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SECOND VICTORIAN WEED CONFERENCE

Smart Weed Control, Managing for Success

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Early detection and response

Weeds in botanic gardens

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'Wonder and India, magic and China'
Dylan Thomas

Abstract Botanical gardens must play their part in the global attempt to reduce the impacts of invasive plants. The challenge is to minimise the importation, cultivation and promotion of known or potential weeds. An Australian Botanic Gardens Weed Network (ABGWN) has been formed to combine information and expertise in the formulation of a united approach to weed policy and weed management. The ABGWN is also working with the Cooperative Research Centre for Australian Weed Management to produce a weed risk assessment procedure that can be used by Australian botanic gardens. The paper outlines the context of botanic gardens in relation to weeds, the tension between botanic garden and environmental values, and current progress of the ABGWN.

Then

The role of Botanic gardens has changed over the years according to the demands and interests of the day.

Botanic gardens are generally assumed to have originated in the sixteenth century with the Italian gardens of Pisa (est. 1543 but site moved) and Padua (est. 1545) still in existence. These gardens hark back still further to earlier monastery gardens which were laid out formally with a section called a 'herbularis' or physic garden for medicinal plants known as the 'simples' or 'officinals'. These plants were studied and dispensed by the resident apothecaries in a time when botany had not yet emerged as a scientific discipline. One major aspect of botanic gardens from this time on has been the fascination with plants from other places. From the sixteenth century onwards European colonial expansion and exploration gathered momentum and the focus of botanic gardens changed as they became the repositories for the beautiful, curious and new plant trophies that were being returned from distant lands. In the late sixteenth and early seventeenth centuries the plants came from Eastern Europe and nearby Asia. Gardens competed with one-another to have the most exciting collections and in the late seventeenth century the *Jardin des Plantes* in Paris was leading other European gardens with its diversity of collections, notably the new introductions from Canada. In the eighteenth century novelties came from the Cape of South Africa and the East Indies and plants from warm climates initiated a boom in glasshouse collections. Here we have, presumably, the first stirring of globalisation – the opening up of the world to Europe. Scientific endeavour was stimulated by the myriad newly discovered organisms brought triumphantly home for description and classification. Botanic gardens began to display systems gardens or 'order beds' demonstrating the new plant classification schemes of the day. But the demands of economic botany and ornamental horticulture were not to be distracted as, during the late eighteenth and early nineteenth century, the influx of plant treasures continued. Collection sources included Western North America, South America, the Himalayas, China, East Asia and, of course, the tropics and Oceania, especially Australia, Tasmania and New Zealand[1,2,3]. Of course it was not long before these countries were setting up their own botanic gardens.

In retrospect we can see clearly how botanic gardens were a significant part of the era of Romanticism. There was the intrepid individualism of the botanical explorers in far-off lands and tales of vast rivers, jungles, strange and fascinating foreign cultures and customs, and the breathtaking wonders of the natural world to be seen on distant parts of the globe. This was an unattainable world, but everyone was keen to share in the bounty gleaned by the few. The plant kingdom was an exciting and unrestricted palette of colours and textures with seemingly infinite variety to be harnessed for commerce and garden decoration.

Now

How dramatically, profoundly and permanently our perception of these former times has changed. In those days gardens, both public and private, were seen as relatively small and insignificant sanctuaries in an almost infinite world ruled by the prodigious and unpredictable forces of nature. Now, in a desperately short space of time, the sad reality is that over much of the globe this situation has completely reversed with nature strongly in retreat under the human invasion. Large areas of encroaching cultivated land surround small patches of former wilderness. Distant reaches of the globe are a short flight away in a jet airliner.

The recent Millennium Ecosystem Assessment[22] paints the broad picture:

> 'The structure of the world's ecosystems has changed more rapidly in the second half of the twentieth century than at any time in recorded history, and virtually all the Earth's ecosystems have now been significantly transformed through human actions.
>
> Over the past few hundred years, humans have increased the species extinction rate by as much as 1000 times background rates typical over the planet's history (medium certainty).'

Botanic gardens not only display the plant world in all its glory but also, consciously or not, help mould the public perception of what plants mean. The current dire state of the biosphere is not a sexy message to sell – but it is a story that must be told nevertheless, for the sake of future generations. We can both enjoy and protect plants and that must be part of the botanic gardens mantra. And high on the agenda must be the environmental and agricultural damage caused by invasive plants.

The environmental cost

Some general statistics:

- In 1930 it is estimated that 10% of the planet's primary productivity was directed to human needs, mostly food crops: by 2000 this had grown to 40%. In other words, towards half of the plant matter on the planet is now catering for human needs[4].
- About 24% of the planet's land surface is now devoted to agriculture[22].
- In Australia 60% of the land surface has been harnessed for agriculture and

approximately one third of the forests that existed prior to European settlement have been cleared for agriculture, forestry and mining[6].

Garden plants, naturalised plants and declared weeds

- 60–70% of the naturalised plants in Australia have escaped from gardens[7,8].
- In 1999 the Australian National Weeds Strategy Executive Committee announced a list of 20 weeds of national significance (WoNS). These are considered the most damaging weeds in the country based on their invasiveness, potential for spread, and their socio-economic and environmental impacts: 14 of these plants (70%) are garden escapes.
- About 40% of Australia's current declared weeds are invasive garden plants[8].

Present-day figures indicate that, even with the wisdom of hindsight, we have a long way to go in increasing public awareness, and managing potential weeds used in horticulture.

- Between 1971 and 1995 about 200 of the 300 newly naturalised plants in Australia were introduced to the country as ornamentals[9].
- About 54% of the currently recognised 720 naturalised invasive garden plants were on sale in nurseries in 2002[8].

The economic cost

- Current estimates suggest that the cost to Australia's primary industries in lost production and weed control now exceeds $4 billion p.a.[10, 11].

Botanic Gardens nowadays are multifaceted. There is still an interest in rare, attractive and curious plants from around the world so horticultural display is well on the agenda. There is still the process of documentation and ordering to be done by classification botanists in Herbaria, the apothecaries of the twenty-first century, but now there is greater emphasis on the less obvious groups – fungi, algae, lichens and mosses. The public, as always, is ever eager for new excitement and entertainment. To give them 'bang for their buck' there are the events, new structures and garden displays, shops, cafes, art exhibitions, sculpture, theatre, music, educational activities and so on.

On the environmental front botanic gardens began to tackle conservation issues as the environmental movement got underway in the 1960s and 1970s. Conservation collections of rare or threatened plants were established, and botanic gardens became plant havens. But the agenda has changed. As the natural world staggers under the pressures of an ever-increasing human population efforts to slow the process of environmental degradation have galvanised around the notion of sustainability, the attempt to leave the biological world in as good a state as possible for future generations. High on the list of priorities is the devastation caused by biological invasions.

To date botanic gardens have played a relatively small role in the effort to stem invasive plants; regulating their own activities in relation to weeds has been largely informal, the result of expert opinion, which nowadays gets pretty bad press. It is a difficult and controversial area. Outcomes are likely to be regulatory or prohibitive and the process will involve time, labour and money – factors that discourage enthusiastic action.

Best estimates of numbers of plants in botanic gardens and the nursery industry, together with numbers of naturalised plants and those on important weed lists are given in Table 1.

The way forward

For many years Botanic Gardens were part of an international network exchanging seed lists (Index Semina) – this being the main means of plant acquisition, especially the rare and unusual species. However, seed exchange is now restricted. Firstly, there is the legally binding Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES). Secondly, under Article 8 of the 1993 Convention on Biological Diversity (CBD) national governments are called on 'to prevent the introduction of' and 'control or eradicate those alien species which threaten ecosystems, habitats or species'. The Global Invasive Species Program (GISP), was established in 1997 to address the global threat and support the implementation of Article 8 of the CBD. As a result of these international initiatives there is now a common agreement among many botanic gardens to carefully monitor the acquisition and use of genetic resources, one aspect of which is obtaining consent from the country and/or organisation of origin to ensure potential benefit sharing (including non-monetary benefits). There is no more dipping into the Seed List candy store. The major Australian botanic gardens have not produced Index Semina for many years and seed acquisition from overseas is dealt with by special request and supervised with caution.

Australian Botanic Gardens Weed Network

In October 2004 the Council of Heads of Australian Botanic Gardens (CHABG) approved a proposal for a cooperative effort to deal with the problem of environmental and agricultural weeds. This issue had emerged clearly at the Botanic Gardens of Australia and New Zealand Conference in Geelong in 2003. CHABG supported the development of common policies, procedures and a weed risk assessment methodology for Australian botanic gardens, committing staff to the process. I was appointed facilitator for the establishment of a Working Group to coordinate a clear statement of objectives and a possible time-line to meet these objectives. The task was to be carried out with the assistance of the Cooperative Research Centre for Australian Weed Management.

A working group of representatives has been established, called the Australian

Table 1. Numbers of plants in Australian botanic gardens, in the nursery industry, and on lists of national importance

	Kind of weed	Number
Total number of alien species in Australia		27 000[12]
Total number of taxa in major urban botanic gardens (includes hybrids and cultivars)		c. 33 400[13]
	Naturalised	3 244[14]
	Declared	429[15]
	Alert List	28[16]
	WoNS	20[17]
	NAQs	41[18]
Estimate of total number of taxa in the nursery industry (includes hybrids and cultivars)		c.35 000[19]
	Garden thugs	958[20]
	Naturalised invasive and potentially invasive gardens plants	1 036[21]
	Naturalised invasive garden plants	720[21]

Botanic Gardens Weed Network (ABGWN). To date the ABGWN has a membership of about 75 organisations with representatives from the major city botanic gardens, the regional botanic gardens of Victoria and New South Wales, and also representation from the zoo community.

