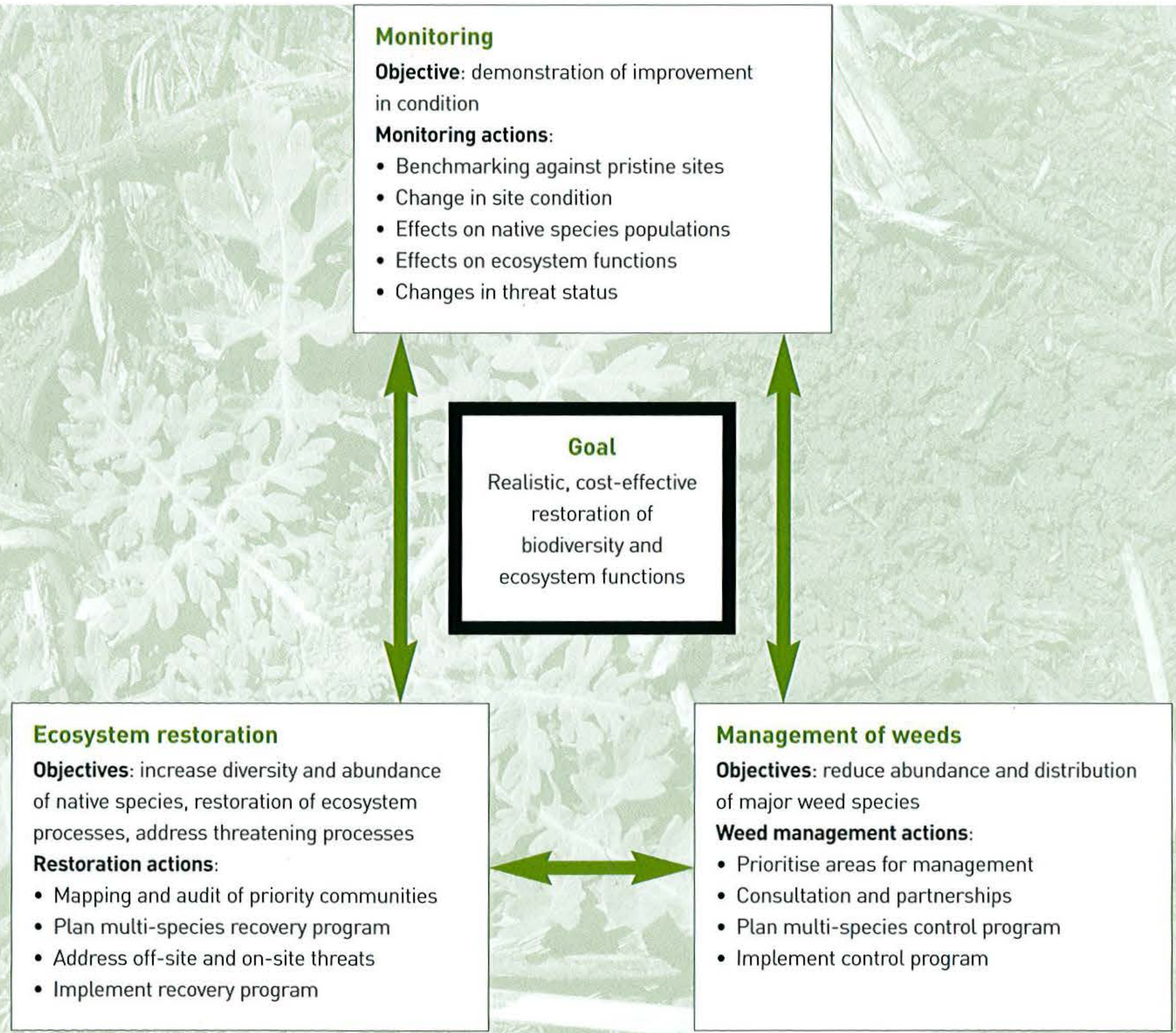
Photo Louise Morin, CSIRO Entomology.

A planning process for management of environmental weeds

How does a manager select sites where the greatest ecological outcomes might be achieved? Priority setting includes consideration of both assets and threats amongst different sites, but also the weeds present within a site. Unless an environmental weed is the target of a feasible eradication or containment program, control should target multiple weed species and have the long-term aim of restoring native communities and ecosystem processes. So at some sites all weeds would be targeted, whereas at others some weeds might be managed and the rest left in place.

The stages and questions outlined in the panel opposite represent the weed management component of an integrated natural resource management program (see diagram). Consultation with key stakeholders is integral to planning, and development of partnerships will improve the likelihood of long-term success. Although the process outlined opposite is step-wise, an iterative, adaptive management approach will be most effective. Thus information gained during the development of one part of the program is fed back to refine the program. Adaptive feedback allows the data collected during the monitoring and evaluation phase to be used to inform feasibility of management objectives, threat control and the most appropriate control options.

A conceptual framework for integrating monitoring, weed management and actions to assist recovery of the ecosystem to more effectively restore weed-invaded natural ecosystems.



Strategic planning

1. Identify the assets in the system being managed. What key assets will management activities protect or enhance, and what are the physical, biological and cultural values of these assets? Are there off-site assets that require protection?

2. Identify and assess the threats posed to those assets (such as altered hydrology, soil nutrients, weeds). What factors pose a threat to the assets and their values and are they major or minor? Which threats require priority management?

3. Identify the feasibility of managing each threat. Is it possible to manage all the threats and are management strategies for different threats co-dependent or synergistic? Will managing all the threats result in an acceptable benefit for the required investment?

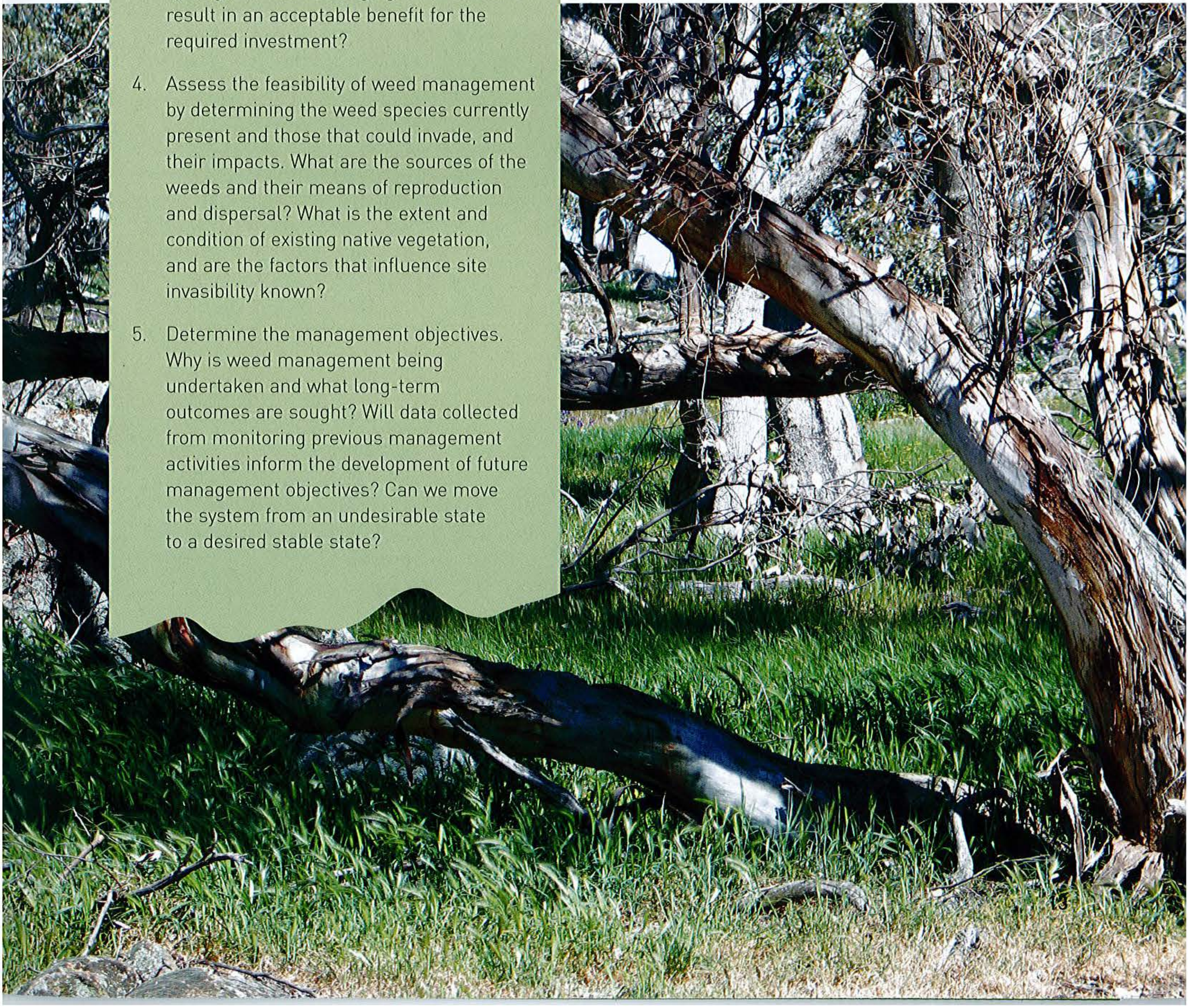
4. Assess the feasibility of weed management by determining the weed species currently present and those that could invade, and their impacts. What are the sources of the weeds and their means of reproduction and dispersal? What is the extent and condition of existing native vegetation, and are the factors that influence site invasibility known?

5. Determine the management objectives. Why is weed management being undertaken and what long-term outcomes are sought? Will data collected from monitoring previous management activities inform the development of future management objectives? Can we move the system from an undesirable state to a desired stable state?

Addressing these steps will require an assessment of the landscape context of the area to be managed. Where degradation has significantly changed communities and ecosystems it will be very difficult to restore the original native vegetation. Under such circumstances the main initial purpose of control might be to contain the spread of weeds and therefore reduce their impact on sites of higher native diversity nearby.

Undertaking the steps in the strategic plan will help determine if an environmental weed management program is appropriate. If it is, these same steps can be used to assist in prioritising sites. Once these decisions have been made, the operational details can be developed.

Weed invasion near Boorowa, NSW due to nutrient enrichment in grassy woodland adjacent to agricultural land. Photo Elizabeth Lindsay, CSIRO.



Natural regeneration of *Acacia* sp. adjacent to an area invaded by blue periwinkle (*Vinca major*), Tambo River, Victoria. Photo Fiona Ede.

Future directions

We are just beginning to understand the complexities of how natural ecosystems work. Ideally, we need a deeper understanding of ecosystem functions, processes and responses before we even attempt weed control. But, as in many cases in natural resource management, we are obliged to act with incomplete information. This does not preclude developing clear objectives based on current knowledge and the desired ecosystem state. Improving our understanding of the overall ecological context of weed management and other management activities has two main implications.

First, we are beginning to focus on understanding the impacts of environmental weeds on ecosystems. These include effects on the structure and composition of plant and animal communities, interactions between species and between biotic and abiotic components of ecosystems, and on ecosystem functions such as soil nutrient cycling. Knowing what effect weeds have on these processes better enables us to plan our management actions. Some weeds may have relatively little impact, whereas others like willows, legumes, pasture grasses or climbers may be transformer species, or ecosystem engineers, that significantly affect one or more processes or assets of interest.

Second, we need much better understanding of the outcomes of our management actions. This forces us to face questions such as whether our interventions are achieving the positive outcomes we are seeking. The inclusion of adequate monitoring and evaluation, often extending beyond the life of the intervention activities, as standard components of many natural resource management programs will enhance not only the assessment of success for specific interventions, but aid the generation of knowledge that would lead to improved predictive capacity.

Acknowledgements

We thank Shon Schooler and John Scott (CSIRO Entomology), Bruce Auld (Charles Sturt University) and Judy Lambert (Community Solutions) for reviewing the manuscript and their suggestions for its improvement. For providing photographs, we thank Keith Ward (Goulburn Broken Catchment Management Authority), Trevor Hunt (Department of Primary Industries, Victoria), Shon Schooler, Kim Pullen and Rieks van Klinken (CSIRO Entomology).

We also thank the Land & Water Australia Defeating the Weed Menace Program team — Jim Donaldson, Judy Lambert, Nolani McColl, Teresa Oppy and Nadeem Samnakay — for their support, encouragement and collaboration.

Further reading

Australian Government NRM Team 2008, *Australian Government Natural Resource Management Monitoring, Evaluation, Reporting and Improvement Framework*, 32 pages. http://www.nrm.gov.au/publications/frameworks/pubs/meri-framework.pdf (accessed 25 November 2008).

