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

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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.

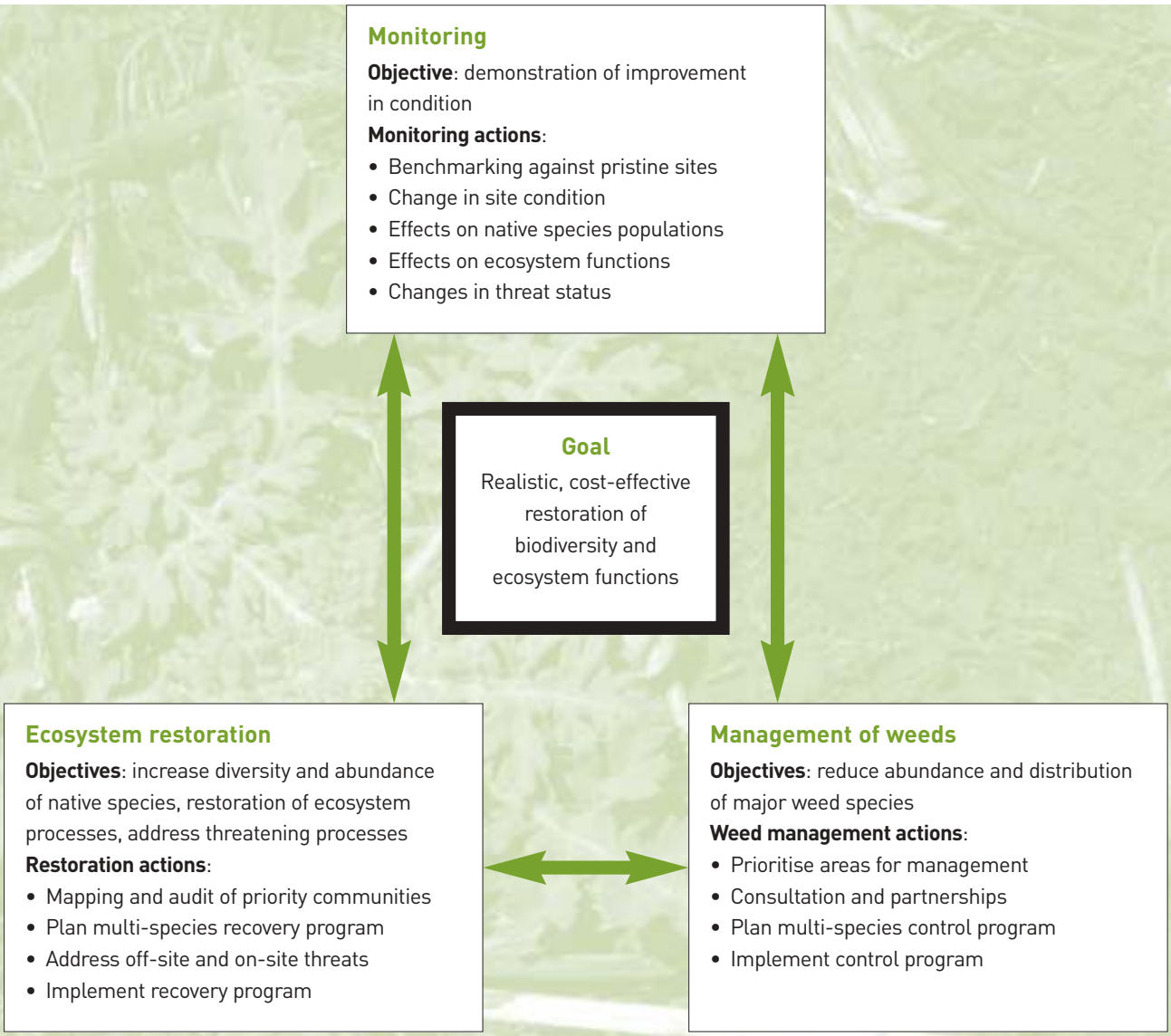
Photo Louise Morin, CSIRO Entomology.

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?