The following targets were established:

1. Development of a common Weed Policy statement
2. Establishment of an initial cooperative sharing of policies, weed procedures, lists, and information resources and approaches to weed risk assessment and weed risk management
3. Development of an effective strategy for the detection and management of weeds in botanic gardens through the use of agreed Weed Risk Assessment and Weed Risk Management Procedures

At the time of writing (early July 2005) Targets 1 and 2 are essentially complete and a combined workshop is due in late July to discuss the way forward with Target 3.

Environmental and botanic garden values

Australian Botanic Gardens have a poor reputation in relation to weeds, with blackberry (*Rubus* spp.) supposedly dispersed from the Royal Botanic Gardens, Melbourne, and *Mimosa pigra* from the Darwin Botanic Gardens. A study of those plants originating from botanic gardens and known to be environmental or economic weeds is yet to be done. Realising I should not pre-empt its conclusions it seems to me that, in most cases, weed dangers posed by botanic gardens are more likely to result from the supply of plants to other organisations and people than by their direct escape into the environment.

The difficulties confronting botanic gardens will no doubt focus on the tension between environmental values and what may be termed botanic gardens values such as: heritage, education, science and scientific research, conservation, and public landscape. Botanic gardens also often enjoy good relations with the nursery industry. It is not difficult to think of examples in each of these areas where specific cases are likely to test our weed risk assessment methodology to its limits. Here are a few examples.

Botanic gardens have traditionally displayed a wide range of plant diversity: this not only serves science and a natural human curiosity about the plant kingdom but also has a valuable educational function.

Several of the major botanic gardens are cultural landscapes of such significance that they have been placed on the National Register and are therefore subject to heritage planning legislation. These landscapes contain trees of historical significance within an overall landscape style exemplified by few other sites. They are therefore sites of great cultural, educational and scientific value and are managed according to recommendations outlined in their Conservation Analyses. Undoubtedly some of the major structural components of these landscapes would pose a threat were they to 'escape'.

Here, an example of difficulties with commerce and education. Wheat and carrots are widely naturalised plants – should they be grown in a botanic gardens kitchen garden? If the answer to this is 'yes', then what about *Olea europaea*, olive, and *Cynara scolymus*, globe artichoke which are possibly more invasive species? And then what about widely grown plants such as mints, nasturtium, asparagus, fennel, and mustards?

And here a difficulty with science and education. The horsetail, *Equisetum,* is extremely distinctive and botanically important as it is the only genus in the family Equisetaceae that, in turn, is the only family within the broader Horsetail group Sphenopsida. This unusual plant genus exemplifies the kinds of plants that thrived on the Earth in the Carboniferous period over 350 million years ago. It is valuable for botany students to study the botanical structures of such an important plant group, while its form and history make this a very interesting curiosity for the general public and visiting students. However, *Equisetum* is also a highly destructive weed with underground spreading rhizomes that can penetrate to a depth of 1 m or so and, once established, is extremely difficult to eradicate; it is undoubtedly an environmental threat when it escapes from gardens, whether public or private.

Other factors

No doubt part of the task ahead will be to develop monitoring procedures for plants that pose some weed potential.

One area of particular concern is the supervision of affiliated organisations. These include: Friends of Botanic Gardens; groups that deal with botanic gardens plants such as the Growing Friends at Melbourne; retail outlets that might unwittingly supply the public with invasive plants or seeds; education sections that are not in touch with the latest information; craft groups; commercial agreements or exchange with the nursery industry; and plants going to staff.

Botanic gardens are noted for their introduction and cultivation of rare and unusual plants. These are especially difficult to assess for their weed potential because their cultivation history is non-existent or negligible.

With this combined effort it is to be hoped that botanic gardens can help stem the tide of invasive plants. There will be scope to share the workload; keeping records of plant performance in particular areas will help together with building up profiles of particular species and genera. It may be possible to do some weed trials to help the process of risk analysis. Certainly botanic gardens can assist with preventing future weed invasions but perhaps their greatest contribution will be to assisting with a necessary change of public perceptions.

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Review of Victoria's noxious weed list

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Summary Weeds are an emotive issue throughout Victoria. The ten Victorian Catchment Management Authorities (CMAs) have all ranked weeds amongst the top-three natural resource issues in their Regional Catchment Strategies.

A systematic review of Victoria's noxious weed list and potential additions is currently being conducted. This is the first detailed review since 1974. There is the potential that the review will create differences of opinion. To reduce the possible negative impact of the review, species assessments, extensive consultation and extension about the process of the review has been underway since 2001.

The review process is following the principles contained in the Proposed National Protocol for Post-Border Weed Risk Management produced by the CRC for Australian Weed Management.

This paper describes the strategies, issues and difficulties faced in this review.

Keywords Weed risk assessment, consultation, implementation, noxious weed review.

Introduction

The main Victorian weed policy document, The Victorian Pest Management Framework – Weed Management Framework (Anon 2002), requires the CMAs to review the noxious weed list, including the economic, environmental and social impacts, by the end of 2005.

CMAs were established by the Victorian government in 1997 under *The Catchment and Land Protection Act* 1994 (CaLP Act), as community-based organisations responsible for integrated planning and coordination of land and water management in each of the State's catchment-based regions (Figure 1). The CMAs under the CaLP Act have the responsibility to review, consult with the public, stakeholders and nominate plants for noxious weed declaration.

The present noxious weed list in Victoria is outdated. There has not been a systematic review of the weeds since 1974. Minor revisions and additions occurred with the proclamation of the CaLP Act in 1994 and again by DPI and the CMAs in 2003, but most weeds have not changed their declaration status.

The CMAs through their Regional Weed Action Strategies, have since 2000, updated their priorities and actions against specific weeds. These regional weed priorities are sometimes inconsistent with the current declaration status of those weeds.

Prior to a weeds declaration the CaLP Act (Section 69) also requires an assessment of the extent and severity of the impact in Victoria and suggested measures and costs for the management of the plant.

To support the review and to ensure all relevant issues are dealt with a decision support framework was utilised. The

Figure 1. Victorian Catchment Management Regions

framework (Figure 2) ensured input from weed scientists, regional staff and community consultation with an overview by the Victorian Catchment Management Council (VCMC).

The Noxious weed review is being done in three phases. Phase one consists of reviewing the existing declared noxious weeds, Phase two; the non-declared weeds identified as a priority in Regional Weed Action Plans, while Phase three focuses on national weeds (WoNS and Alert Lists) as well as new weeds nominated by the CMAs.

To ensure objective decisions were made in the prioritisation of pest plants, a decision support system was developed and utilised. (Weiss and McLaren 2002, Weiss *et al*. 2004). This process followed the Proposed National Technical Specification for Post-Border Weed Risk Management (CRC for Australian Weed Management) which outlines four main considerations for determining the relative importance of invasive species. These are:

- How invasive is the weed.
- The present and potential extent of the species.
- What social, environmental and agricultural values are impacted.
- The feasibility of control or Cost : Benefit analysis.

The Victorian decision support system meets the above requirements. This paper documents the process by which the above criteria were used to review and justify weed declarations in Victoria.

Review process stage 1

Victoria has developed a risk assessment process, the Pest Plant Prioritisation Process (PPPP) (Weiss and McLaren 2002, Weiss *et al*. 2004). The PPPP is a decision support system relying on multi-criteria analysis/analytical hierarchical process (AHP). The AHP assists with decisions about priorities using qualitative and/or quantitative information and facilitates effective decisions on complex issues by simplifying and expediting the intuitive decision making process.

Basically the AHP is a method of breaking down a complex unstructured situation into its component parts; arranging these parts into a hierarchical order; assigning numerical values to subjective judgements on the relative importance of each variable; and weighting the components to determine which variables have the highest priority. The three components, invasiveness, impact and distribution, each sit above a hierarchy of criteria and intensity ratings. Criteria for evaluating these components were developed, grouped into similar themes and assigned weightings according their perceived importance.

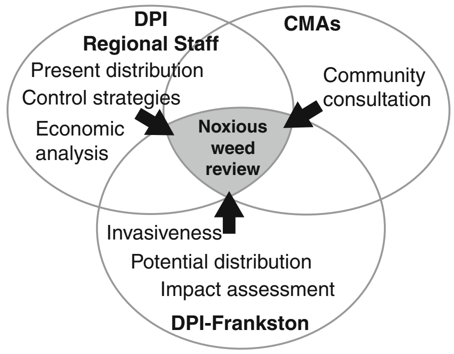

Figure 2. The inputs into the Victorian Noxious Weed review

Invasiveness

Workshops in June 1998 decided on a set of criteria to assess the biological properties of a plant to indicate its potential to be an invasive weed. The criteria have been published (Weiss *et al*. 2004) and fall into four main categories based upon the plants ability to establish, grow and compete, reproduce and disperse.

Impact

A further three workshops with stakeholders in 2002–3 identified criteria to assess potential impact on Victorian social, agricultural and environmental values. These focus on social, natural resources, native flora and fauna, vegetation and agricultural values (Weiss *et al*. 2004).

Distribution

Potential distribution is a major factor in comparing the threats posed by weed species (Panetta and Dodd 1987). The greater the potential distribution of a weed species, the greater the potential impact and management costs. The present Victorian distribution of a plant was estimated from a number of GIS and non-spatial databases. These include Victorian herbarium records, Flora Information Systems, Integrated Pest Management Systems and a 1980 survey of noxious weeds of Victoria. This information was compiled and regional DPI staff had input in updating and validating the data. Potential distribution was estimated for Victoria and CMAs using climate modelling overlayed upon susceptible vegetation and land-use geospatial layers as described by Weiss *et al*. (2002). A ratio of present area from the input from regional staff and the predicted potential area was used to obtain the intensity level for distribution.

The final weed score is obtained by multiplying the score for each component by its weighting to obtain a value between 0 and 1. The higher the score, the greater the risk potential of a species. The Pest Plant Assessment score is expressed as:

$$\text{PestPlantScore} = \alpha(\text{Invasivenessscore}) + \beta\,(\text{Present : Potential Distribution}) + \delta\,(\text{Impact})$$

(where α, β and δ are the subcomponent's weightings).