Duncan, D.H., Dorrough, J., White, M. & Moxham, C. 2008, 'Blowing in the wind? Nutrient enrichment of remnant woodlands in an agricultural landscape', *Landscape Ecology*, vol. 23, pp. 107–119.

Didham, R.K., Tylianakis, J.M., Hutchison, M.A., Ewers, R.M. & Gemmell, N.J. 2005, 'Are invasive species the drivers of ecological change?', *Trends in Ecology and Evolution*, vol. 20, pp. 470–474.

Ede, F. & Hunt, T. 2008, *Habitat management guide — Riparian: weed management in riparian areas: south-eastern Australia*, CRC for Australian Weed Management, Adelaide, 20 pp.

Greenwood, H., O'Dowd, D.J. & Lake, P.S. 2004, 'Willow (*Salix x rubens*) invasion of the riparian zone in south-eastern Australia: reduced abundance and altered composition of terrestrial arthropods', *Diversity and Distributions*, vol. 10, pp. 485–492.

Herpich, M. & Lindsay, A. 2008, *Environmental Weed Management Action Tool*, Department for Environment and Heritage, Mount Gambier, SA.

Holland-Clift, S. & Davies, J. 2007, *Willows National Management Guide: Current Management and Control Options for Willows (*Salix *spp.) in Australia*, Victorian Department of Primary Industries, Geelong, www.weeds.org.au/WoNS/willows

Levine, J.M., Vilà, M., Carla, M.D.A., Jeffrey, S.D., Karl, G. & Sandra, L. 2003, 'Mechanisms underlying the impacts of exotic plant invasions', *Proceedings of the Royal Society B: Biological Sciences*, vol. 270, pp. 775–781.

Mason, T.J. & French, K. 2007, 'Management regimes for a plant invader differentially impact resident communities', *Biological Conservation*, vol. 136, pp. 246–259.

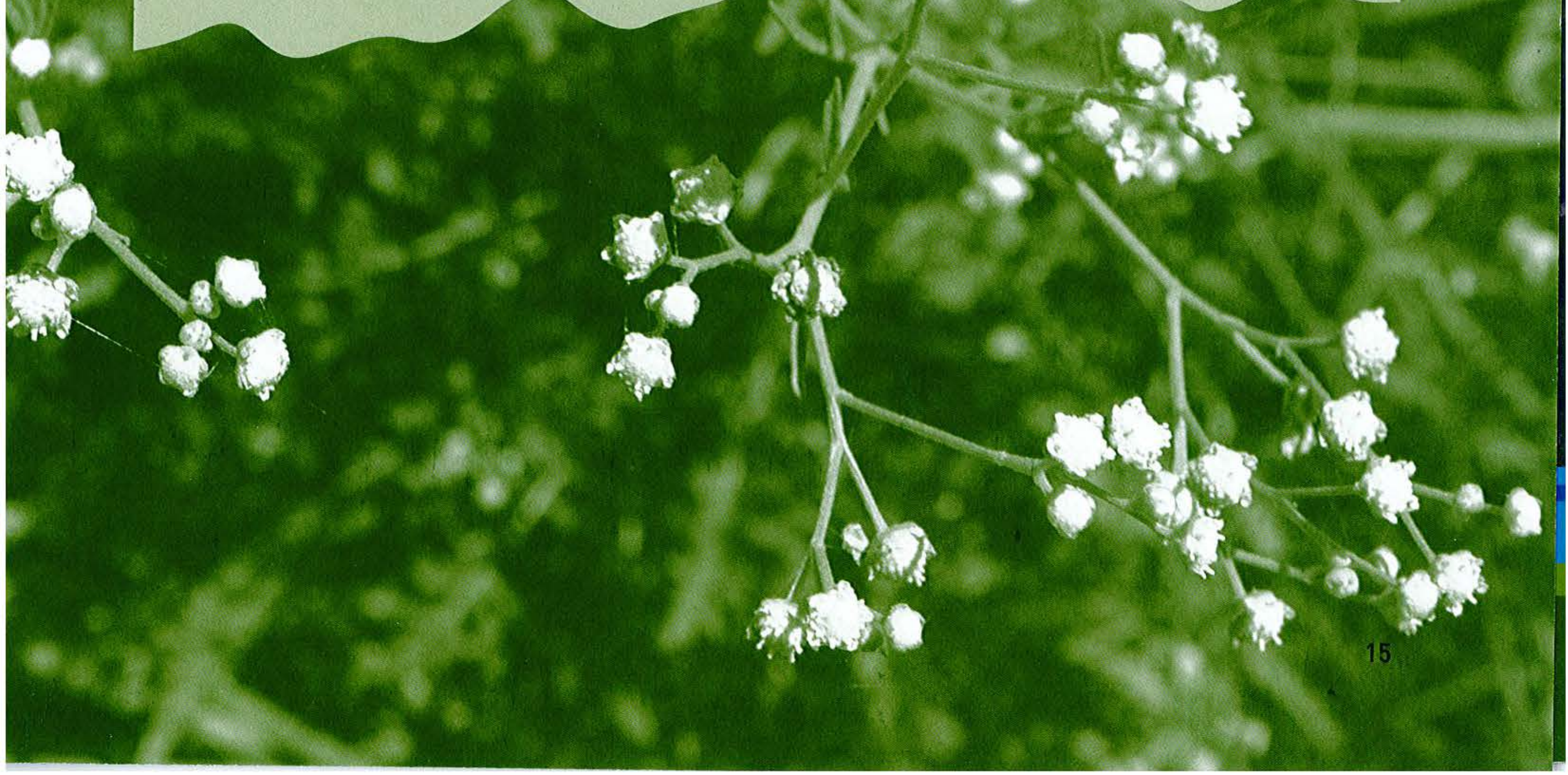
Reid, A.M., Morin, L., Downey, P.O., French, K. & Virtue, J.G. 2008, *Evaluating the environmental benefits from managing WoNS in natural ecosystems. A report prepared for Land and Water Australia*, CSIRO Entomology, Canberra.

Reinhart, K.O. & Callaway, R.M. 2006, 'Soil biota and invasive plants', *New Phytologist*, vol. 170, pp. 445–457.

Schulze, D.J. & Walker, K.F. 1997, 'Riparian eucalypts and willows and their significance for aquatic invertebrates in the River Murray, South Australia', *Regulated Rivers: Research and Management*, vol. 13, pp. 557–577.

Tylianakis, J.M., Rand, T.A., Kahmen, A., Klein, A.-M., Buchmann, N., Perner, J. & Tscharntke, T. 2008, 'Resource heterogeneity moderates the biodiversity-function relationship in real world ecosystems', *PLoS Biology*, vol. 6, no. 5, e122 doi:10.1371/journal.pbio.0060122

Wolfe, B.E. & Klironomos, J.N. 2005, Breaking new ground: soil communities and exotic plant invasion, *BioScience*, vol. 55, pp. 477–487.



PRODUCED BY LWA'S WEEDS R&D PROGRAM. FUNDED BY THE AUSTRALIAN GOVERNMENT'S DEFEATING THE WEED MENACE PROGRAM.

This is a discussion document prepared on behalf of the Defeating the Weed Menace Program for Land & Water Australia.

For more information e-mail: Matt.Colloff@csiro.au or see the website lwa.gov.au/weeds

Parthenium (*Parthenium hysterophorus*), a Weed of National Significance. Photo Arthur Mostead.

Printed on Revive Silk which is made in Australia from elemental chlorine free pulp with 65% derived from sustainable plantation forests and 35% recovered fibre. It is PEFC Certified and Australian Paper is an ISO 14001 certified mill which utilises renewable energy sources.

Published by: Land & Water Australia
Web: www.lwa.gov.au
ISBN print: 978-1-921544-61-3
ISBN electronic: 978-1-921544-62-0

This publication can be ordered free of charge from CanPrint Communications, freecall: 1800 776 616, or e-mail: lwa@canprint.com.au and quote product code **PN22368**

Photos: Front page, Keith Ward
Design: Angel Ink
Print: Paragon Printers, June 2009

Australian Government
Land & Water Australia

A commentary on funded biological control projects

Bruce Auld

Overview

In a suite of 27 national weeds research projects funded as part of the "Defeating the Weed Menace Program", Land & Water Australia funded seven projects under the theme "Biocontrol agents for national priority weeds". The projects related to weeds in all states and territories and included insects and fungi as control agents:

- **CEN7** – Enhancing noogoora burr biocontrol in northern Australia
- **CEN8** – Boneseed rust: A highly promising candidate for biological control
- **CEN11** – Biological control and ecology of alligator weed
- **CEN12** – Development of new biocontrol agents for parkinsonia
- **SARDI1** – Importation, rearing and field release of the Cape broom psyllid
- **UW07** – Improving management of salvinia in temperate aquatic ecosystems
- **VPI10** – Importation and release of a new biological control agent for Scotch broom

In addition, two projects under other themes, involved assessments of biological control of weeds:

- **CEN23** – Optimising management of core mesquite infestations across Australia
- **CEN24** – Evaluating the environmental benefits from managing WoNS in natural ecosystems

Cover photo: Cape ivy replacing bridal creeper following successful biological control at Broulee, New South Wales. Photo Louise Morin, CSIRO Entomology. Above: Mesquite (*Prosopsis*). Photo LWA.

These nine projects embraced the whole range of activities involved in classical biological control research and implementation, including:

1. Exploration overseas for potential candidate organisms.
2. Host range and efficacy testing of potential agents.
3. Importation of new agents.
4. Release of new agents.
5. Augmentative releases with agents already introduced.
6. Evaluation of agents released in the field.

The research projects met issues frequently encountered in biocontrol projects in Australia over many years:

1. The need for a long-term commitment in terms of both time and money to achieve a successful outcome.
2. The value in supporting projects that have reached a critical stage but lack future funding.
3. Logistical and legal problems involved in working in, and importing organisms from, several countries, as well as limited taxonomic knowledge of endemic flora and fauna in those countries.
4. Uncertainty in relation to host range of potential agents including genetic variation in target weed in native range.
5. Unpredictability in terms of efficacy of an agent once it is released into a new environment.
6. Unpredictability in terms of impact of successful biocontrol on either production or ecosystem recovery.

Highlights

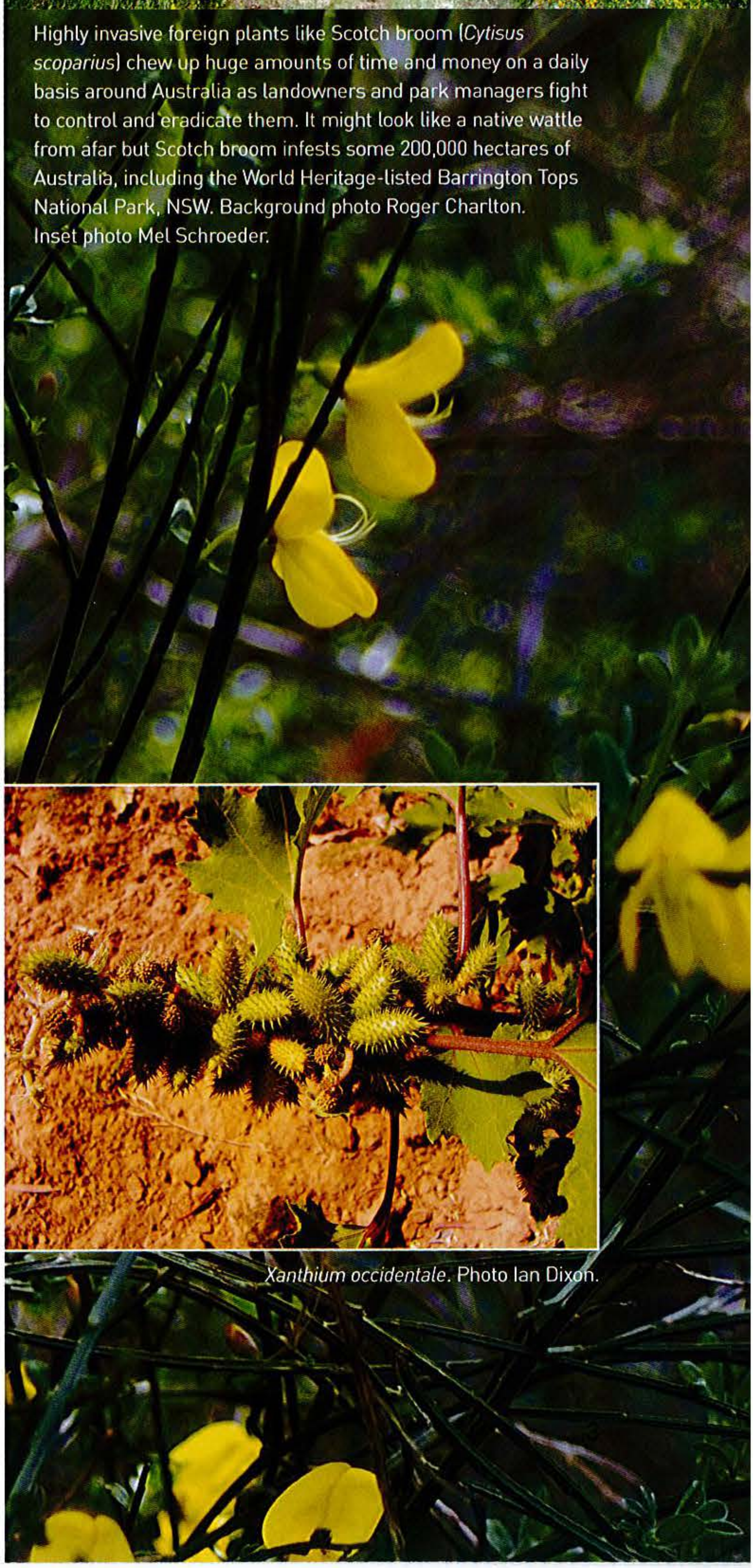
One project, VPI10, resulted in the importation, mass rearing and release of a new but previously approved biological control agent, the broom mite *Aceria genistae*, for control of Scotch broom *Cytisus scoparius*. The agent has been released in Victoria, South Australia and Tasmania and a release kit has been developed.