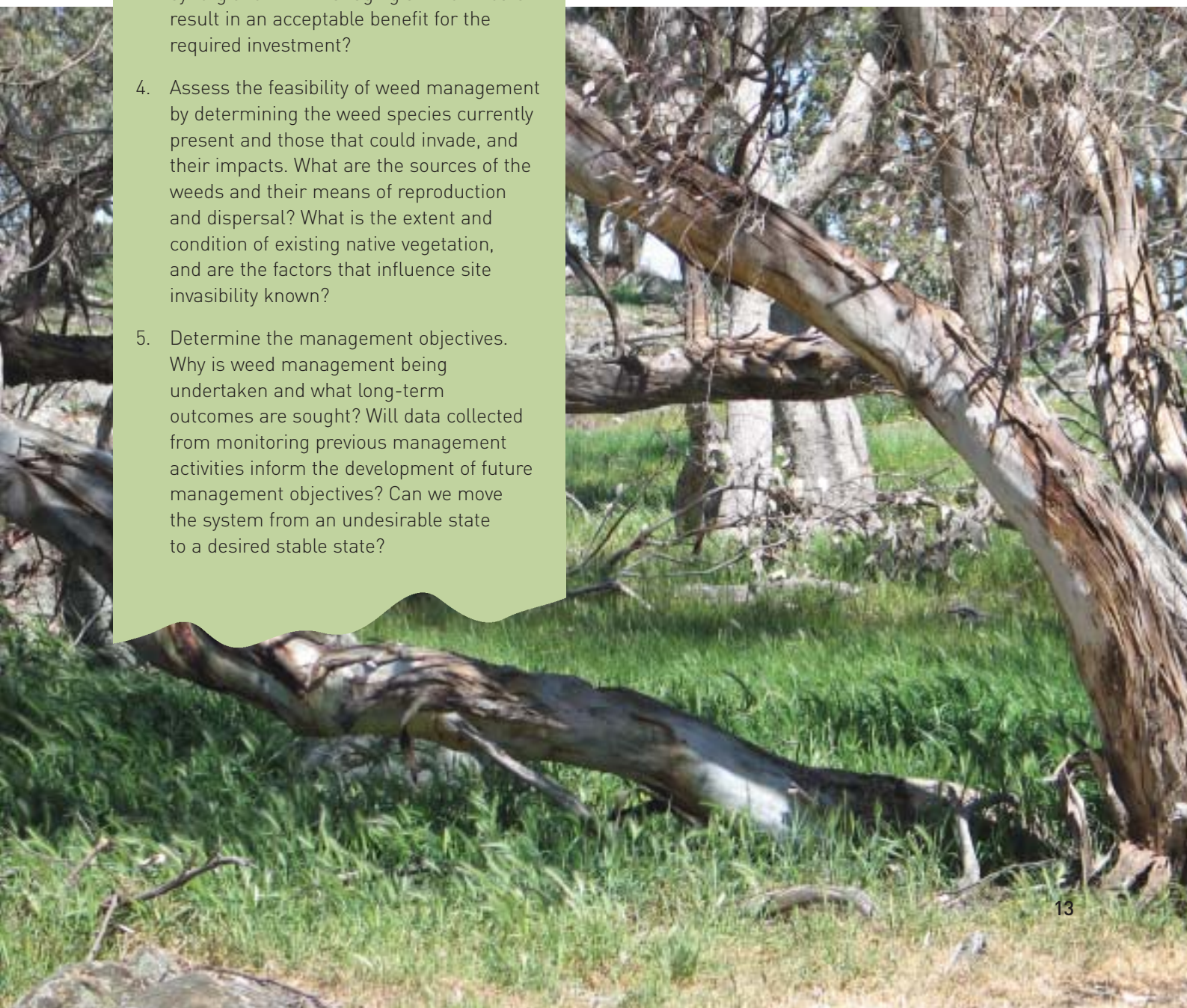
4. Assess the feasibility of weed management by determining the weed species currently present and those that could invade, and their impacts. What are the sources of the weeds and their means of reproduction and dispersal? What is the extent and condition of existing native vegetation, and are the factors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

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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.

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