Review process stage two

An economic assessment process (Weiss *et al.* 2002) was utilised in a second stage of this prioritisation process. This process allows for scenario building of different control strategies and the return on government investment in weed control.

Communication

Because of the newness of the process, the amount and detail of information, Department of Primary Industry (DPI) regional staff and members of the CMAs and Victorian Catchment Management Council have been regularly briefed, since 2002, at presentations and workshops on the process and information outputs of the scientific assessments. To date over 110 existing declared species have been assessed for their invasiveness, impact and distribution.

Discussion

The scientific assessment of the data produced a ranking of weeds for each of the CMAs. As expected State Prohibited weeds generally scored highly in all CMAs. Weeds that scored higher should then be of higher priority for control than lower scored or rank ones. However recommendations for which declaration category, rely on criteria outlined in the CaLP Act.

State prohibited weeds are those that it is reasonable to expect that it can be eradicated from the state. Regionally prohibited weeds are those that it is reasonable to eradicate from the region. Regionally controlled weeds are those where to prevent its spread, continuing control measures are required and Restricted weeds are those where if sold or traded there would be a risk of it spreading within Victoria.

So although a weed may rank highly, such as serrated tussock and blackberry in nearly all the CMAs, based on Groves and Panetta (2002) principles, it may not be able to be eradicated. The weed may then be allocated to one of the lower categories, but still be sufficiently resourced. However with limited resources available some existing weed control programs may have to be reassigned to higher priority weeds and these species dropped down the list to the Restricted weed category.

Preliminary results indicate that there are no major changes to the noxious weeds list. No weeds were dropped off the list, while some high ranking species such as African feather grass, *Pennisetum macrourum*, became more important in most of the CMAs (Figures 3 and 4).

It is unlikely that there will be disagreement about the increased

Figure 3. Current declaration of African feather grass under the *Catchment and Land Protection Act* 1994. Dark shaded CMAs indicate where Regionally prohibited weed declaration. Light shaded area indicates where declared Regionally controlled (East Port Phillip CMA only)

Figure 4. Proposed declaration of African feather grass. Dark shaded CMAs indicate where Regionally prohibited weed declared

importance of some of the weeds, however the downgrading of others is more likely to receive negative public comment. To try and manage this 'fall out' over the review process, a strong reliance on the scientific assessment, understanding of the process and extension is required. Regional DPI co-ordinators assisting the CMAs in making recommendation are one of the key components in the successful adoption of this review. Communicating preliminary results, involving these co-ordinators in validating information and feedback ensure they support the review.

The community consultation process resulted in preliminary recommendations. These underwent a statewide review to check for inconsistencies between adjacent CMAs. Minor alterations were made and a final statewide review was undertaken by the VCMC with final recommendation for Phase 1 weeds going to the Minister. It is expected that the scientific assessment and the trained DPI regional co-ordinators will play a crucial role in managing community expectations about the lowered position of some widespread weeds. The review will be ongoing with Phase two and three assessments circulated for CMA and public consultation and recommendations to the Minister on a regular yearly or bi-yearly basis.

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SESSION 2
Integrated weed management

Integrated Weed Management on a National scale

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Integrated Weed Management (IWM)

IWM is generally taken to mean two slightly different things: i) integration of different weed management methods in the one paddock or farm; ii) integration of weed management into the other processes/systems used on the property or catchment. The first can be thought of as integrating different weed management methods to achieve the best weed management outcome, usually understood in economic terms i.e. minimum yield loss for minimum cost. The second looks at managing weeds as one of the many processes underway on a property or catchment (others might be preservation of water quality and soil sustainability, spread of economic risk), and attempts to integrate the methods used in order to achieve the best overall outcome for the whole system. For example, the best herbicide may not be appropriate close to waterways, or additional vegetation control may be needed as a vermin-management tool.

The most frequent use of the term IWM is the first one, for a single paddock or farm. The new CRC publication 'Integrated Weed Management for Australian Cropping Systems' (in preparation) starts with a series of 'tactics' – depleting the weed seedbank, killing weeds, stopping weed seed set, preventing viable seed entering the seedbank, and preventing new weed infestation. The focus is on finding the best tactic to manage existing weeds within the particular paddock and crop, and only secondarily on preventing new weeds coming onto the paddock or farm.

IWM on a national scale

On a national scale, IWM falls into the second category, integration of weed management into the other processes/systems used, and is closest to IWM within a large catchment, such as the Natural Resource Management Regional Areas or Catchment Management Authorities. The issues to be considered are not primarily which are the best control methods for particular weeds, but rather they are issues of prioritisation - prioritising weed management as one of many competing NRM problems, determining which are priority areas for protection from invasive plants, and which weed species are priorities for management action. Only then is it appropriate to consider the 'best management method' for individual species.

Nationally, therefore, the first step is to determine what is the objective of weed management. This means consideration of which are the 'assets' or 'values' which we wish to protect from damage from invasive plants. These are usually agreed to be our agricultural (and general economic) productivity (Sinden *et al.* 2004), the health and well-being of our human population (which include maintenance of water flows and clean waterways), and our native biodiversity. Preservation of biodiversity encompasses both the protection of whole ecosystems, usually in designated National Parks and World Heritage areas, and of individual species where these have been identified as Threatened or Endangered. Preservation of human well-being also includes the maintenance of recreational areas including smaller environmental parks in urban and semi-urban regions. These may not be important to the preservation of threatened and endangered species as such, but provide a 'bush' experience and contact with native wildlife important to the people living nearby.

In all cases, it is first necessary to demonstrate that the invasive plant or plants are a specific threat to the assets or values to be preserved, that is, to the survival of the ecosystems or species, or to water quality or quantity, or human health. The main reason why weeds have not been taken seriously on a national level is that this link has not been made. The urban public does not understand that weed pollen may be the cause of their hayfever. They quickly react if waterweed infestations prevent them boating and fishing on the local river, but have no understanding of weed impact on water quality, or on evaporation of scarce water from dams. They admire the spectacular "wild flowers" in Western Australia, and never ask how many are invasive species from elsewhere and how many of the native wildflowers are still surviving. So the first priority is to demonstrate the environmental damage that can be caused by the worst invasive species, and then to get that information out into the public arena (Martin 2003).

As part of this, we also need to counter the belief that invasive plants do not affect wilderness areas, i.e. that it is possible to declare an area a National Park, restrict all human traffic and the environment will then look after itself. Unfortunately, this is often not true. Invasive plant seeds are blown in or brought in by birds and wildlife, or are already present along existing tracks and roads. Too often, the edge of the park, or roads through it, runs along the ridges, and initial infestations then spread downstream through untracked country. Natural disturbances such as storm damage, fires, landslips and stream bank erosion, all leave open spaces and gaps for invaders. Some invasive plants, such as Siam weed in the grasslands of the north or bridal creeper in southern Australia, can invade intact native vegetation without any need for disturbance. Therefore management is needed even in set-aside wilderness areas, and certainly in National Parks subject to human traffic along tracks and from camping grounds. Adequate resources for weed management has to be part of any National Park system; too often, this is still not true (Sinden *et al.* 2004).

Prioritisation

Once objectives have been set, the next issue is prioritisation, which can be thought of as determining where resources should be directed. The National Weeds Strategy is currently being revised, nearly 10 years from its first inception. The initial Strategy identified three main goals: prevention (stopping the flow of new weeds); managing existing weeds; and developing national capacity, but most effort went into the second two tasks. The National Weeds Executive undertook the mammoth task of developing a national priority list for major weeds, which resulted in a list of 71 priority national weeds, with the worst 20 becoming the Weeds of

National Significance (WoNS). Hopefully the revised Strategy will put more emphasis on the first goal: just as for an individual landholder, the best return on investment comes from prevention, preventing the weeds getting hold in the first place. On a national scale, this means border control (preventing them coming into Australia) followed by regional-scale containment (keeping them contained into the one or two original infested areas). Our border control system is generally good, even excellent by international standards, but our post-border containment is still woeful (Australian Biosecurity Group 2005). For example, in northern Australia, major efforts are made to eradicate new areas of *Mimosa pigra* in Queensland, or of rubbervine in the Northern Territory or Western Australia, but gamba grass is still planted and promoted across the north, and hymenachne, even though it is a WoNS, is still sold and planted in the NT and WA. There are innumerable examples of ornamental plants which are declared noxious weeds in some states or councils, but are legally sold across the state boundary. So a first priority must be to establish a national system to control the promotion and sale of known invasive plant species (Australian Biosecurity Group 2005).

The next priority must be to determine which areas most need protection. To some extent, this has already been done: World Heritage areas, national biodiversity 'hotspots', and National Parks have been identified and set aside with the priority objective of preserving our native biodiversity. There is therefore a clear priority to protect these areas from invasive species, both plants and animals, and, for example, significant national resources have been expended to keep mimosa out of Kakadu (Sinden *et al.* 2004). Unfortunately, very little money has been made available to control pond apple in the Wet Tropics World Heritage area, or buffel grass spreading across central Australia, and no doubt there are many other examples.

Other priority areas are those which, on a regional or landscape scale, are most easily invaded, i.e. under most threat. These might be remnant ecosystems which are fragmented and under high human pressure, i.e. with many invasive weeds planted nearby. Examples would be the Blue Mountains and the Adelaide Hills, where housing is moving deeper and deeper into previously uninvaded environments, or remnant rainforest east of the Dividing Range. Riparian areas generally have richer soils and better water supply and for these reasons are often heavily invaded, often by a complex of weed species. Yet the very same features make them key ecosystems for many wildlife species. Management of weed invasions in these key environments must be a high priority for any national IWM system.