The boneseed rust (a systemic fungus) *Endophyllum osteospermi* (CEN8) has been imported from South Africa into quarantine for efficacy evaluation and host range testing. Although previously thought to take up to three years to produce disease symptoms on host boneseed plants *Chrysanthemoides monilifera* ssp. *monilifera* research has revealed that symptoms may be produced much earlier on some plants. A PCR (polymerase chain reaction) technique has been developed to detect whether the fungus has infected symptomless plants. These two findings will lead to a much quicker evaluation of the agent.

Exploration in Brazil, Ecuador and Peru, as well as finalising surveys in Central and North America and processing material from earlier surveys in Argentina and Paraguay has identified 50 new insect species associated with parkinsonia *Parkinsonia aculeate* (CEN12). From these, a prioritised list of 10 potential biocontrol agents for the weed has been developed as a basis for future work.

Other findings

New strains of the rust fungus *Puccinia xanthii* were imported from the Dominican Republic and Mexico as potential biocontrol agents for noogoora burr *Xanthium occidentale* in northern Australia (CEN7) in an attempt to find agents from similar climates. These strains did not infect Australian noogoora burr, highlighting the difficulties in matching agents with target weeds of both widespread origin and extensive distribution in Australia. In Australia, noogoora burr is a complex of four species of different origins in North and South America and unique hybrids may occur here, although the plants in northern Australia are apparently all one species *X. occidentale*. In the Americas, similar *Xanthium* species occur from Canada to Argentina. Similar problems could arise with parkinsonia, another species with a wide native range.



Highly invasive foreign plants like Scotch broom (*Cytisus scoparius*) chew up huge amounts of time and money on a daily basis around Australia as landowners and park managers fight to control and eradicate them. It might look like a native wattle from afar but Scotch broom infests some 200,000 hectares of Australia, including the World Heritage-listed Barrington Tops National Park, NSW. Background photo Roger Charlton. Inset photo Mel Schroeder.

Xanthium occidentale. Photo Ian Dixon.

Alligator weed. Photo Shon Schooler.

Witches' broom caused by the rust fungus *Endophyllum osteospermi* on a boneseed plant. Photo Louise Morin, CSIRO Entomology.

A potential biocontrol agent for alligator weed *Alternanthera philoxeroides*, a tip gall fly *Clinodiplosis alternantherae* failed host range tests by attacking two native plant species and will not be released. This project (CEN11) encountered difficulties in importing agents from Argentina and host range testing of two other potential agents: *Ophiomya morelli* (leaf mining fly) and *Systena nitenula* (beetle), are still awaiting completion. A new potential agent, a fungus *Uredo pacensis* from Bolivia, was also identified during this project. Again, this project has revealed genetic complexity in the target weed. There are at least three genotypes of alligator weed originating from Argentina in Australia. Fortunately these races apparently do not reproduce sexually here. Notwithstanding this, the finding emphasises the need for continued quarantine surveillance and exclusion for weeds already in Australia.

A project (SARDI1) aimed to import the Cape broom psyllid *Arytinnis hakani* to control Cape or Montpellier broom *Genista monspessulana* took a sharp change in direction when the psyllid was discovered to already be in Australia in the Mount Lofty Ranges. Subsequent host range tests suggest that the agent could be redistributed to other states.

Another project with a focus on mass rearing/redistribution, the augmentative approach to biocontrol, was conducted on the aquatic fern, salvinia *Salvinia molesta* (UW07). A biocontrol agent, the weevil *Cyrtobagous salviniae* already released with success in northern regions was investigated for distribution in temperate areas. Although temperatures lower than 20°C prevented larval development, factors other than temperature apparently also influence weevil activity.

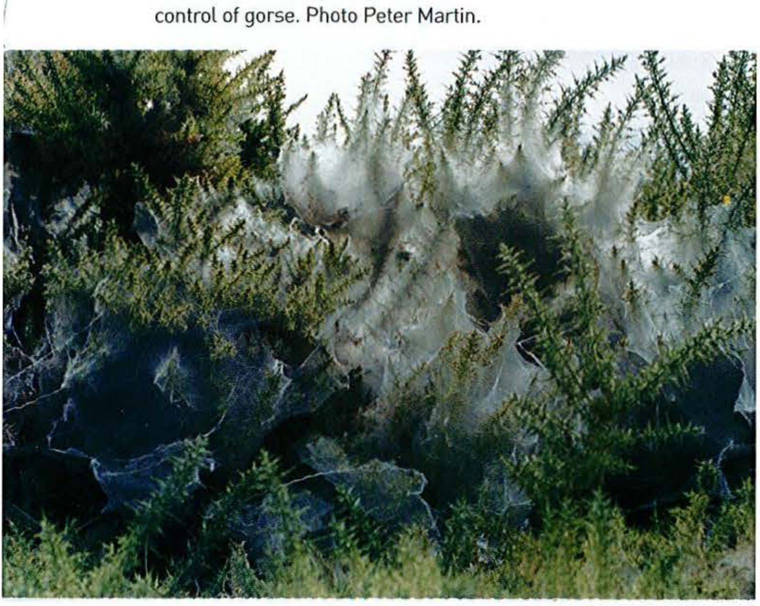
Impact of biological control

A study of the effect of management techniques on control of mesquite *Prosopsis* spp. (CEN23) showed that of three biocontrol agents released only one, the leaf tying moth *Evippe* sp. was having an impact. Mesquite consists of three species and hybrids that occur over vast areas of northern Australia. The moth's impact was greatest on hybrid mesquite in the Pilbara but other management of mesquite will be required to capitalise on the damage caused by the moth.

In areas where biocontrol of salvina had occurred (UW07) replacement of salvinia was frequently by another exotic weed *Egeria densa* dense water weed.

An evaluation of benefits from controlling Weeds of National Significance (CEN24), demonstrated that there are very few documented cases where responses and recovery were monitored. In a case study of the impact of the rust fungus *Puccinia myrsiphylli* on recovery of areas invaded by bridal creeper *Asparagus asparagoides* it was noted that whilst bridal creeper cover had decreased, there was an increase in bare areas and leaf litter and a slight increase in both native and weed species.

Above: Close-up of an adult of the leaf-feeding beetle (*Zygogramma bicolorata*) feeding on parthenium weed. Photo K. Dhileepan, Department of Primary Industries and Fisheries, Queensland. Below: Gorse spider mite (*Tetranychus lintearius*); a biological control of gorse. Photo Peter Martin.



Lessons and future prospects

The outcomes of the funded projects confirmed that while biological control is a highly suitable and desirable method for weed control in Australia, it is not a "silver bullet" that is a complete answer to weed management. Unpredictability in efficacy of agents, once released, remains as a limitation.

Control of a weed does not, in itself, necessarily lead to increased production or its replacement by desirable plants. Biological control must be integrated with other weed management tactics for successful production and biodiversity outcomes.

There is an urgent need for improved monitoring and evaluation of biological control of weed programs. Follow-up monitoring after release of agents should be built into research program plans. Investment in these activities should be increased although current short-term funding cycles do not encourage long-term evaluation.

This program has supported some projects that will clearly benefit from further funding to progress them towards completion (CEN8, CEN11, CEN12). With limited resources, future research efforts should target priority weeds where chances of success are considered relatively high.

The table on the following pages shows the weeds on which there has been some level of biological control research over the last decade. Of the 52 species (or groups, e.g. *Sida* spp.) at least 23 have been worked on for a much longer period (e.g. *Lantana camara*).

Clearly, research efforts and funding could be more focused on fewer target species. With this in mind, this program commissioned a project to assist in prioritising future research into biological control of weeds: "Improved targeting of weed biological control projects". A report on that project will be available on Land & Water Australia's website (lwa.gov.au) and will be widely disseminated to program and policy managers at national and state levels.

Please note: The table on the following pages is simply a summary overview. Evaluation of releases or impact is not included. For details of specific programs please contact the researchers involved.

Australian biocontrol projects: 1998–2008

Target species or group	Common name	Institutions involved (generally self-nominated)	Current status*				
			NA	OH	RS	RL	RD
Alternanthera philoxeroides	alligator weed	csiro, nsw dpi, dpi vic			X	X	
Xanthium spinosum	bathurst burr	csiro, nsw dpi	X		X		
Jatropha gossypiifolia	bellyache bush	csiro, dpi&f qld			X	X	X
Chrysanthemoides monilifera ssp. *rotundata*	bitou bush	csiro, nsw dpi, dpi vic			X	X	X
Rubus spp.	blackberry	csiro, dpi vic, nsw dpi, rmit			X	X	X
Heliotropium amplexicaule	blue heliotrope	csiro			X	X	X
Chrysanthemoides monilifera ssp. *monilifera*	bonessed	csiro, dpi vic			X	X	
Asparagus asparagoides	bridal creeper	csiro, dpi vic, nsw dpi				X	X
Cabomba caroliniana	cabomba	csiro			X		
Cassinia spp.	cassinia	nsw dpi	X			X	
Macfadyena unguis-cati	cats claw creeper	dpi&f qld, nsw dpi			X	X	X
Nassella neesiana	chilean needlegrass	dpi vic			X		
Rumex spp.	docks	dpi vic				X	
Emex spp.	emex	csiro	X			X	
Senecio madagascariensis	fireweed	csiro		X			
Fumaria spp.	fumitory	csiro, nsw dpi		X			
Ulex europaeus	gorse	tiar tas, dpi vic, csiro			X	X	X
Baccharis halimifolia	groundsel bush	dpi&f qld			X	X	
Marrubium vulgare	horehound	dpi vic			X	X	
Hyptis suaveolens	hyptis	csiro	X		X		
Cylindropuntia rosea	hudson pear	nsw dpi			X		
Lantana camara sens. lat.	lantana	dpi&f qld, nsw dpi			X	X	X
Lantana montevidensis	lantana, creeping	dpi&f qld		X			
Phyla nodiflora	lippia	csiro			X		
Anredera cordifolia	madeira vine	dpi&f qld			X		
Prosopis spp.	mesquite	csiro, dpi&f qld			X	X	
Mimosa pigra	mimosa	csiro, nretas nt			X	X	X
Genista monspessulana	montpellier broom	csiro, dwlbc sa			X	X	X
Bryophyllum spp.	mother-of-millions	dpi&f qld		X	X		
Carduus nutans ssp. *nutans*	nodding thistle	csiro, nsw dpi, dpi vic				X	
Xanthium occidentale	noogoora burr	csiro, nretas nt, dafwa, dpi&f qld			X	X	
Moraea spp.	one/two leaf cape tulips	csiro		X			

Australian biocontrol projects: 1998–2008 (continued)

Target species or group	Common name	Institutions involved (generally self-nominated)	Current status*				
			NA	OH	RS	RL	RD
Onopordum spp.	onopordum thistles	csiro, dpi vic, nsw dpi				X	
Parkinsonia aculeata	parkinsonia	csiro, uni qld, dpi&f qld			X		
Parthenium hysterophorus	parthenium	dpi&f qld				X	
Echium plantagineum	patersons curse	csiro, nsw dpi, dpi vic, sardi, wa dpi					X
Physalis viscosa	prairie ground cherry	dpi vic			X		
Acacia nilotica	prickly acacia	dpi&f qld			X	X	
Senecio jacobeae	ragwort	dpi vic				X	
Carthamus lanatus	saffron thistle	csiro			X		
Salvinia molesta	salvinia	csiro, nsw dpi				X	X
Cytisus scoparius	scotch broom	csiro, nsw dpi, dpi vic			X	X	
Euphorbia paralias	sea spurge	csiro			X		
Nassella trichotoma	serrated tussock	dpi vic			X		
Senna obtusifolia	sicklepod	dpi&f qld	X				
Sida spp.	sidas	csiro				X	
Solanum elaeagnifolium	silver leaf nightshade	dpi vic			X		
Sonchus oleraceus	sowthistle	csiro	X		X		
Sporobolus spp.	sporobolus grasses	dpi&f qld	X				
Hypericum perforatum	st john's wort	csiro, nsw dpi, dpi vic				X	
Eichhornia crassipes	water hyacinth	csiro, nsw dpi			X	X	X
Raphanus raphanistrum	wild radish	csiro	X		X		

* Current status: opinions on this sometimes varied between respondents.