Finally, management of existing already-widespread species requires consideration of IWM principles, that is, use of all appropriate control methods in ways that integrates with other land uses and values. In practical terms, this may mean use of non-chemical control methods where volunteer labour is available, or use of carefully targeted chemicals (such as gel applications) in sensitive areas. In other heavily-invaded environments, the 'heavy artillery' approach, using bulldozers to clear all vegetation beneath the largest trees, burning the trash and then replanting, can give excellent results (field trip, Qld Weeds Symposium Townsville July 2005). For high-impact widespread weeds, biological control gives the best results and has to be a key part of any national IWM strategy (Walton 2005).

Conclusion

In summary, the principles of IWM on a national scale are similar to those for a catchment or region: consider objectives, then prioritise these and determine available resources. Then decide how to use the best available management methods in each site or system in such a way as to support all land-use objectives for that site. Use adaptive management methods, i.e. be prepared to learn from experience and adapt methods as the situation changes, whether this is due to new weeds or new methods or changes in political or other priorities.

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Integrating IWM into crop management plans

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Summary When developing integrated weed management systems, it is necessary to ensure the broader picture of the whole crop management plan is taken in to consideration. The implementation of weed management practices may impact on other aspects of crop management in the current or future seasons. Many of these impacts have been well understood (e.g. the residual effect of herbicides, weed management on disease and insect populations), however their impact on the soil fauna and flora has not been well understood. Since the introduction of biotechnological techniques, the full range of soil microbes is now becoming evident. The role of these microbes on plant function is still being discovered as is the effects of weed management decisions on these microbes and their interaction with plants. Perhaps it is time for those in main stream agriculture to pay a little more attention to those that have been utilising 'biological farming systems' and for us to understand the full interactions that occur between the plant that we are wishing to enhance and their environment.

Introduction

Integrated weed management (IWM) has been developed from integrated pest management (IPM) utilising biological, chemical, physical, ecological and genetic method to manage weeds (Sindel 2000). IWM as did IPM due to the development of resistance of the control species to applied chemicals. The reliance of the chemical management option caused high selection pressure which enhanced the resistance gene within the original population to become dominant. Alternating management options then reduced the gene frequency. Initially the change in management was just to another chemical, sometimes even with the same mode of action. This however was short lived before multiple resistance started to occur. Then IWM or IPM becomes necessary in order to continue cropping. As the resistance issue was the driving force to ensure crop production there was a tendency for practitioners to solely focus on its management and not consider the side effects of the resistance management options on the whole crop/paddock plan not just in one season but over seasons. This paper reflects on the IWM strategies and the side effects that can occur due to their implementation.

IWM Effects

Biological management effects

While biological control has offered many examples of effective weed management (Briese 2000), integrating these into management plan whether these be crop, farm or catchment scale can offer some difficulty. For many biological agents the implementation of other IWM techniques can be detrimental to the biocontrol agent, as the agents food source is depleted (Ireson *et al.* 2000, Huwer *et al.* 2005). Perhaps another approach is required such as those used to combat insect resistance. For instance, in GM cotton IPM systems; there has been the use of insect refuges to ensure that there remains enough susceptible populations to dilute any effects of resistant insect populations increasing (Carriere *et al.* 2004). A similar approach has been suggested in theory for herbicide resistance utilising a mosaic boomspray pattern (Roux 2004).

Physical management effects

Physical management techniques include cultivation, cutting, mulches, flooding, and seed collection (Pratley 2000). While cultivation is effective in controlling many arable weeds, the negative effect of cultivation on soil structure makes it undesirable on Australian soils. The utilisation of burying seeds (Young 2003) to stop emergence again is effective but not practical in continuous large scale cropping enterprises. The use of mulches can provide both a mechanism of weed management but also increase plant nutrition through improving organic matter but cause issues in sowing crops and harbouring crop pests such as snails and slugs.

Ecological management effects

Changing the ecological balance of plant populations through altering sowing dates, increasing sowing rates (Lemerle *et al.* 2004), retaining stubble, providing quarantine can also affect populations of other organisms.

Genetic management effects

Immediately these days one thinks of genetic engineering, but the whole process of weed management is to manipulate the populations' genetics through favouring of some species against another, by applying artificial selection pressure. Other methods of genetic effects are to utilise competitive ability of crop plants in breeding programmes (Lemerle *et al.* 2001a, Lemerle *et al.* 2001b). Herbicide tolerant crop whether GM or conventional also introduce new selection pressures and implications in their use, especially GM crops. While, the release of GM varieties needs to have an approval from the Office of the Gene Technology Regulator to ensure that there are no adverse implications to human health and the environment, their effect on off target species is under question on some fronts (Snow *et al.* 2005) but other studies have shown no change in soil microbial populations when comparing GM to non GM crops (Lee *et al.* 2003; Milling *et al.* 2004).

Chemical management effects

Herbicides can have several non target effects which if used according to label instructions should not occur (e.g. spray drift). Labels also give an indication of the persistence of herbicides in the soil. Here there has been a welcome change in labels getting away from just a time frame (plant back period) to also including information about biological activity /requiring soil moisture as well (e.g. Syngenta's Logran® and DuPont's Glean® labels). While this change in labels occurred due to the prolonged dry season over the last decade, it has allowed users to be more aware of the processes required to degrade herbicides.

Plant and soil microbes interactions

An area that is becoming a major research area is that of the soil microbial populations and how agricultural practices are changing their populations. Only 17% of the known fungal species can be cultured , yet there has been the identification of 80 000 species of fungi from observation of fruiting bodies in situ or by culturing soil extracts, with more species being identified through genomics (Bridge and Spooner 2001). Present research is investigating the role of agricultural production systems including GM based systems on their effect of the soil microbial diversity.

In work conducted at the University of Melbourne, Dookie campus, the effect of herbicides on non target soil microbes has been investigated in vitro (Sutton 2003, Bennett 2004, Schilg 2004). The effect of changing canola cropping systems from triazine tolerant canola to either glyphosate tolerant or glufosinate tolerant canola, indicated that there could be an increase in the amount of sclerotinia present under glyphosate tolerant crops(Sutton 2003, Schilg 2004). Though (Lee *et al.* 2003) reported that glyphosate did not affect the defence response of glyphosate resistant soybeans to sclerotinia. The effect of the triazine herbicides atrazine and simazine was to stop the formation of asci hence to the sporolation of sclerotinia. As asci formation has a light requirement, the use of herbicides affecting the photosytems, it could be theorised these herbicides act in a similar way in fungi. Glufosinate also stopped the formation of asci. And has been shown to be produced naturally by *Streptomyces* spp. has some antimicrobial activity (Sessitsch *et al.* 2004). The dinitroanaline herbicides also have been shown to affect the nodule formation in legumes (Bennett 2004), due to the interference of the bacterial protein FtsZ required for cell division. This protein is of similar structure to tubulin, the site of activity for these dinitroanaline herbicides (Erickson 1998).

Conclusion

Herbicides are not always detrimental to soil microbes with some studies reporting an increase in the numbers of bacteria and fungi (eg:(Balasubramanian and Sankaran 2001, Araujo *et al.* 2003). Also many soil microbes are beneficial to plant growth, with more of these fungi bacteria and invertebrates being discovered each year (Bonkowski 2004). Hence, it is important to determine what the effect of herbicides are on the soil microbial populations, not just in numbers but also on which are promoted and which are decreased. Those herbicides that enhance the beneficial groups and either suppress or not effect the harmful groups are the herbicides that we need to utilise and conserve within our plant production systems.

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SESSION 3
Early detection and response (concurrent)

Site management strategies for six National Environmental Alert List weed species in Victoria

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Summary Six National Environmental Alert List weed species (three of which are declared State Prohibited Weeds in Victoria) were targeted for early detection and eradication in Victoria by the Department of Primary Industries: *Nassella charruana, Acacia karroo*, *Hieracium aurantiacum, Trianoptiles solitaria, Piptochaetium montevidense, Cytisus multiflorus.* During the course of the project, which ran from May 2003 to December 2004, more infestation sites were discovered for several of the species, although *Piptochaetium montevidense* was unable to be detected in Victoria and may already have been eradicated. All species detected have received at least one treatment of the original infestation sites, with the exception of *Trianoptiles solitaria*, which initially proved difficult to detect. Treatment programs for *Nassella charruana, Acacia karroo*, and *Hieracium aurantiacum* are now well advanced. Critical success factors in eradication programs include that containment of further spread is achieved by the use of weed spread and hygiene protocols, and best-practice control techniques are instigated at each site of occurrence.

Keywords National Environmental Alert List, *Nassella charruana, Acacia karroo, Hieracium aurantiacum, Trianoptiles solitaria, Piptochaetium montevidense, Cytisus multiflorus*, weed hygiene, eradication.

Introduction
The National Environmental Alert List (Alert List of Environmental Weeds) identifies 28 weed species in the early stages of establishment which have the potential to become a significant threat to biodiversity in Australia if they are not managed (Department of Environment and Heritage 2004). Six National Alert List weed species were targeted for early detection and eradication in Victoria by the Department of Primary Industries (DPI): *Nassella charruana*, lobed needle grass*; Acacia karroo*, Karoo thorn; *Hieracium aurantiacum,* orange hawkweed*; Trianoptiles solitaria,* subterranean Cape sedge*; Piptochaetium montevidense,* Uruguayan rice grass; *Cytisus multiflorus*, white Spanish broom. The six species were targeted through a Natural Heritage Trust funded project called 'Victoria's Dirty Half-Dozen – Alert and action on six new weeds in Victoria'. The project, which ran from May 2003 to December 2004, was delivered as a part of a broader, Victorian Government project targeting new weed incursions, called 'Weed Alert Rapid Response' (Department of Primary Industries 2005). Three of the targeted species, *N. charruana*, *A. karroo*, and *H. aurantiacum* are declared State Prohibited weeds in Victoria under *The Catchment and Land Protection Act 1994*, a status which requires these species to be eradicated from the State if possible (Table 1.). In addition, two of the targeted species, *N. charruana,* and *P. montevidense* are Priority Sleeper Weeds (Cunningham *et al.* 2003).

Materials and methods
Site management strategies

1. Site hygiene Staff and contractors involved in surveying and treating the weed species were briefed on the importance of site hygiene. For example, they were required to inspect / clean their boots, clothing, tools and vehicles on exiting infestation sites to help prevent the spread of propagules. In the case of *Hieracium aurantiacum*, if flowers and seedheads were present on the plants at the time of treatment, it was usually possible to remove and bag these propagules prior to the spot spraying operation to reduce the chances of seed spread from the site.

2. Managing the soil seedbank In the case of *Nassella charruana, Hieracium aurantiacum* and *Cytisus multiflorus*, the strategy was to 'spot spray' the plants to kill them before they set seed and to enable the germination of soil stored seed and to continue to follow up spray, so exhausting the seedbank over time.

3. Physical removal of the seedbank In the case of *Acacia karroo*, with so few trees to remove, and a large and persistent seedbank beneath the trees, it was considered advantageous to physically remove the top few centimetres of soil from beneath the trees. This 'contaminated soil' was then disposed of at an appropriate landfill and deeply buried along with the removed *A. karroo* trees themselves. At the sites of removal, the topsoil was then replaced with 'clean' fill prior to revegetation of the sites.

Physical removal of the seedbank of one entire *Nassella charruana* infestation was also undertaken. This was done to reduce the risk of seed spread from the soil seedbank at the site, which was about to be developed as a housing estate. With numerous construction workers and their machinery about to start undertaking earthworks at the site, appropriate hygiene measures would have been very difficult to implement. Removal and burial of the seedbank prior to the land development phase was seen as a best-bet option to reduce the risk of seed spread from the site. With *N. charruana*, there is certainly scope to further utilise and harness land development to remove or permanently bury seedbanks. This is because this species is only known to occur on the northern outskirts of Melbourne, mainly on land about to be developed for housing or other developments in the near future.

4. Site rehabilitation Site rehabilitation was undertaken on a case by case basis, depending on the requirements at each site. No revegetation was normally undertaken with spot spraying among other vegetation, because weeds will be normally be replaced by the natural regeneration of the surrounding vegetation. Indeed, in cases where follow-up spraying for several years is required, having to protect planted vegetation at the sites could hinder further spraying attempts. However, where the large *Acacia karroo* trees had been removed from parks and zoos, revegetation was usually undertaken to rehabilitate the landscape values of these sites.

Site monitoring

DPI's Integrated Pest Management Information System (IPMS) is the database used to collect the data for infestations, assessments, and treatments of the six species in Victoria.

Results and discussion

Treatment/eradication strategies for individual species

***Nassella charruana* – lobed needle grass**

Nassella charruana is a serious weed due to its invasiveness and competitiveness. In Australia, it is limited to a few small infestations on the northern outskirts of Melbourne. It was discovered on a rural property, 20 km to the north of Melbourne in the 1990s. It is not known when or how it was originally introduced to Australia, but the landowner of the original rural property at Epping has recognised the grass's presence at his property at least since the 1950s (CRC for Australian Weed Management 2003a).

Harnessing land development A small number of the *N. charruana* infestation sites are in grassland reserves, but the majority of infestation sites are on private land on the northern fringes of Melbourne, in the Epping area (Table 2). It is anticipated that most of the properties with *N. charruana* infestations will be sold for residential and/or industrial development in a few years time, enabling the harnessing of land development to help eradicate the infestations. DPI will maintain contact with the landholders regarding the timeframe for land development. This will enable an opportunity for DPI to work with the developers to ensure the use of hygiene protocols during the development process and that any remaining seedbank topsoil is removed or buried on the sites as part of the land development process. This will ensure the eradication of the species from these sites. In the meantime, the strategy is to 'spot spray' individual plants to kill individual plants before they set seed and to enable the germination of soil stored seed and to continue to follow-up spray whenever growth conditions allow, so exhausting the seedbank over time. This strategy will continue to exhaust the seedbank over time to reduce the risk for any eventual removal or burial of the seedbank at these sites.

Freeway construction, has it spread *N. charruana*? The new Cragieburn Bypass freeway extension was constructed in a northerly direction through the most heavily infested *N. charruana* affected property in late 2002. The freeway construction was the subject of a VicRoads weeds strategy (McMahon 2002), and it is hoped that the road construction has not spread the weed northwards, away from Melbourne. To this end, DPI has engaged with both VicRoads and its contractors regarding the need for DPI to conduct surveys for *N. charruana* for several years along the construction route.

***Acacia karroo* – Karoo thorn**

Acacia karroo is considered a serious competitor and can form dense thorny thickets. In Australia, it is limited to a number of horticultural plantings in zoos, parks and arboreta, and its pre-emptive removal from these sites has been undertaken in light of its weed risk potential to Australia (CRC for Australian Weed Management 2003b).

In Victoria, *A. karroo* is known from a limited number of Zoo and garden plantings (Table 2), and so far it has not been recorded as naturalised in the State, although seedlings have been observed growing under planted *A. karroo* trees at Werribee Open Range Zoo (Hansford 2004).

Just a few trees left in zoos and parks The strategy is to physically remove each tree and the top few centimetres of soil from underneath each tree to remove the seedbank and tree to landfill disposal. Site rehabilitation, including topsoil replacement and revegetation is then undertaken. There are so few trees to be removed in Victoria that eradication from the State should be achievable in the near future. Six infestations were removed by DPI during 2003–2004. There are now believed to be only seven remaining trees in Victoria, with five trees remaining at Werribee Open Range Zoo, one tree in the Melbourne area and one at Bendigo. In some cases, the trees have been valued as exhibits. For example, the Werribee Open Range Zoo has based its visitor experience around an African savanna landscape, including the use of *A. karroo* trees. A staged removal and revegetation program is being negotiated to minimise the impact to the Zoo (Hansford 2004). Due to the Melbourne Zoo's diligence in removing its *A. karroo* trees in August 2003 (with assistance from DPI in hygiene and disposal), the Zoo won a Special Achievement Certificate at the 2003 Weedbuster Awards (Keel and Joubert 2004).

***Hieracium aurantiacum* – orange hawkweed**

Hieracium aurantiacum is a threat to the alpine country and the temperate tablelands of eastern Australia. It was probably introduced to Tasmania as a garden plant in the early 20th century, but was not recorded in mainland Australia until much later. *H aurantiacum* spreads by runners over short distances and by seed over larger areas (CRC for Australian Weed Management 2003c). New Zealand experience with this and other hawkweed species has shown the danger of letting these weeds become established (Espie 2001).

In Victoria, a combination of surveying by staff of Falls Creek Resort Management, Parks Victoria, and contractors has detected infestations in and around the Falls Creek village and in the Alpine National Park (Carr *et al*. 2004) (Table 2). Strategic management has been undertaken as a cooperative effort between DPI, Parks Victoria and the Falls Creek Resort Management Board. For example, DPI has provided chemical control advice, Parks Victoria has run the spraying operation in the national park areas, Falls Creek Resort Management Board staff and contractors have run the spraying operation within the Falls Creek village area. The strategy is to 'spot spray' individual plants or patches of plants to kill these plants before they set seed and to enable the germination of soil stored seed and to continue to follow up spray, so exhausting the seedbank over time. Seed and flower heads should be removed and bagged before spraying, if practical. Ideally, plants would be sprayed prior to flowering. All sites surveyed in the summer of 2003/2004 were revisited and sprayed again in the 2004/2005 season. This work will need to continue and any new outbreaks will also need to be detected and sprayed each time. During the project period, another species of *Hieracium* was detected in the Alpine National Park, King devil hawkweed, *H. praealtum* ssp. *bauhinii*. This is the first time this species has been recorded in Australia. The new infestation of *H. praealtum* ssp. *bauhinii* has since received treatment by spot spraying.

***Trianoptiles solitaria* – subterranean Cape sedge**

Trianoptiles solitaria may out-compete more desirable indigenous plants. The earliest known record of this species in Australia was a population in a reserve at North Balwyn, Melbourne in 1989. The origin of the population is unknown. The weed is a small, leafy annual herb that grows to about 200 mm in height (CRC for Australian Weed Management 2003d).

During the project period, *Trianoptiles solitaria* proved difficult to detect at the North Balwyn site. It was finally sighted by DPI for the first time in September 2004 (Table 2). However, within a few weeks of the tiny plant's emergence, it became obscured by grass growth. The grass was then mowed by the landowner, making it difficult to observe the plant, and the plant then progressed to its annual dormancy. The brief seasonal opportunity to treat the weed and the regular mowing of the site by the landowner adds complexity to its ease of control. More work needs to be done to forge a closer working relationship with the landowner in order to see that the site is treated and the landowner's grass mowing is postponed during the brief seasonal opportunity available for treatment each year.

***Piptochaetium montevidense* – Uruguayan rice grass**

Piptochaetium montevidense forms dense tussocks, is stimulated by fire and is resistant to grazing. It is a South American stipoid grass, estimated to have a huge potential distribution in Victoria and New South Wales. So far, only one infestation has been found in Australia, discovered at Cherry Lake at Altona, Melbourne in 1988 (CRC for Australian Weed Management 2003e). It is not known how or when the species was first introduced to Australia.

During the project period, several attempts were made to detect the species at the Altona site, however, no plants of *P. montevidense* were detected (Table 2). It was then determined, and confirmed by the original botanist who discovered the infestation, that the construction of a large embankment at the site for this species has likely buried the entire infestation. This 'inadvertent eradication' may have occurred several years prior to the start of this project. No additional sites have been detected in Victoria. However, in November 2004, the occurrence of another *Piptochaetium* species (*P. uruguense*) was discovered in a reserve in the northern Melbourne suburb of Reservoir. This discovery was confirmed by the National Herbarium of Victoria to be the first and only record of this species in Australia. The land manager, the Merri Creek Management Committee, then spot sprayed all the plants that could be found to attempt to eradicate this infestation. It is baffling as to how this species became established, as there are no records in surrounding areas, or anywhere else in Australia.