NA Non active: program abandoned (various reasons)

OH On hold: no active research current; program awaiting funding; administrative +/or staff constraints

RS Research: pre release research; searching; host range testing

RL Released: at least one agent released at some time

RD Redistribution: continuing redistribution/breeding of released agents by researchers

Other potential targets mentioned by respondents:

Ageratina riparia	mistflower
Euphorbia paralias	sea spurge
Opuntia robusta	wheel cactus
Sagittaria graminea (two ssp.)	sagittaria; arrowhead

Acronyms (in alphabetical order)

csiro: Commonwealth Scientific and Industrial Research Organisation. **dafwa**: Department of Agriculture and Food, Western Australia. **dpi&f qld**: Department of Primary Industries and Fisheries, Queensland. **dpi vic**: Department of Primary Industries, Victoria. **dwlbc sa**: South Australian Department of Water, Land and Biodiversity Conservation. **nretas nt**: Northern Territory Department of Natural Resources, Environment, The Arts and Sport. **nsw dpi**: NSW Department of Primary Industries. **rmit**: Royal Melbourne Institute of Technology. **sardi**: South Australian Research and Development Institute. **tiar tas**: Tasmanian Institute of Agricultural Research. **uni qld**: University of Queensland. **wa dpi**: Western Australian Department for Planning and Infrastructure.

PRODUCED BY LWA'S WEEDS R&D PROGRAM. FUNDED BY THE AUSTRALIAN GOVERNMENT'S DEFEATING THE WEED MENACE PROGRAM.

Acknowledgements

Thanks to several colleagues who provided information, including: Mike Day, Tim Heard, Royce Holtkamp, David McLaren, Louise Morin, Bill Palmer, Shon Schooler, John K. Scott, Andy Sheppard, and Rieks D. van Klinken.

For more weeds documents — lwa.gov.au/weeds

Photo: This rare white Coast Swainson Pea (*Swainsona lessertiifolia*) is flowering abundantly in restored coastal Banksia woodland after a five year management program targeting bridal creeper. Photo Mae Adams, Venus Bay, Victoria.

Printed on Revive Silk which is made in Australia from elemental chlorine free pulp with 65% derived from sustainable plantation forests and 35% recovered fibre. It is PEFC Certified and Australian Paper is an ISO 14001 certified mill which utilises renewable energy sources.

Published by:	Land & Water Australia
Web:	www.lwa.gov.au
ISBN print:	978-1-921544-57-6
ISBN electronic:	978-1-921544-58-3

This publication can be ordered free of charge from CanPrint Communications, freecall: 1800 776 616, or e-mail: lwa@canprint.com.au and quote product code **PN22364**

Photos:	Front page, Louise Morin
Design:	Angel Ink
Print:	Paragon Printers, June 2009

LWA project code USY13

Australian Government
Land & Water Australia

The University of Sydney

Australian Centre for Field Robotics

Aquatic weed surveillance using robotic aircraft

Salah Sukkarieh

Introduction

Several aquatic weeds are aggressive invaders of waterways in Australia. Species such as alligator weed, cabomba and salvinia, which have been declared Weeds of National Significance, can cover entire water surfaces. Flows are prevented, channels blocked and flood patterns altered. Weed mats reduce available oxygen in waterways, resulting in increased fish kills and loss of native plant species, and adversely affecting water quality. Unchecked, aquatic weed invasions cause millions of dollars of damage to agriculture, fisheries and the environment.

One major limitation in controlling aquatic weeds is the difficulty of conducting detailed surveillance over vast areas such as irrigation schemes, or over inaccessible aquatic habitats. Satellite remote sensing has been used in the past to overcome this limitation, but is not cost effective and cannot detect small infestations, especially where overhanging foliage or environmental sensor clutter and backscattering can affect surveillance performance.

About the project

For the 2007/08 Defeating the Weed Menace program (DWM), we proposed to build and test a prototype robotic aircraft and surveillance system to detect aquatic weeds in inaccessible habitats. The know-how and technology is not new: we have been working on such systems for the aerospace industry for over a decade. However, a new application of the technology and the different test environment meant we had to devise new technologies and approaches.

The prototype aerial robot houses sensors and spray systems. The sensors take imagery of the environment the robot flies over, classify the imagery so as to detect where the weeds are (if any), and geo-reference the location of those weeds. The robot can then be tasked to go back to those weed locations and spray them with an appropriate herbicide, or be tasked to spray them at the same time that they are detected.

The project was divided up into two key areas:

1. Development of the robotic aerial platform
2. Development of novel machine learning algorithms to discriminate between different plant species.

An aquatic weed infestation in an area that would prove difficult to map and control by conventional means. The objective of this project was to develop a system which could easily conduct surveillance and control missions over such environments. Photo courtesy of Andrew Petroeschevsky, NSW DPI. Opposite: Salvina. Photo Arthur Mostead.

What are robotic aircraft?

Robotic aircraft, otherwise known as unmanned air vehicles (UAVs), have been around since the development of manned aircraft. They are essentially the same platform minus the pilot. The pilot is replaced with sensors, computers, actuators and algorithms. The sensors detect properties such as the velocity of the platform and wind speed; the actuators provide a way to drive the various control surfaces on the platform; and the computers house the algorithms which do all the "thinking" the pilot would do, such as waypoint traversal, hovering, and sensor pointing. Modern day commercial aircraft, such as 747s and the A380, are essentially UAVs because most of their flight is autonomous.

Robotic aircraft come in various shapes and sizes; from the Global Hawk which has a wing span of over 35 metres, to micro-UAVs which can easily sit on the palm of a hand. The decision as to size and shape, and whether it should be a fixed wing UAV or a rotary UAV, comes down to the payload weight one wants to carry, the flight duration and the distance to be travelled.

What is machine learning?

Machine learning is the science and implementation of computer algorithms that give the computer the ability to "learn": to improve its performance in a particular task based on the data that it receives. Machine learning has been used in a wide variety of applications, from the control of helicopters, to medical diagnosis, speech recognition, and the detection of individual faces.

There are many machine learning techniques, but the most important for our work is "supervised learning". In supervised learning you provide the algorithm with training data (input and output data). The algorithm then aims to learn a model which describes the input-output relationship. This learnt model can be used to predict the output of any new input data.

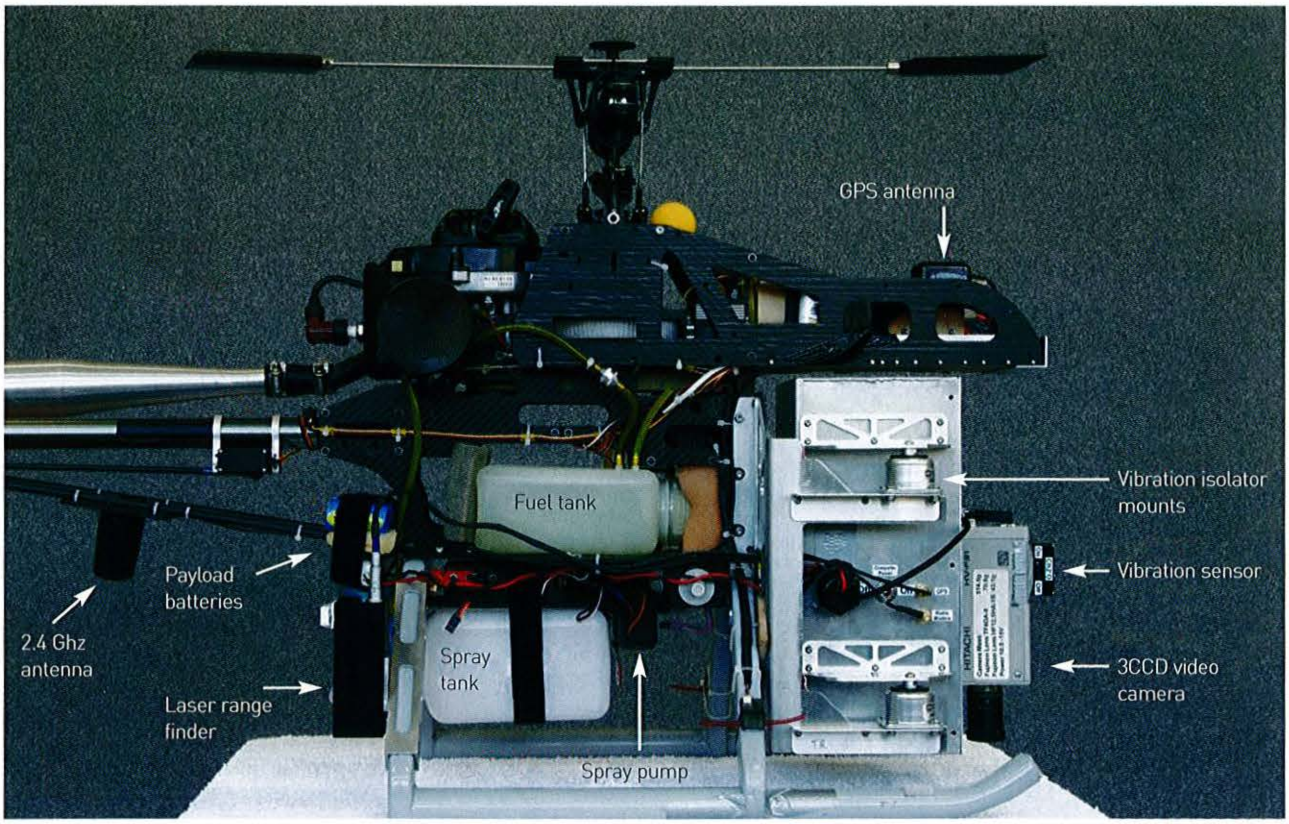
The robotic platform

We used a modified model helicopter as the platform. Using a helicopter gave full manoeuvrability, including ability to hover, making it possible to traverse large distances, move in tight situations, and hold position to take imagery or to spray herbicide. This involved development and tuning of flight control and navigation algorithms and spray mechanisms. The final system can fly for approximately two hours and carry approximately 500 ml of herbicide (water was used in the project for demonstration). Image on the front cover shows the robotic aerial vehicle over sprayed salvinia.

Surveillance system

Early in the project, many experiments were conducted testing various ideas on the type of sensors and detection algorithms we could use. We needed this information to establish the size of the surveillance system, which in turn would decide how we would mount the system on the helicopter. Colour and multi-spectral vision systems including IR and NIR were analysed. We determined that a light-weight, high resolution sensing device which provided separate RGB colour information was needed. See figure 1 below.

Figure 1. A closer look at the robotic platform. The metal box at the front holds most of the "intelligence" of the platform. The 3CCD Video camera passes the imagery information into the computer processors located within this box. Here classification of the imagery takes place. The GPS position system and other sensors provide position and velocity information. The laser range finder provides height-above-ground information. Also located at the bottom of the platform is the spray tank which housed water (herbicide in real applications), and a spray pump. When activated the spray pump transfers the liquid from the tank through the spray boom arms (shown here).



In order to classify weeds in near real-time we needed a means of learning the particular attributes of a weed so that an algorithmic model describing the weed could be developed and used on the platform. This would provide us with a computationally efficient algorithm that could reasonably quickly detect the likelihood and provide a probability measure of a particular weed being present. Using supervised learning techniques we were able to learn classification models of alligator weed and salvinia. The classification algorithm is based on maximum margin classification. A large data set of $n \times n$ pixels of imagery taken from the camera is collected, and the set separated manually into what is and what is not a weed. Each $n \times n$ pixel is in itself marked as an image of p dimensions. These dimensions take into consideration colour, shape and texture. The classification algorithm then tries to determine a hyperplane which separates the images into two sets. The objective of the algorithm is to determine this hyperplane, which is of maximum distance (Euclidean in the imagery space) between the two datasets. When found, this hyperplane becomes the detection model. As new data is collected it is passed to this model and will fall on either side of the hyperplane depending on whether it is or is not a weed. Depending on how far the image fits away from the hyperplane will determine the probability that the image is within that set. The algorithm proved to be very robust and reliable. See figure 2 below for a representation of this process.

Flight tests

Flight tests were conducted at the Killarney Chain of Ponds in Pitt Town near Sydney. This area is known for its spread of alligator weed and salvinia. The tests were conducted in April (alligator weed) and in August (sprayed salvinia) 2008, on one of the farms we had access to. The system worked as planned, being able to fly over the aquatic site, collect imagery, communicate to the ground station, and spray at designated locations. See figure 3 on the following page.

Where do we go from here?

The project developed a prototype system and demonstrated its effectiveness. The various approaches to weed management using the system were discussed with stakeholders of the project. This led us to discuss the potential of the system with other interested bodies, specifically council officers.

There is significant scope for this system to be actively used in weed surveillance. It provides a means of traversing large distances, accessing difficult ground operation areas, and for improving the efficiency of the weed management cycle.

There were many new challenges and these form part of the ongoing work in the area.

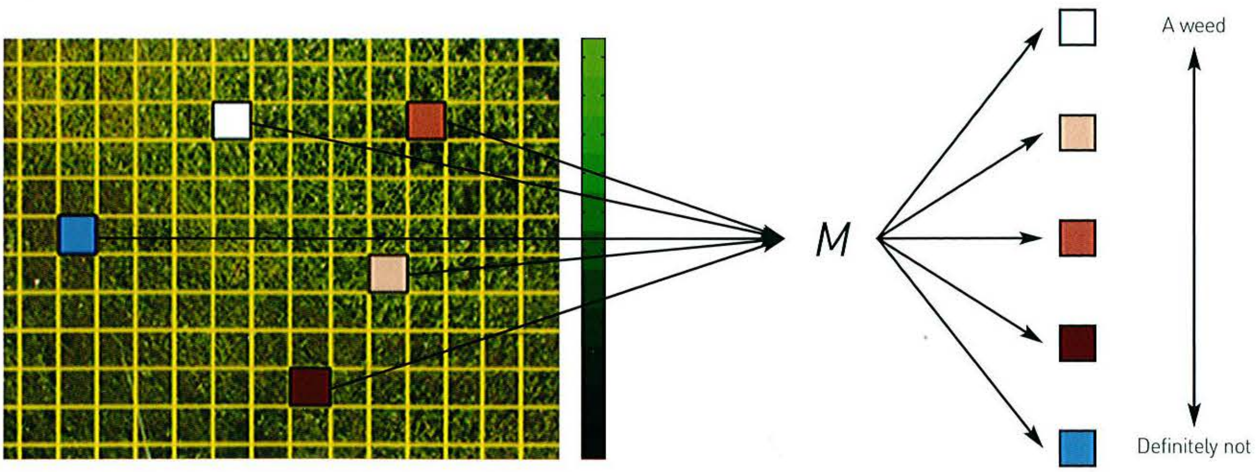


Figure 2. A representation of how the on-line classification process works. A model "M", which is an algorithmic representation of relationship between colour, texture and shape, is "learnt" off-line, and then implemented on-line. Each image taken by the camera in operation is divided up into n x n pixels, known as a "sub-image". Each sub-image is now considered to be an image in its own right, and is passed to the model M. The output of the model M is a probability measure which represents whether the sub-image contains a weed or not.

Figure 3. The top images represent the classification results of alligator weed, and the bottom that of sprayed salvinia. The images in the left hand column are those directly from the imaging system, and that in the right hand column are the output of the learnt classification model.

CASA regulations

Flying a UAV in a populated area requires the users to overcome significant regulation hurdles. Even the process of flying along a river with houses nearby will be an issue. Doing so with herbicide on board adds an extra complication. Discussions with CASA regulators suggest that gaining permission is possible, but needs to be carefully approached. Regulations for flying in remote areas, or along irrigation channels, are not as strict, and this is where we see the introduction of such a system.

Team of people

Operating the system as a UAV requires three people: two that deal with flight operations and safety, and one to deal with computing and communications. Instead of flying the system as a UAV, it could be flown remotely, but the vehicle has to remain within line-of-sight. As the technology progresses, the number of people will drop. Five years ago, six people would have been needed to operate such a system. One of the key areas for research and development is in appropriate human-machine interfacing.

Detection algorithms

The detection algorithms need to be as accurate as possible to minimise false detections. The current algorithms proved to be very effective and will become more robust as more data is collected. However, tuning is required, and so a way for the operator to easily tune and validate the results is needed. Again, research and development in the area of human/machine interfaces is required.

Decision about spraying

The "operator-in-the-loop" is a classic example of how autonomous systems interact with human ground operators in making collective decisions. Before a weed can be sprayed, there needs to be confirmation of the decision from an operator. This will probably continue to happen regardless of how accurate the detection algorithms become, because of the potential to cause widespread damage, and for OH&S reasons. Safety mechanisms need to be in place both from a hardware and software perspective and tight logic control needs to be placed around the system's decision functions for it to be used safely and effectively.

Flight control

Flight control proves to be the most delicate aspect of the system. The flight control unit needs to safely move the platform and conduct the operation at hand. Off-the-shelf flight control systems will stabilise the platform and allow you to command it to go to designated waypoints, but flight control management is a mission-specific task. Therefore the system will inevitably require a computer module that talks to the flight control computer to command it to do actions at specific instances both under normal operation and under safety critical operations. Such operations are specific to the mission at hand — you cannot buy an off-the-shelf version of such management systems. This computer module could either be autonomous and placed on the platform or could be at the ground station and managed by the operator. If the former, then extensive testing and an understanding of the limitations is required; if the latter then there needs to be a certain level of operator knowledge of the flight control system and its operation. The way forward is through human operator management and training, to better appreciate the system's limitations.

Collision avoidance

The system needs to be able to conduct collision avoidance. This is a long-term research issue. In many cases the flight path can be constructed to be safe, but the system still requires the ability to detect whether an obstacle has come within a safe bounding box. This involves sensing capabilities as well as fusion algorithms. What this implies is that in the short term, an operator needs to judge whether detection is required and how to overcome this through better path management. For many missions, such as irrigation channels and wide spaces, it is less of an issue, but caution is required for aquatic weed management along rivers, or where there are trees within the area.

The potential

The future looks very exciting for this intelligent little machine. We plan to continue the project with a specific focus on aquatic weeds, and to broaden its capabilities into other ecology management arenas, such as woody weeds and biomass measurements.

More information

More information on the project can be found at:

- www.acfr.usyd.edu.au/research/aerospace.shtml
- lwa.gov.au/weeds

Or, contact:

Salah Sukkarieh, Associate Professor, Australian Centre for Field Robotics, The University of Sydney. E-mail: salah@acfr.usyd.edu.au

Acknowledgements

Special thanks to the aerospace team: Jeremy Randle, Steve Keep, Ali Goktogan, Muhammad Esa Attia, Mitch Bryson, Todd Lupton and Calvin Hung.

We would like to thank Land & Water Australia for funding this project and recognising its potential. We would also like to thank Andrew Petroeschevsky from NSW Department of Primary Industries, Luke Joseph from Farm and Dam Control, and Sunwater for their in-kind contribution, knowledge, and constant enthusiasm. Finally, we thank the Australian Research Council for their support.

PRODUCED BY LWA'S WEEDS R&D PROGRAM. FUNDED BY THE AUSTRALIAN GOVERNMENT'S DEFEATING THE WEED MENACE PROGRAM.

Photo on this and previous page: The McKenzie River clogged with water plants, near St Lawrence, Queensland. Photo Arthur Mostead.

Printed on Revive Silk which is made in Australia from elemental chlorine free pulp with 65% derived from sustainable plantation forests and 35% recovered fibre. It is PEFC Certified and Australian Paper is an ISO 14001 certified mill which utilises renewable energy sources.

Published by: Land & Water Australia
Web: www.lwa.gov.au
ISBN print: 978-1-921544-69-9
ISBN electronic: 978-1-921544-71-2

This publication can be ordered free of charge from CanPrint Communications, freecall: 1800 776 616, or e-mail: lwa@canprint.com.au and quote product code **PN22514**

Photos: Front page, Muhammad Esa Attia
Design: Angel Ink
Print: Paragon Printers, June 2009

LWA project code CSE52

Australian Government
Land & Water Australia

CSIRO

Benefits and costs of buffel grass: Understanding perceptions can contribute to policy development

Margaret Friedel, Rieks D. van Klinken, Tony Grice and Nadine Marshall

The issue

Buffel grass (*Cenchrus ciliaris*) is a valuable introduced species for pastoral production but its invasion into arid and semi-arid rangelands represents a key threatening process for conservation values.

Due to the apparent polarity of views on benefits and costs of buffel grass, there has been no progress toward a policy to support its sustainable use and management.

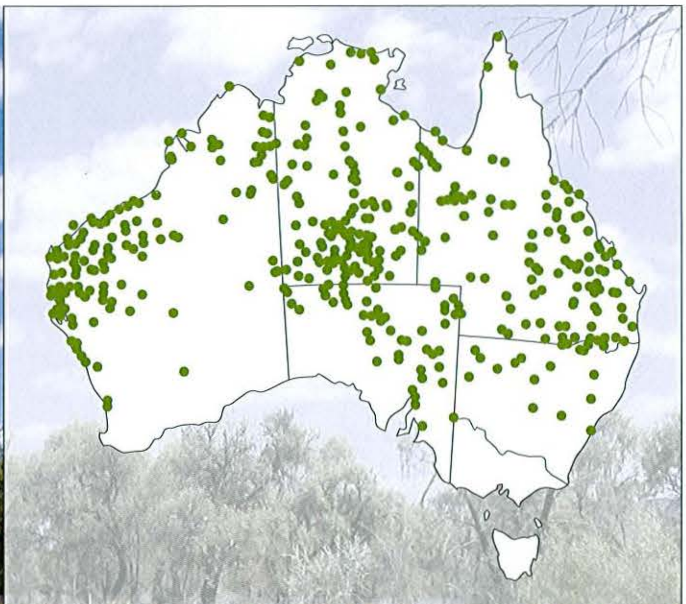
Ways forward

Perceptions of the benefits and costs are not as polarised as is popularly believed. Stakeholders can often agree on the benefits and costs to each others' interests and, where they do not, they can acknowledge the validity of the others' perceptions. This provides us with opportunities to build on areas of agreement and advance options which support the development of a national strategy.

Present approaches to management of contentious introduced species are either to take no action, so that individual proponents continue to seek the benefits of the species while opponents bear the negative consequences, or to seek the declaration of the species as a weed in order to deal with its negative consequences and prohibit cultivation. Declaration enables funding for weed management but not for beneficial uses. Declaration is also a state responsibility, so that inconsistencies across jurisdictional boundaries are possible.

We propose an alternative approach to the management of buffel grass which is strategic and non-confrontational, realistic and national in scope. The first step is to engage in extensive dialogue amongst stakeholders to ensure that their diverse needs and preferences are understood and acknowledged.

Map: Distribution of buffel grass (shown by ●), data from Meg Robertson and Weeds CRC 2008. **Background photo**: Buffel grass helps to maintain soil stability during drought and recovers quickly after rain in central Australia. Photo Margaret Friedel.



Need for stakeholder engagement

At the regional and local scale, the management objectives, strategies and tools for managing buffel grass are relatively uncontroversial on environmental lands or on pastoral lands where environmental values are low. Nevertheless there will be a need for stakeholders to negotiate to identify acceptable and achievable outcomes, and this will help develop trust and effective processes. The contentious issues are those relating to management objectives for pastoral land of high environmental value, rather than the particular local strategies and tools for achieving them. Actions that could improve environmental values, but also impinge on management of pastoral land, would currently not achieve much support or might be actively opposed by landholders. Consequently, there is a need for non-confrontational ways of negotiating acceptable changes in buffel grass management, beginning with those issues that are likely to be most easily resolved.