***Cytisus multiflorus* – white Spanish broom**

Cytisus multiflorus is a serious environmental weed that can form dense stands and out-compete native species. There is also concern that the species could hybridise with it close relative, *Cytisus scoparius*, to possibly form a hybrid weed (CRC for Australian Weed Management 2003e).

During the project period, all plants that could be reliably detected within the boundaries of the Creswick Regional Park were treated (Table 2). Plants reported outside the park boundary have not necessarily been treated. The strategy is to 'spot spray' individual plants to kill these plants before they set seed and to enable the germination of soil stored seed and to continue to follow up spray, so exhausting the seedbank over time. A selective chemical was used. Spraying before the flowers have fully developed is the best approach, since flowering and seed set is then prevented. However, it is often difficult to locate scattered *C. multiflorus* plants when they are not flowering. In a limited number of situations, where the plants grow along the boundary of the park with private gardens, *C. multiflorus* plants were treated by a cut-stump herbicide method. The seedbank may be persistent in the affected areas of the park and is likely to require several years of follow-up spraying and surveys in order to eventually eradicate the species from the park.

Conclusion

The project was successful. It has enabled the detection of many more infestation sites than were originally known. Treatment regimes have been set up for most species and sites. Some species such as *Acacia karroo* are now likely to be eradicated from Victoria in the near future. Other species, such as *Nassella charruana* are likely to be longer-term candidates. The innovative treatment strategies developed during this project, such as physical removal of the seedbank, and the use of hygiene and disposal protocols will likely have application to other eradication campaigns elsewhere.

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Table 2. Detection and treatment of the six species during the project period

Species	Number of infestations covered by original project scope (May 2003)	Location of original project scope infestations	Additional number of infestations detected by December 2004	Total number of infestations detected by December 2004	Number of infestations treated by December 2004
Nassella charruana	2	Thomastown, Epping	13	15	15
Acacia karroo	2	Parkville, East Melbourne	8	10	7
Hieracium aurantiacum	4	Falls Creek	23	27	27
Trianoptiles solitaria	1	Balwyn North	0	1	0
Piptochaetium montevidense	1	Altona	0	0	0
Cytisus multiflorus	4	Creswick	0	4	3

Table 1. Weed status of the six species. Note multiple status of several species

Species	Common name	National Environmental Alert List	Declared noxious (Victoria) State Prohibited Weed	Priority Sleeper Weed (Cunningham *et al.* 2003)
Nassella charruana	Lobed needle grass	✓	✓	✓
Acacia karroo	Karoo thorn	✓	✓	
Hieracium aurantiacum	Orange hawkweed	✓	✓	
Trianoptiles solitaria	Subterranean Cape sedge	✓		
Piptochaetium montevidense	Uruguayan rice grass	✓		✓
Cytisus multiflorus	White Spanish broom	✓		

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What is a weed?

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What is a 'weed'; should we continue to say that whether a plant is a weed is in the eye of the beholder?

Introduction

The community response to weeds is affected by the way we talk about them. The literature provides many examples of 'weed' being defined by reference to human preferences, e.g. 'A plant growing where it is not wanted by man' (Usher 1996); or 'weediness is in the eye of the beholder' (Roth 2001). Stearn wrote that weeds 'are not so much a botanical as a human psychological category' (Stearn 1956). It is common to hear that a plant may be a weed to one person and a valued plant to another. It is suggested that this is too permissive. Although such definitions continue to be given, the true position today is that some plants are weeds by reason of characteristics such as invasiveness, and remain weeds even if some people want to grow them.

Definitions of 'weed'

Edna Walling wrote that in one of her first lectures at the Burnley School of Horticulture in 1916 she was told that a 'weed is a plant out of place' (Hardy 2005). This definition was probably a standard one for the time (Ewart and Tovey 1909). The botanist Dr Winifred Brenchley, however, in *Weeds of Farm Land*, noted a few years later that the word was used very loosely, and sometimes was made to apply to 'almost any plant in any situation'. She sought to narrow the meaning down to 'an exact significance'. What resulted were separate definitions, for each of the two distinct systems of working farm land: land under the plough, and grass-land. A weed of arable land was defined as 'any plant other than the crop sown'. A weed of grass-land was defined as (a) 'a plant of low feeding value' or (b) 'a plant that grows so luxuriantly or plentifully that it chokes out other plants that possess more valuable nutritive properties' (Brenchley 1920). It may be suggested that these definitions hardly provide the exact significance sought, but serve rather to demonstrate that precision is hard to achieve. The definitions are also confined to what are sometimes called 'agrestals', weeds of agricultural land (Usher 1996). Other categories of weeds have long been recognised, e.g. 'ruderals', or weeds of waste places and roadsides (Usher 1996). (From the Latin, *agrestris*, meaning 'of the fields' and, *rudus* meaning 'broken stone, rubbish, debris').

The two most frequently used definitions in the weeds literature today are: 'a plant growing where it is not wanted' and 'a plant out of place' (Usher 1996). Although sometimes treated as if they are equivalents, or used in combination, there may be differences between them. Dr William Parsons, for example, began his *Noxious Weeds of Victoria* with the following:

> 'A weed is usually defined as a plant growing out of place (that is, growing where we do not want it to grow). Both of these definitions involve man's assessment of the plant in a situation – it is growing out of place as we interpret the meaning of "place" or it is growing where "we" do not want it to grow.'

In the weed science literature, texts commonly begin with the matter of definition, and commonly accept definitions such as those set out above. In 1956 the Terminology Committee of the Weed Science Society of America adopted the definition, 'a plant growing where it is not desired'. American weed science texts often accept this definition. For example, *Weed Science Principles and Practices* begins with an 'Introduction to Weed Science' which contains the following passage,

> 'The first question is "What is a weed?" Before a plant can be considered a weed, humans must provide a definition. Many varying definitions have been developed for weeds, depending on each particular situation where they occur and the plants involved. For the purpose of this book, we define a *weed* as *a plant growing where it is not desired, or a plant out of place* – some plant that, according to human criteria, is *undesirable*. We decide for each particular situation which plants are or are not desired in terms of how they affect our health, our crops, our domesticated animals, or aesthetics. For example, some people consider a dandelion in a lawn a weed and want to control it, whereas others feel the dandelion is desirable and do not control it. The same thinking is involved for any weed situation, whether in a crop field, a pasture, a body of water, or in a non-cropland or natural site' (Monaco *et al.* 2002).

As might be expected from such a beginning, this book is mostly about herbicides and other ways of controlling weeds rather than about the weeds themselves.

It does contain a short section on invasive plant species generally, but this is clearly marginal in terms of the book's concerns. At the same time reference is made, in this work as in other texts, to attempts to identify biological characteristics which may serve to describe weeds, often by reference to the work of the botanist Herbert Baker (1974).

Definitions by ecologists

Ecologists also tend to use the 'plant out of place' definition. The glossary to *Ecology: an Australian Perspective* adopts the usual definition: 'Quite simply, a plant growing in the wrong place (a place where we do not want it to grow). A plant that is neither desired nor appreciated in that place.' (Attiwill and Wilson 2003).

The *Oxford Dictionary of Ecology* takes the definition a little further:

> 'A plant in the wrong place, being one that occurs opportunistically on land or in water that has been disturbed by human activity (see RUDERAL) or on cultivated land where it competes for nutrients, water, sunlight, or other resources with cultivated plants…' (Allaby 1998).

Such wrong place definitions depend logically on there being a right place, and the right place seems likely to take us back to what humans want. Some ecologists, troubled by the feature of the 'un-wanted' definition that one man's crop may be another man's weed, have preferred to define weeds as 'pioneers of secondary succession' (Bunting 1960, Harlan and de Wet 1965). There is something troubling about the standard definition.

Problems with the standard definition

When encountered in the scientific literature such definitions of 'weed' have a strange uncertainty about them. It is as if the task of developing a definition by which weeds could be distinguished from non-weeds has been avoided. The question, 'How are we to tell whether this plant is a weed?' has been given not even the response, 'It all depends on the circumstances', but rather, 'That is not a question for botanical science to answer.' Dr B. Auld and Dr R. Medd for example, having defined a weed as 'a plant growing where it is not wanted', go on to say that 'Any species in the plant kingdom, including algae, ferns and trees can be a weed' (Auld and Medd 1996). A number of writers have taken the view that any plant may be a weed, and that as a corollary, 'weediness is in the eye of the beholder', as Roth (2001) put it. If, as Auld and Medd assert, any plant may be a weed, it cannot be by reason of some feature or characteristic of the plant that it is a weed. That definition means that it is always a contingent matter as to whether any particular plant is a weed. Thus Campbell (1923) wrote, '…a plant is a weed – not according to specific qualities – nor by a definite concept in the mind of man, but by human caprice'. This extreme position is not supported by linguistic use. There are usually grounds for describing a plant as a weed, and examples of capricious attribution are hard to find.

Alfred Crosby (2000) asserted that weed is not a scientific word, and does not refer to plants of any specific species or genus or any category recognised by scientific taxonomy. This, however, may mean no more than that in formulating the scientific categories the features or qualities which make a plant a weed were not taken into account. The question whether such characteristics are able to be discovered is not to be deflected by a definition.

Professor William Stearn suggested that the appropriate sphere of science for considering weeds was psychology rather than botany:

> 'Taken as a whole, weeds are not so much a botanical as a human psychological category within the plant kingdom, for a weed is simply a plant which in a particular place at a particular time arouses human dislike and attempts are made at its eradication or control, usually because it competes with more desirable plants, or sometimes because it serves as a host to their pests and diseases or is unpalatable or dangerous to domestic beasts' (Stearn, 1956).