Recommendation 1: Manage change by involving landholders in an open dialogue about the costs and benefits of buffel grass and in the setting of agreed goals.

Pathways for disseminating information amongst pastoralists about buffel grass and its management include both formal and informal networks. These networks will be an important means of two-way communication enabling pastoralists to engage effectively and contribute to goal-setting.

Recommendation 2: Understand and use landholders' formal and informal networks to enhance information exchange.

Government-based natural resource managers often view community involvement in the design of resource protection strategies as cumbersome, time consuming and difficult. In addition, community participants often have limited knowledge of the context in which they have to operate, of their role in the process and of the role of organisations, and this can complicate the interactions. Nevertheless real progress is unlikely without involvement of all parties.

Recommendation 3: Recognise and accept the transaction costs of community engagement so that the economic and social benefits of buffel grass can be maximised and the environmental costs minimised.

Delivering a strategy

Rangeland regions vary in their biophysical, economic and social potential to support buffel grass. For example climates and soils differ, and buffel grass may be entrenched in the landscape or a recent arrival; the use of fire or grazing as tools is locally specific. For both environmental and pastoral lands, the management objectives and the exact way in which any management strategies and tools are used are strongly influenced by local environmental, economic and social conditions. There is no single formula for management.

Recommendation 4: Ensure objectives, strategies and tools for management of buffel grass are tailored to local and regional contexts.

Buffel grass is arguably the most important introduced pasture grass in the rangelands, providing great economic benefit to pastoral communities. It is tolerant of drought, fire and heavy grazing and aids the control of soil erosion. Photo Paul Jones.

Buffel grass has been long-established in some areas but not others. Where it has a minimal presence, pastoralists have a lower dependency on it and are more likely to find alternative management strategies acceptable. This provides an opportunity to consider the balance of production and conservation needs and what alternative strategies could meet those needs.

Recommendation 5: In situations where buffel grass is yet to colonise large areas, such as southern pastoral lands or various deserts, initiate early community discussion about the benefits and costs of buffel grass and its management.

In areas of high environmental value where buffel grass is well established, it is not realistic to expect every asset to be protected, due to limitations of money and personnel. On pastoral lands there are potentially competing objectives for the same piece of land. It is important therefore to know where and how efforts should be focussed to protect high value environmental assets. Where are the valued assets that can be most feasibly protected at a sufficiently large scale and what is the appropriate response when areas are relatively free of buffel grass, as compared with areas where buffel grass is well established?

Recommendation 6: Develop processes for identifying and prioritising areas of high biodiversity value where management of buffel grass is required.

Buffel grass is regarded as a threat to conservation because of its direct effects on biodiversity and because its rapid accumulation of fuel generates more intense and frequent fires than native grasses do. Photo Dave Albrecht.

Ways of supporting the delivery of environmental outcomes at a catchment or landscape scale should be considered, for example through offering incentives for better management of areas of high environmental value on pastoral properties, and avenues for resourcing this should be made available. Interventions which focus on delivery should be designed to encourage protection of neighbouring reserves or downstream areas of high environmental value, through, for example, the establishment of buffer zones or through grazing buffel grass pastures prior to seed set.

Recommendation 7: Develop ways of encouraging land managers to deliver environmental outcomes at landscape scale through management of buffel grass.

Policy, regulatory and management options should be canvassed with stakeholders in order to establish and make operational best-practice guidelines. Any attempt to develop policies for managing buffel grass will need to recognise the critical importance of the grass to many pastoral enterprises and consider the likelihood that outcomes can be achieved. A standardised weed risk assessment framework could assist with transparency of process but it must be balanced by comprehensive assessment of benefits. Hence an essential step is to set up jurisdictional advisory groups. Cross-jurisdictional bodies will also be required to ensure consistency nationally.

Recommendation 8: Develop policy recommendations for governments through establishment of representative advisory groups at state and cross jurisdictional levels.

Buffel grass dominates nutrient rich frontages of creeks and rivers in central Australia, excluding native species. Photo Margaret Friedel.

The development of a national strategy for management of a plant species that is both economically important and weedy is novel — there are few precedents to follow and it is essential that we learn from our experiences.

Recommendation 9: In developing policy, include the ability to monitor and evaluate outcomes and make adaptive change.

What additional knowledge is required to make progress?

Recommendation 7 proposes encouraging land managers to deliver environmental outcomes but it is not yet clear that there is a good connection between particular management actions and the desired landscape scale outcomes. Better documentation and development of management options will help managers and policy makers make informed choices. Actions should include recording experience, experimentation and adaptive management to determine how to e.g. "manage for dominance of buffel grass" or "manage for suppression of buffel grass". Understanding the influence on potential options of regional differences in environmental, economic and social characteristics will be a necessary component of this activity.

Better quantification of the link between production, buffel grass dominance and conservation is required. For example, what are the potential grazing strategies for environmental reserves and are there conservation benefits in managing high production/high environmental value pastoral land for dominance of buffel grass? Existing analyses of economic benefits and costs should be refined to value a wider suite of benefits and costs (not simply of production) using case study regions to clarify regional differences.

Recommendation 10: Improve understanding of management options and benefits/costs by documenting existing experience and developing new research; keep regional differences in focus.

PRODUCED BY LWA'S WEEDS R&D PROGRAM. FUNDED BY THE AUSTRALIAN GOVERNMENT'S DEFEATING THE WEED MENACE PROGRAM.

In conclusion

There is sufficient common ground amongst stakeholders to make progress towards a national strategy for the management of buffel grass. The impediments to progress may not be as great as has been perceived.

A national strategy, supported by state and regional jurisdictions, would enable a systematic approach to management of buffel grass. It would enable the reduction of negative effects without seriously constraining its production benefits. Such a strategy would need to be relevant to local and to regional scales, taking account of the large environmental, social and economic differences amongst regions, the diversity of available buffel grass varieties and the potential for varieties to adapt to local conditions through hybridisation. The strategy would provide a framework for the management of buffel grass, the prioritisation of research and of resources for on-ground management efforts, and provide a mechanism for continued engagement and interaction amongst sectors.

Recommendation 11: Develop a national strategy for the sustainable management of buffel grass for production and conservation, relevant to regional scales.

This paper is based on the report "Quantifying costs and benefits of buffel grass" by Margaret Friedel, Nadine Marshall, Rieks D. van Klinken and Tony Grice.

The full report is available from lwa.gov.au/weeds
For more information contact Margaret Friedel —
tel: (08) 8950 7140 or e-mail: margaret.friedel@csiro.au

Printed on Revive Silk which is made in Australia from elemental chlorine free pulp with 65% derived from sustainable plantation forests and 35% recovered fibre. It is PEFC Certified and Australian Paper is an ISO 14001 certified mill which utilises renewable energy sources.

Published by: Land & Water Australia
Web: www.lwa.gov.au
ISBN print: 978-1-921544-65-1
ISBN electronic: 978-1-921544-66-8

This publication can be ordered free of charge from CanPrint Communications, freecall: 1800 776 616, or e-mail: lwa@canprint.com.au and quote product code **PN22374**

Photos: Front page and this page, Rick Davies
Design: Angel Ink
Print: Paragon Printers, June 2009

Australian Government
Land & Water Australia

Policy, institutional and managerial considerations in managing weeds with a commercial value

R.L. Miles, S. Kinnear, M. Friedel, A.C. Grice, R.D. van Klinken, S. Setterfield and M. Herpich

Olive (*Olea europaea*). Photo Roger Charlton.

Contributors to this short discussion paper are:

- Robert L. Miles (Miles Consulting Services)
- Susan Kinnear (Central Queensland University)
- Margaret Friedel (CSIRO)
- Anthony C. Grice (CSIRO)
- Rieks D. van Klinken (CSIRO)
- Samantha Setterfield (Charles Darwin University)
- Melissa Herpich (South Australian Department of Environment and Heritage).

Introduction

In Australia, governments spend approximately $116.4 million on weed management, monitoring and research each year[1]. This figure does not include resources provided by volunteers or weed management undertaken as a component of other landcare activities, nor costs incurred by agricultural industries as a result of weeds.

In recent years a wider recognition of the economic, biological and social impacts of weeds has resulted in a greater commitment and investment in weed management. However, the management of plant species that have significant economic value but are, at the same time, invasive has received little attention. For convenience, these species are referred to here as 'commercial weeds'.

Pastoralists, farmers, conservationists, traditional landholders and local councils are all concerned about weeds and their impact but they often have different perceptions about individual species. In part, this is due to socio-economic factors. Conflicting views of the benefits and costs of commercial weeds have inhibited the holistic or coordinated approach to managing or controlling these plants. A poor knowledge of the offsite impacts of these species on other land uses and the environment continues to impede the development and implementation of effective management strategies. This, combined with the complexity of relevant policies and regulations, means that commercial weeds present problems that require cooperation between individual landholders, sectors, jurisdictions and government agencies.

Several research projects funded within the Defeating the Weed Menace (DWM) program provide valuable insights into the ways in which these issues might be addressed, pointing to the possibility of national approaches that take account of sectoral and regional differences.

In the shaded panels on the following pages are four research case studies involving 'commercial weeds'.

Buffel grass — a pathway to more effective management and policy[2]

Buffel grass, a valuable introduced species for pastoral production, is well established and naturalised in many ecosystems in Australia's rangelands. Its invasion into the arid and semi-arid rangelands represents a key threatening process for conservation values and, possibly, indigenous cultural values. Due to the apparent polarity of views on benefits and costs, there has been little progress toward a policy that supports the sustainable use and management of buffel grass.

A DWM research project placed particular emphasis on a consultative process, engaging all stakeholders, and found that perceptions of the benefits and costs were not as polarised as is popularly believed. Stakeholders often agreed on the benefits and costs to each others' interests and, where they could not, they acknowledged the validity of the others' perceptions. This provided an opportunity to build on areas of agreement and to advance options that would support the development of a national strategy.

Present approaches to management of commercial weeds are either to take no action, so that individual proponents continue to seek the benefits of the species while opponents bear the negative consequences, or to seek the legal declaration of the species as a weed in order to deal with its negative consequences and prohibit cultivation. Declaration provides financial and other incentives for weed management but, generally, does not facilitate beneficial uses.

The first step toward a strategic, non-confrontational and national approach to the management of buffel grass is to encourage comprehensive discussion amongst stakeholders to ensure that their diverse needs and preferences are understood and acknowledged.

Need for stakeholder engagement

At the regional and local scales, the management objectives, strategies and tools for managing buffel grass are relatively non-controversial on environmental lands and on pastoral lands where environmental values are low. Nevertheless, stakeholders must negotiate to identify acceptable and achievable goals, this will help develop trust and effective processes. Management objectives for pastoral land of high environmental value are more contentious than the particular local strategies and tools for achieving them. Actions that could improve environmental values but which impinge on management of pastoral land, would currently attract little support or would be opposed by pastoral landholders. Consequently, there is a need to focus on non-confrontational ways to negotiate acceptable changes in buffel grass management, beginning with those issues that are likely to be most easily resolved.

Information about buffel grass and its management should be disseminated amongst pastoralists through formal and informal networks. There is a need to understand and use landholders' formal and informal networks which are important means of two-way communication that enable pastoralists to engage effectively and contribute to goal-setting.

Government-based natural resource managers often view community involvement in the design of resource protection strategies as cumbersome, time consuming and difficult. Furthermore, community participants often have limited knowledge of the context in which they have to operate, of their role in the process and of the role of various organisations. This can complicate the interactions. Nevertheless, real progress is unlikely unless all parties are involved and this should be accepted as a transaction cost of community engagement that helps maximise the economic and social benefits of buffel grass and minimise the environmental costs.

Buffel grass (*Cenchrus ciliaris*). Photo Rick Davies.

Delivering a strategy

For environmental and pastoral lands, management objectives, strategies and tools are strongly influenced by local environmental, economic and social conditions and should be tailored to local and regional contexts.

Rangeland regions vary in their biophysical, economic and social potential to support buffel grass. Buffel grass has been long-established in some areas but not others. Where it has a minimal presence, pastoralists have a lower dependency on it and are more likely to find alternative management strategies acceptable. This provides an opportunity to consider the balance of production and conservation needs and strategies to meet those needs. Therefore, in situations where buffel grass is yet to colonise large areas, such as southern pastoral lands or various deserts, early community discussion about the benefits and costs of buffel grass and its management should be initiated.

In areas of high environmental value where buffel grass is well established, it is unrealistic to protect every asset, due to limitations of money and personnel. On pastoral lands there are potentially competing objectives for the same piece of land. It is important, therefore, to know where and how efforts should be focussed to protect high value environmental assets. It will be important to locate high-value assets that can be most feasibly protected at a sufficiently large scale and resolve appropriate responses for areas that are relatively free of buffel grass and those where it is well established.

Where possible, environmental outcomes should be delivered at catchment or landscape scales for example, through incentives for better management of areas of high environmental value on pastoral properties. Interventions could protect neighbouring reserves or downstream areas of high environmental value, through the establishment of buffer zones or by grazing buffel grass prior to seed set.

Best-practice guidelines should be devised and implemented, supported by appropriate policies and regulations. Policies for managing buffel grass should recognise the critical importance of the grass to many pastoral enterprises.

A standardised Weed Risk Assessment framework could ensure that the process is transparent and considers the benefits of the species. Non-legislative solutions could involve, for example, a code of practice. Cross-jurisdictional bodies could help develop mutually agreeable goals and ensure a balance between national consistency and appropriate regionally tailored approaches.

Enablers for progress

Improved development of options will help managers and policy makers make informed choices and adaptive management will be facilitated by recording experience and experimentation. It is necessary to consider how regional differences in environmental, economic and social characteristics influence options. The link between production, buffel grass dominance and conservation must be better understood. For example, what are the potential grazing strategies for environmental reserves and are there conservation benefits in managing high environmental value pastoral land for dominance of buffel grass? Existing analyses of economic benefits and costs should be expanded to assess a wider suite of benefits and costs using case studies in different regions to clarify regional differences.

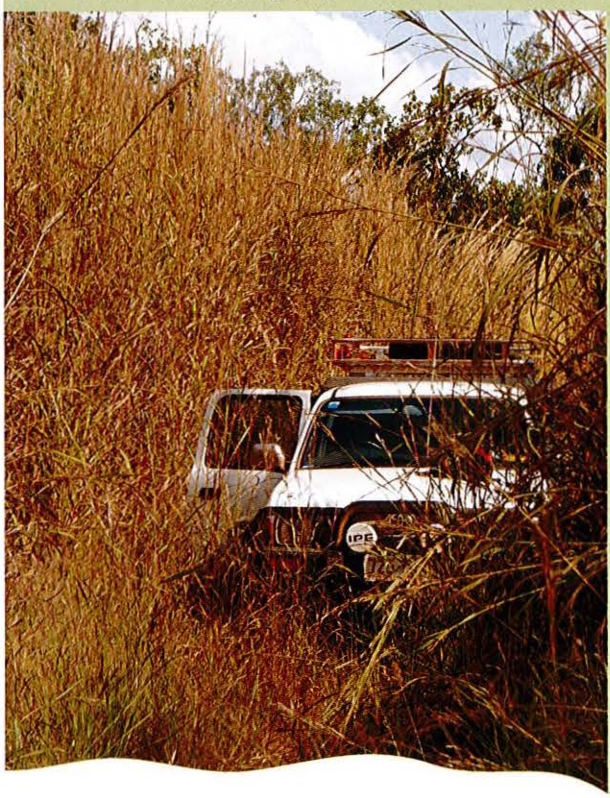
This study suggests there is sufficient common ground amongst stakeholders to make progress towards national strategies to manage buffel grass and other commercial weeds. A national strategy, supported by state and regional jurisdictions, would enable a systematic approach which should attempt to reduce the negative effects of the species without seriously constraining its production benefits. Such a strategy should take account of the large inter-regional environmental, social and economic differences, the diversity of buffel grass cultivars and their potential to adapt to local conditions, for example through inbreeding. The strategy would provide a framework for the management of buffel grass, the prioritisation of research, management and resources for on-ground effort, and provide a mechanism for continued engagement and interaction amongst sectors.

Gamba and para grasses — the importance of stakeholder engagement and policy support[3]

Gamba and para grasses (*Andropogon gayanus* and *Brachiaria mutica*) are species that were introduced as fodder for cattle in northern Australia but they have spread from planted areas to subsequently invade extensive areas of environmental and cultural significance, impacted on service providers (transport, water) and other primary industries (e.g. horticulture). For the past decade these species have been the subject of considerable controversy due to community and sectoral concern that they were not declared as a weed. This concern was based on considerable evidence of significant environmental and social impacts. Controversy within the community over these plants has steadily increased due to perceived inaction by government. There was pressure to retain the commercial use of these species for the pastoral industry.

As a result of these concerns, a major research program was undertaken to evaluate the risk of these introduced grasses to environmental, social and cultural values in the Northern Territory and to develop a weed risk management (WRM) process to formally assess risk and direct management action.

Gamba grass (*Andropogon gayanus*). Photo Michael Douglas.



In the Northern Territory, declaration under the *Weeds Management Act 2001* is regarded as an important legislative step in managing commercial weeds. Listing requires that the species be restricted from sale and transport and that a gazetted management plan be implemented for the species' control and use. There are no alternative policy or institutional/regulatory processes in the Northern Territory. The legislation allows for the commercial use of a declared plant within constraints imposed by the management plan. However, there is no requirement under the Act to evaluate the economic and social benefits of or risks from introduced plants, or to implement particular actions based on the level of risk. There are few systematically collected and analysed data to inform weed managers of the distribution and spread of introduced species.

A WRM system was developed for the Northern Territory based on the extensive research on commercial weeds. This system evaluates the risk from a plant species to the Northern Territory environment and the ability of managers to control it. Its outputs can be used to direct appropriate management responses.

A critical component of the WRM system is a policy framework based on a set of guiding principles that clearly articulate the intent of the system. It was prepared in consultation with all key stakeholders (pastoral, indigenous, environmental and horticultural). The system requires the precautionary principle to "be applied throughout all stages of the WRM process" and that "plants already present in the Northern Territory and categorised as high or very high weed risk will trigger nomination as a declared weed and other legislative actions and associated management responses to mitigate the risk posed by these species irrespective of economic benefits" (Northern Territory Weed Risk Management Technical Committee 2008). This both makes clear the intent of the WRM system and identifies a policy and management pathway for action. The system is consistent with the standards established by the National Post-border WRM Protocol. The WRM system has now been officially adopted by the lead weed management agency in the Northern Territory and been submitted for whole-of-government adoption.

Radiata pine (*Pinus radiata*). Photo Roger Charlton.

Radiata pine — avoiding invasion of significant vegetation remnants[4]

The invasion of remnant vegetation by commercial, garden and agricultural plants is an increasingly serious issue in bushland areas of Victoria and South Australia. In highly modified and fragmented landscapes, the impact of environmental weeds is amplified and their management becomes more critical. Some of these species attract national attention and resources are readily available to study and manage them. Other species, particularly those such as radiata pine, with economic potential, are less likely to be formally recognised as having environmental weed potential. Ignoring the weed potential of a species on the basis of its economic importance undermines the process of sustainable natural resource management (NRM) planning and gives a false impression of the true cost of economic activities.

A study on invasion of remnant native vegetation by *Pinus radiata*, commonly called pine wildlings, in the Green Triangle region (lower south east of South Australia and south western Victoria), developed projections for the potential impact of the species. This was done by assessing correlations between occurrence of pine wildlings and vegetation communities, distance from and age of plantations.

Pinus radiata has long been recognised for its weed potential, both here and overseas. Its invasive potential and impact on bushland sites has been documented. An example is the national recovery plan for the South Eastern Red-tailed Black Cockatoo which recognises that pine wildlings impact on remnant feeding habitat for this nationally-listed endangered bird. Also, a recent weed survey by the South Australian Department of Environment and Heritage of environmentally significant vegetation patches in the lower south east of the state revealed that pine wildlings were present in 45% of patches.

While the methodology developed in this project still requires some refinement, current results allow comparisons between areas with low, medium and high density pine wildling infestations. As higher resolution, multi-spectral imagery becomes available this approach will provide a valuable tool for shared use in managing invasion of significant areas of remnant vegetation. It is already apparent from the current project that pine plantations should not be established next to susceptible vegetation types.

Olive hymenachne — pathways to holistic regional management[5]

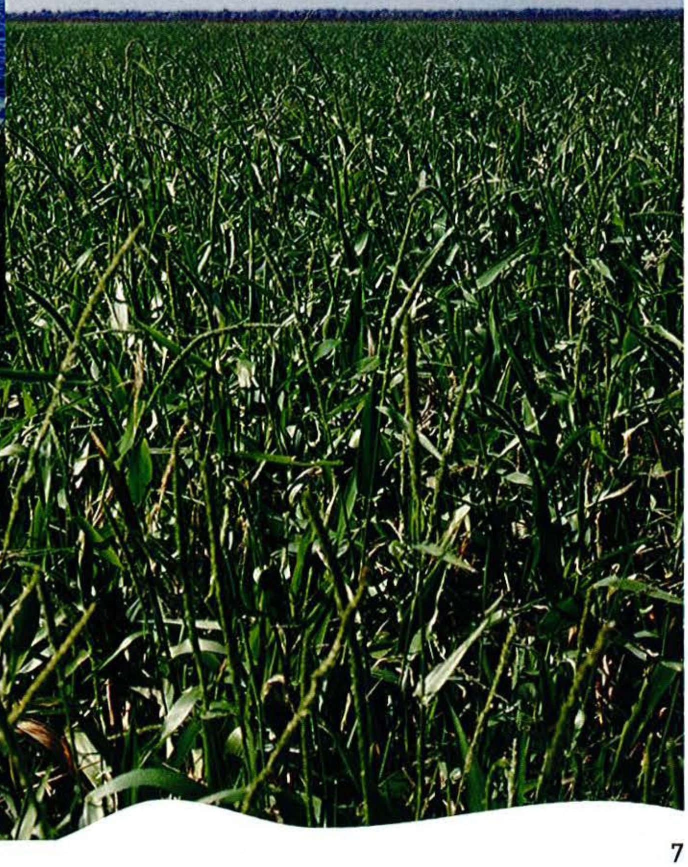
Olive hymenachne (*Hymenachne amplexicaulis*, commonly known as 'hymenachne' but needing to be distinguished from the native species *Hymenachne acutigluma*) is an aquatic grass invading wetlands and waterways of tropical and subtropical Australia. The management challenge presented by this plant relates to its beneficial use as a ponded pasture species for livestock production and drought management, compared with its serious and wide-ranging environmental impacts.

A recent DWM study examined the ecological, social and environmental issues surrounding the control of hymenachne in central Queensland. This study aimed to develop an holistic management strategy, at the regional level, using integrated weed management. In particular, the work identified the need for a coordinated and inclusive approach to hymenachne control involving all stakeholders, with suitable incentives being made available and governments, councils and the community taking responsibility for control.

Developing broad-scale control activities for hymenachne will be difficult because of varying attitudes and opinions towards the plant. In addition, attempting to introduce and enforce a blanket approach across all regions, infestations and landholder types is unlikely to be successful, given (a) the variability in values and opinions surrounding hymenachne; and (b) the physical differences between infestations regarding accessibility and the efficacy of different control measures. On the other hand, the need to integrate activities aimed at the control and management of hymenachne is clear. The engagement of all stakeholders, working in an appropriately prioritised, consistent and persistent way, and considering other activities being undertaken in the region, is critical in progressing successful management.

This study identified seven components upon which a regional strategy for olive hymenachne management should be built. They are: (1) taking responsibility; (2) education and engagement; (3) motivate and compensate; (4) resource and enforce; (5) do the research; (6) apply the science; and (7) coordination, flexibility and persistence.

Before and after photos of a Hymenachne (*Hymenachne amplexicaulis*) invasion of Beatrice Lagoon, Northern Territory. Photos Colin Wilson.



Plants having both commercial value and weed impacts in Australia

The species studied in recent DWM research projects are but a few of the diverse plants that have been identified in Australia as having both commercial value and weed impacts (Table 1). This table does not include ornamental plants that have weed impacts.