Despite this suggestion, scientists such as horticulturists, ecologists, botanists, and others persist in the attempt. *The New Royal Horticultural Society Dictionary of Gardening* entry begins with the customary definition, but seeks to take the analysis further:

> 'A weed is any plant growing where it is not wanted – the wrong plant in the wrong place at the wrong time. The distinction between weeds and more desirable plants is a subjective one: one gardener's deliberately grown plant may be a weed to another, and generally desirable plants like Himalayan primroses can under certain circumstances become weeds needing to be eradicated. All kinds of plants can occur as weeds including algae, ferns and horsetails, but the majority are flowering plants, both woody and herbaceous. Weeds are opportunists, taking full advantage of gaps in plant cover, often showing exceptional plasticity which allows them to thrive under a wide range of environmental conditions' (Huxley 1999).

The last sentence of this quotation illustrates the muddled thinking which so often accompanies discourse about weeds. It contains a slide from the notion that any plant may be a weed depending on human wants to a proposition, perhaps with a paradigm weed in mind, about weedy behaviour quite independent of human wants and thus inconsistent with that notion.

A paradox

This paradox of weeds discourse was recognised long ago. The agronomist Professor Jack Harlan and J. de Wet of the Oklahoma State University pointed out forty years ago that it was characteristic of 'the professional weed men' that despite adopting the open ended 'unwanted' definition; they demonstrated a belief that there is a body of plants which are weeds. They 'give long lists of "weeds" as though weeds were species' and speak of 'weediness' when they do not mean 'unwantedness' (Harlan and de Wet 1965). Despite this paper, which has been widely cited, this pattern of behaviour has continued.

An Australian example is provided by Charles Lamp and Frank Collet's *A Field Guide to Weeds in Australia* (Lamp and Collet 1984). The work begins with an interesting discussion of 'What is a weed?' which adopts as the best working definition, 'a plant growing in the wrong place'. Their discussion considers the usual point about some plants being welcome additions to the flora to some, and weeds to others. But they proceed to give very useful illustrated descriptions of 283 weeds, the unwantedness of which is taken for granted.

The true position appears to be that books about weeds and weed science are directed not to all or any plants but rather to specific plants which are recognised as or accepted to be weeds. While adopting the generally accepted definition, the literature is usually prescriptive about what plants are weeds and about the need to prevent their spread. Lists of the world's worst weeds (Holm *et al.* 1977) do not appear to be compiled on the basis of mere preference or caprice. They rest on an assumption that there will be objective agreement as to which plants are weeds. It follows that objective, scientific defining characteristics by which plants are included as weeds should be able to be identified. Perhaps we need to look beyond the standard definitions to see what writers have in mind when they talk about weeds.

Noxious weeds

Declared noxious weeds have always been a special case, standing outside the standard definitions. Weed status is determined by statute. Legislation in Victoria proscribed designated plants, first as 'thistles' (*Thistle Prevention Act* 1856 and successive *Thistle Acts*) and from 1922 as 'noxious weeds' (*Vermin and Noxious Weeds Act* 1922). The statutory regime under which plants were declared 'noxious' has now been replaced by the *Catchment and Land Protection Act* 1994 under which plants may be declared 'State prohibited weeds, regionally prohibited weeds, regionally controlled weeds or restricted weeds'. The logical status of declared weeds remains the same, in that weed status is still determined by the declaration; other definitions have been superseded by stipulation, even though the concept of weed has been used in that stipulation.

Environmental weeds

In the 1970s some weeds began to be recognised as environmental weeds. The earliest publication referring to environmental weeds was by R.L. Amor and P.L. Stephens from the Keith Turnbull Research Institute, Frankston in 1975. Their reference was taken up by W. Holzner from the Institute of Botany, University fur Bodenkultur, Vienna, Austria in *Biology and Ecology of Weeds*, where a definition was given; 'Environmental weeds are introduced, aggressive species that colonise natural vegetation and suppress the native species to a certain extent' (Holzner 1982). This definition provides criteria which are not about human wants or desires, but about what the plants do.

That some plants were behaving in this way was recognised long before the expression 'environmental weed' was adopted, even as early as the 1850s, for example see John Robertson's 1853 writing about 'silk-grass' (*Vulpia myuros*) in Sayers (1983). South African bone-seed, (*Chrysanthemoides monilifera*), the plant which Amor and Stevens called an environmental weed, provides an interesting 20th century example. The harm which boneseed was causing to native plant communities in the You Yangs was documented by Jack Wheeler in the *Victorian Naturalist* in 1964 (Wheeler 1964). Soon afterwards boneseed was proclaimed a noxious weed in Victoria (*Victoria Gazette* February 21, 1969).

Concern about environmental weeds increased as the environment movement gathered strength in the 1960s and 1970s. Increasing concern found expression in the 1976 publication by the Australian Institute of Agricultural Science, *The threat of weeds to bushland. A Victorian study* (Anon 1976), which Richard Groves saw as the beginning of 'the recent attention to environmental weeds' (Groves 1991). The 1976 study, which did not use the term, is about what would today commonly be called 'environmental weeds', and is important as a demonstration of growing concern about the problem. It identified three weeds which posed a serious threat to bushland in Victoria: boneseed (*Chrysanthemoides monilifera*), blackberry (*Rubus fruticosus*) and horehound (*Marrubium vulgare*); and included Appendix 1 'Important Weeds of Public Land in Victoria' containing those plants and a further 21. It is worth noting that many of these plants had been declared noxious weeds in Victoria for many years. Blackberry was declared for the whole of Victoria in 1908, and horehound in 1932. Both had earlier been proclaimed for particular shires. Of the 24 weeds listed as 'Important Weeds of Public Land in Victoria', nineteen were declared noxious weeds, most of very long standing. What was new in this pamphlet is the consideration of well-known weeds, not as weeds of agriculture or horticulture, but of bushland and reserves. The weeds which threaten native plant communities have often been well known agrestal or ruderal weeds.

Following a national conference in 1984, *Bitou bush and boneseed* (Love and Dyson 1985), there was a series of workshops in Victoria on environmental weeds between 1988 and 1991. Don Saunders (1991) from the Department of Conservation and Environment, in his invited editorial to a special number of *Plant Protection Quarterly* on environmental weeds, said of the 1988 workshop, *Weeds on Public Land – an action plan for today* (Richardson 1988).

> 'Although some people had been concerned about environmental weeds before then, that symposium was responsible for bringing more widespread attention to the problem of environmental weeds in Victoria' (Saunders (1991).

The Minister for Conservation, Forests and Lands, Joan Kirner took part in the symposium; as did Dick de Fegely MLC on behalf of the Liberal Party. Both expressed concern at the spread of weeds and supported their eradication and control (Richardson 1988).

By 1991 there was widespread acceptance by environmentalists of the need for action to deal with environmental weeds. That year also saw the publication of Kowari 2 *Plant Invasions: the Incidence of Environmental Weeds in Australia* (Humphries *et al.* 1991) and G.W. Carr's contribution to *Flora of Melbourne*, 'Environmental weed invasions and their conservation implications' (Carr 1991).

Publications such as Kate Blood's *Environmental weeds: a field guide for SE Australia*, demonstrate increasing concern that effective action be taken regarding environmental weeds. Indeed, the whole movement formalised in the CRC for Australian Weeds Management could be seen as a demonstration of that concern. It should be noted, however, that the lists of plants said to be environmental weeds are now becoming very large. Many plants which have not previously been regarded as weeds, but as popular garden plants are being included in such lists (see for example Carr *et al.* 1992 and Randall 2001). Further, the lists are not confined to naturalised exotic plants. By 'exotic' I mean 'introduced' or 'alien': see Michael (2001) and Ewart and Tovey (1909). Native plants 'outside their natural range' are now being classified as weeds, e.g. *Pittosporum undulatum*, for example see Dwyer (2004). There are contentious issues to resolve as to which plants should be regarded as environmental weeds, but this paper cannot be extended to consider them.

Use of the expression 'environmental weed' is largely confined to Australia (Randall 1996). But there is concern world wide about plant invasions of indigenous plant communities, as demonstrated by the vast literature on the topic, including *Invasive Plant Species of the World* (Weber 2003). It may be that invasiveness is a key defining characteristic of weed species. It is, of course, well recognised that many invasive species are not invasive everywhere, and that factors such as climate, disturbance and competition from native species may be significant in a plant becoming invasive.

Conclusion

As has been demonstrated by examples from the weeds literature, weeds have been defined so often as a plant growing out of place or where it is not wanted (or desired) that this can be called the standard definition. The standard definition of weed, however does not accord with agreement in practice about which plants should be included in lists of weeds. The definition does not sit well with the designation of invasive alien plants as weeds, or lists of environmental weeds. In addition, gardeners may not only choose to grow environmental weeds in their gardens, but may also deny weed status on the ground that their desire to grow the plants takes them outside the standard definition (see Blood and Slattery 1996). They may argue that it cannot be said of plants which they choose to grow that they are growing where they are not wanted. It is suggested that efforts to gain community support for the control of invasive plant species should recognise that the standard definition may itself be part of the problem. If it was ever the case that weediness is in the eye of the beholder, environmentalists may wish to argue that there are grounds for saying that it is no longer appropriate to talk about weeds in this way. The standard definition may thus require revision.

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Invasive garden plant display at the Melbourne International Flower and Garden Show 2005

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Cooperative Research Centre for Australian Weed Management

Summary In April 2005, the Victorian Government staged an exhibit at the Melbourne International Flower and Garden Show (MIFGS). The exhibit was about invasive garden plants and safer alternatives. The exhibit was a joint effort by the Victorian Department of Primary Industries (DPI) and Department of Sustainability and Environment (DSE). This was achieved with the support and involvement of the Royal Botanic Gardens Melbourne (RBG), the Nursery and Garden Industry Victoria (NGIV), the Cooperative Research Centre for Australian Weed Management (Weeds CRC) and the Weed Society of Victoria (WSV).