Table 1. Plants with both commercial value and weed impacts

Scientific name, family and authority	Common name	Growth form	Use	Weed impacts
Desmodium spp Desv. Fabaceae	Desmodium	Forb	Pasture	Environmental: northern woodlands
Cenchrus ciliaris L. Poaceae	Buffel grass	Grass	Pasture	Environmental: tropical and warm temperate rangelands, woodlands
Andropogon gayanus Kunth Poaceae	Gamba grass	Grass	Pasture	Environmental: tropical savannas
Hymenachne amplexicaulis Nees Poaceae	Hymenachne	Grass	Pasture	Environmental: northern coastal wetlands. Production: sugar cane
Urochloa mutica (Forssk.) T.Q. Nguyen Poaceae	Para grass	Grass	Pasture	Environmental: northern coastal wetlands
Ehrharta calycita Sm. Poaceae	Perennial veldt grass	Grass	Pasture	Environmental: southern woodlands
Phalaris aquatica L. Poaceae	Phalaris	Grass	Pasture	Environmental: northern coastal wetlands. Production: annual crops
Rubus fruticosus L. Rosaceae	Blackberry	Shrub	Horticulture	Environmental: southern forests, riparian zones
Stylosanthes spp. Sw. Fabaceae	Stylos	Shrub	Forage	Environmental: northern woodlands
Chamaecytisus palmensis (Christ) F.A. Bisby & K.W. Nicholls Fabaceae	Tagasaste	Shrub	Forage	Environmental: southern woodlands
Leucaena leucocephala (Lam.) de Wit Fabaceae	Leucaena	Shrub	Forage	Environmental: northern woodlands
Coffea arabica L. Rubiaceae	Coffee	Tree	Horticulture	Environmental: rainforest
Ficus carica L. Moraceae	Fig	Tree	Horticulture	Environmental: southern forests
Azadirachta indica A. Juss. Meliaceae	Neem	Tree	Ornamental Horticulture	Environmental: northern riparian zones
Olea europaea L. Oleaceae	Olive	Tree	Horticulture	Environmental: southern woodlands, forests
Pinus caribaea Morlet Pinaceae	Caribbean pine	Tree	Forestry	Environmental: forests, woodlands
Pinus radiata D. Don Pinaceae	Radiata pine	Tree	Forestry	Environmental: southern forests and woodlands

Source: Reproduced from Grice[6] (2006, page 41).

Building on the research outcomes and a review of relevant literature, the authors have identified management options and social and community issues, as well as policy and institutional arrangements needed to improve the management of commercial weeds.

Developing management strategies for commercial weeds

Sound strategies for managing commercial weeds require improved understanding of:

- commercial weeds occurring under different land uses and land tenures in Australia
- the social, economic and environmental costs and benefits of commercial weeds for different sectors and how these vary regionally
- the social impediments to resolving commercial weed conflicts and collaborative effort to identify ways to address these, and
- the legislative and policy mechanisms available to effectively address commercial weed species.

It is important to know whether containment of commercial weeds is feasible, at what cost and who should cover those costs. Should it be site based or species based and would the money be better spent on the prevention of other high risk weeds or protection of areas of high biodiversity value?

Landholders, other stakeholders and all tiers of government should take some responsibility for tackling infestations of commercial weeds in areas of conservation value. All landholders are required, by a variety of legislation, to control declared weeds and, ideally, community level action groups are the best placed to achieve local control. However, in many cases, the scale of the problem of commercial weeds exceeds that which could be addressed by the resources of landholders or local community action groups. In these situations, government assistance is necessary. It is important that the responsibilities of different government agencies are more clearly articulated. Cross-jurisdictional (federal, state and local government) responsibilities need clarifying, and should be supported by legislation that is consistent across jurisdictions.

Ultimately, a negotiated balance between public responsibility (i.e. federal, state and local government) for large, inaccessible and/or public areas (e.g. parks, reserves and conservation areas) and private responsibility for localised outbreaks on private properties and leasehold land (and adjacent buffer zones), will provide more effective management of commercial weeds. However, special consideration should be given to the responsibility for managing areas on private land that are of high conservation status such as remnant native vegetation.

A key component of a national strategy for managing a commercial weed should be an effective decision support tool based on holistic risk management. The recently developed National Post-border Weed Risk Management Protocol[7] offers a useful framework for such assessment. It includes a matrix of weed risk versus feasibility of control that could be applied to commercial weeds by taking account of production, environmental and social benefits and costs.

A coordinated national strategic approach to the management of individual commercial weeds would contribute to several of the actions identified in the Australian Weeds Strategy (AWS)[8]. Such a strategy would provide:

- effective processes to resolve conflicts between economic and environmental interests (AWS Strategic Action 2.1.3)
- systems to integrate weed management into production and ecosystem management (AWS Strategic Action 2.3.5)
- responses to other biological, environmental, social and land-use changes that may contribute to weed spread (AWS Strategic Action 1.4.2), and
- improved practices to prevent weed spread to be applied by industries, public agencies and communities (AWS Strategic Action 3.1.5).

Desmodium sp. Photo Forest and Kim Starr.

Para grass (*Urochloa mutica*). Photo Forest and Kim Starr.

Phalaris (*Phalaris aquatica*). Photo Max Campbell, Jackie Miles.

Conclusions and recommendations

The economic, social and environmental importance of commercial weeds are increasingly acknowledged by researchers, land users, conservationists and regulators but little has been done to either quantify their effects or assess the long-term implications of plant growth versus control. Because of their commercial value, they continue to be approved for use in many jurisdictions, and landholders often resist efforts to limit their use or manage their offsite or ecological impacts.

An integrated approach to managing commercial weeds is required, which includes a national framework for assessing their economic, social and environmental cost and benefits. Decisions based on the results of these analyses should be supported by appropriate policies and regulations which are consistent among all tiers of government, and implemented through strategies that employ the most effective management measures. Achieving such measures will depend to a significant extent on engaging stakeholders in the development of solutions.

Recommendation 1. That a national framework for cost-benefit analysis of commercial weeds be developed to encompass economic, social and environmental costs and benefits, consider the broader natural resource management context and provide for evidence-based decision making that is regionally appropriate.

Recommendation 2. That this framework be used to conduct comprehensive cost-benefit analyses of representative commercial weeds. These representative species should cover the range of growth forms, cultivation situations, landscape contexts and economic scenarios.

Recommendation 3. That structures, policies and regulations relating to the management of commercial weeds be reviewed. This review should consider the roles of the three tiers of government, the National Weeds Strategy and the Australian Weeds Committee. It should also assess the place of weed declaration mechanisms in managing commercial weeds.

Blackberry (*Rubus fruticosus*). Photo Kate Blood.

Stylos (*Stylosanthes scabra*). Photo Forest and Kim Starr.

Tagasaste (*Chamaecytisus palmensis*). Photo M. Campbell/J. Miles.

Recommendation 4. That the value of codes of practice and market-based approaches to the management of commercial weeds be assessed and introduced where appropriate.

Recommendation 5. That the effectiveness of eradication and containment programs for commercial weeds be periodically reviewed and modified accordingly.

In areas where commercial weeds are widespread, abundant and impacting on biodiversity, a site-based approach should be adopted to protect areas of high biodiversity value rather than focussing on control of individual species.

Recommendation 6. That social science research examine the nature of conflicts that inhibit the effective management of commercial weeds and propose ways whereby social barriers to progress may be overcome.


Coffee (*Coffea arabica*). Photo Forest and Kim Starr.


Leucaena (*Leucaena leucocephala*). Photo Forest and Kim Starr.

Recommendation 7. That consultative approaches to addressing the issue of commercial weeds be developed, applied and assessed. Consultation should involve relevant agencies in the three tiers of government, industry bodies and other stakeholder groups, including rural landholders, public land managers and community-based conservation interests as well as relevant scientists.

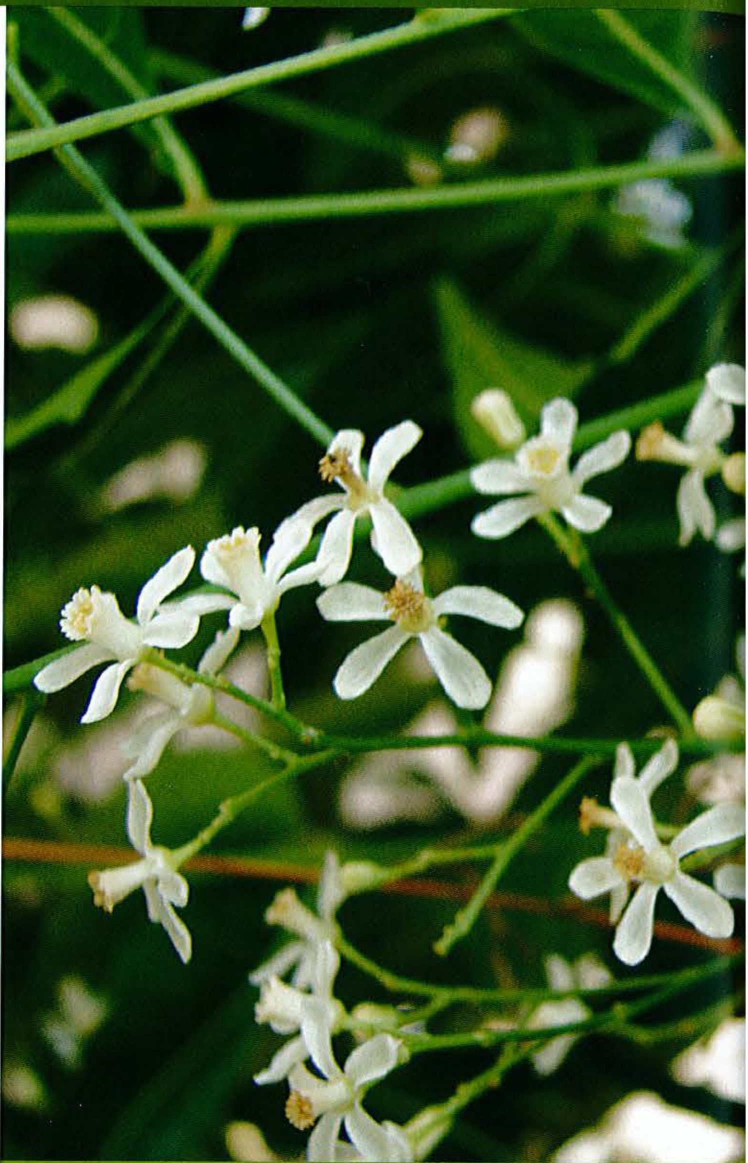
Recommendation 8. That resources be made available to support the expanding roles of local government in managing weeds and pests in general and commercial weeds in particular.


Fig (*Ficus carica*). Photo Allison Mortlock.

PRODUCED BY LWA'S WEEDS R&D PROGRAM. FUNDED BY THE AUSTRALIAN GOVERNMENT'S DEFEATING THE WEED MENACE PROGRAM.

End notes

1. Sinden et al. 2004, *The economic impact of weeds in Australia*, Technical Series No. 8, CRC for Australian Weed Management.
2. Friedel, M., Marshall, N., van Klinken R. & Grice, T. 2008, 'Quantifying costs and benefits of buffel grass', Research project report to Land & Water Australia, www.lwa.gov.au/weeds
3. Setterfield, S., Ferdinands, K. & Drucker, A. 2008, 'Quantification of the environmental costs of weeds', Research project report to Land & Water Australia, www.lwa.gov.au/weeds
4. Herpich, M. & Lindsay, A. 2008, '*Pinus radiata* in bushland: Assessing the issue in the Green Triangle', Research project report to Land & Water Australia, www.lwa.gov.au/weeds
5. Kinnear, S., Rolfe, J. & Miles, R.L. 2008, 'Ecological, economic and social considerations of spray control for *Hymenachne*', Research project report to Land & Water Australia, www.lwa.gov.au/weeds
6. Grice, A.C. 2006, 'Commercially valuable weeds: can we eat our cake without choking on it?', *Ecological Management & Restoration*, Ecological Society of Australia, vol. 7.
7. Standards Australia, *Post-border Weed Risk Management Protocol*, HP 294-2006.
8. *Australian Weeds Strategy — A national strategy for weed management in Australia*, Natural Resource Management Ministerial Council 2007, Australian Government Department of the Environment, Water, Heritage and the Arts, Canberra.



Above: Neem (*Azadirachta indica*). Below left: Caribbean pine (*Pinus caribaea*). Both photos Forest and Kim Starr.

Printed on Revive Silk which is made in Australia from elemental chlorine free pulp with 65% derived from sustainable plantation forests and 35% recovered fibre. It is PEFC Certified and Australian Paper is an ISO 14001 certified mill which utilises renewable energy sources.

Published by: Land & Water Australia
Web: www.lwa.gov.au
ISBN print: 978-1-921544-55-2
ISBN electronic: 978-1-921544-56-9

This publication can be ordered free of charge from CanPrint Communications, freecall: 1800 776 616, or e-mail: lwa@canprint.com.au and quote product code **PN22362**

Photos: Front page, Olive grove, Roger Charlton
Design: Angel Ink
Print: Paragon Printers, June 2009