The exhibit was presented in the form of the 'Future Choice Garden Centre', a garden centre raising awareness about invasive garden plants and suggesting safer alternatives for the home gardener.

The Victorian Government, through DPI and DSE, were involved in the Melbourne International Flower and Garden Show to:

- Generate awareness about the invasive potential of garden escapees;
- Build partnerships;
- Host a quality display; and
- Ensure that State Prohibited Weeds were not exhibited or sold at the event.

The event was seen as a success for the following reasons:

- The display received high praise on its quality and value from attendees at the show;
- The display was developed as a result of collaboration between government and industry, and a community group;
- The 'Future Choice Garden Centre' display won a 'Highly Commended' award in the show's outdoor exhibition category; and
- The DPI compliance team detected only two floral displays exhibiting horsetail stems (*Equisetum* species). No live State Prohibited Weed plants were found. This illustrates compliance by exhibitors and the effectiveness of good extension and communication prior to the event.

Keywords Invasive garden plants, weeds, flower show display.

Introduction

A display incorporating weeds or invasive plants at a garden show is not a new idea. In the United Kingdom at the Chelsea Flower Show, displays incorporating this concept have been staged in the past (for further information refer to: www.rbgkew.org.uk/education/chelsea or www.rhs.org.uk/chelsea/).

Invasive plants have been featured in displays at large garden shows and expos in Australia, including Sydney, Canberra and Perth. The display by DPI and DSE was the first time that an exhibitor at MIFGS has used invasive garden plants as the theme.

MIFGS had its tenth annual exhibition in 2005. This show is regarded as the largest and most successful horticultural event in the Southern Hemisphere, rated among the top five flower and garden shows in the world. For more information refer to www.melbflowershow.com.au/. The event has the support and participation of key industry bodies. This includes NGIV, Flowers Victoria (Flowers Vic), the Landscape Industries Association of Victoria (LIAV), and Australian Institute of Landscape Architects (AILA), plus active participation from leading horticultural colleges and universities throughout Victoria and Australia.

A total of 350 companies and organisations exhibit at the show including landscape designers, floral designers, flower growers, nurseries and allied gardening retailers.

The objectives of the invasive garden plant display at MIFGS were:

- To create a display to increase public, media, and garden and landscape industry awareness about invasive garden plant issues.
- To create a successful partnership between a range of stakeholders. This partnership between the industry, government and the gardener is powerful, as it includes all parties involved, including growers, retailers, open space managers, researchers, regulators, gardeners and conservationists.
- To use the concept of a garden centre entitled 'Future Choice Garden Centre' as the focus of the display. To present selected weed species as nursery stock on benches alongside safer less-invasive alternatives. This provides a readily accessible range of alternative selections, promoting the garden centre in providing non-weedy selections.
- To ensure that State Prohibited Weeds were not displayed by performing good extension and communication prior to the event.

Discussion

The exhibit

The 'Future Choice Garden Centre' exhibit at MIFGS put weeds into a new perspective. MIFGS took place from 6 to 10 April 2005 in the Royal Exhibition Building and surrounding Carlton Gardens on the edge of the central business district of Melbourne, Victoria.

The 'Future Choice Garden Centre' exhibit was in the form of a nursery and garden centre, with the theme 'Your Garden, Our Future', and exhibited a range of invasive garden plants alongside less-invasive, safer alternatives.

Invasive garden plants in pots were exhibited on nursery-style benches. Underneath the benches were pots containing safer alternatives to the invasive garden plants. The safer alternatives were then used to create different themed effects in nearby garden beds. These garden beds were visually attractive and provided five different garden styles for different gardening conditions i.e. shade, aquatic, coastal, etc. The safer alternatives selected were also plants requiring less watering.

DPI, DSE, RBG and the NGIV brought the display to fruition with support from the Weeds CRC and the WSV. A display of this nature, combining government, nursery industry and community group involvement, is an historic achievement, and was rewarded with a 'Highly Commended Award' from a panel of independent judges.

A major contribution by the RBG was the top quality site design by Andrew Laidlaw, the resident landscape architect.

The primary objective of the display was to increase garden and landscape industry, horticultural media and general public awareness of pest plant issues related to ornamental horticulture. Many current and potential pest plant species are sold in nurseries and informal markets or distributed through garden clubs, botanical societies and landscape designers. The focus of the display was the range of invasive garden plants in Australia that were originally garden plants or are still grown in gardens. It is vital that the understanding and cooperation of home gardeners are gained if we are to succeed in preventing the further spread of these plants and the introduction of new ones.

Informing gardeners and the industry is a key component of the Victorian Government's Victorian Pest Management – A Framework for Action.

Organising the exhibit

Once agreement had been reached to stage an exhibit at MIFGS, a Project Manager needed to be appointed. DPI employed Rob Pelletier, trading as R.J. Pelletier Pty Ltd. , a highly experienced Project Manager for the exercise, through a competitive tender process, to assist the DPI Team Leader, Daniel Joubert.

Negotiation and liaison with the funders, partners, sponsors and the event organisers, International Management Group of America Pty Ltd. (IMG) as well as DPI/DSE/RBG staff was an integral and ongoing process.

IMG provided an exhibitor manual covering general information and guidelines to exhibiting at MIFGS. It also contained all terms and conditions, judging criteria, event set-up and pull-down time frames and exhibitor application forms. To be able to exhibit, an application had to be submitted and for 'Landscape Gardens', a design plan and written brief had to be provided.

The Project Manager was responsible for obtaining sponsorship and in-kind contributions from a range of organisations. Several independent businesses supported the exhibit by supplying plants and materials, including Repeat Products (decking, signs and seats), Gardman Garden Products (fence screen panels) and Fud Products (mulch and compost). Plants for display purposes were loaned by Dan's Plants, Lotus Water Gardens, Royal Botanic Gardens (Melbourne and Cranbourne), Smith and Gordon Nursery and the Victorian Indigenous Nurseries Co-operative. DPI and a few NGIV members supplied most of the weedy plant species.

The Project Manager was able to secure a high profile site at no cost. The display occupied a site which was classified under the 'Landscape Gardens' category and was required to contain significant, high quality garden design features. The garden centre theme was an ideal context to exhibit invasive garden plants alongside less-invasive, safer alternatives. This enforces the role of the garden centre in providing non-weedy selections. This display method allowed the use of good interpretative material in the form of point-of-sale posters, signs and plant labels. A large amount of information could be passively supplied in this way, compared to a pure landscaped garden display setting where signage and labels would detract from the presentation. The point-of-sale posters used some humour and made a point about invasiveness of garden plants in general. Refer to www.mediaspread.com for a range of photographs by Rob Pelletier and additional information about the display.

A central garden centre building, in the form of a counter and a basic roof covering, provided a suitable setting to display brochures as well as a space for staff to interact with visitors. This setting was used to reinforce the role of the garden centre as a place to obtain good advice on plant selection, weed identification and weed management. Compared to a landscaped garden display, where most of the area is out of bounds, the garden centre layout, with two access points, enabled large numbers of visitors to occupy and efficiently move through the site.

DPI and RBG staff were trained prior to the event in site construction, visitor relations and general event logistics. A range of information was collated for the training including exhibitor requirements, possible frequently asked questions (FAOs) and copies of important weed documents and site maps. To create the perception of a 'real' garden centre, all staff involved in the display were issued with uniforms displaying the 'Future Choice Garden Centre' logo. This logo was incorporated in all other display material in the exhibit.

The involvement of the RBG highlighted the potential to show leadership and influence visitors from organisations involved in public open space management, such as local government.

Publications

Show-specific publications and general weed publications were produced by DPI/DSE. This included a brochure entitled 'Future Choice Garden Centre' and five postcards illustrating safer alternatives for coastal, shade, grass, succulent and water gardens. Visitors were able to collect postcards corresponding to the five different garden bed designs used in the exhibit. Each postcard had the garden bed design and the names of the safer plants used. The postcards were very popular with the visiting public.

A general publication with the title 'Invasive Garden Plants jump the back fence', was produced in brochure form. The Victorian Tackling Weeds on Private Land (TWoPL) initiative funded these publications. DPI used some images in the postcards with permission from the Port Phillip Catchment Management Authority (CMA). A set of media packs containing a range of weed information was produced. This included publications produced by a range of sources.

Kate Blood was responsible for the risk assessment of all display plants. Plants that were too invasive or were a potential serious threat to Victoria were rejected and not recommended as safer alternative garden plants for the exhibit.

Posters for each of the invasive garden plants were developed with coloured images and information. These were mounted next to each of the weeds to aid identification.

Plant identification labels were produced for all the plants used in the exhibit, both invasive and safer alternatives. The labels were attached to plastic stakes that were inserted in the containers the plants were grown in and displayed common and scientific names. All the weeds were labelled with big red crosses and the safer alternatives were labelled with big green ticks.

Construction

An extensive team of DPI and RBG staff assisted in the set-up, staffing, and dismantling of the MIFGS display. During the set-up phase, skilled labourers were employed to take care of the site construction. DPI facilities at Frankston were used for much of the timberwork storage and processing. A local contractor, Steve Gibson and his team were responsible for this activity. Timber panels, garden bed edges etc were prefabricated and then transported to the Carlton Gardens in a rented truck. Alan Broadbent, a skilled handyman, assisted during the set-up phase on site. The truck was also used for transporting equipment and plants on loan from nurseries. The truck was used to store tools and materials during the set-up phase. During dismantling a second truck was obtained to assist with returning plant material to the sponsoring nurseries.

The rules concerning site preparation and maintenance were strict. Allocated sites had to be returned in good condition after the show and inspections are performed to ensure that this happened. This made construction difficult, as no holes could be dug or vehicles driven or parked on grassed areas. To protect existing vegetation, all works were done on hessian covered with black plastic sheeting.

Set-up and construction took place over a nine-day period. On average, seven staff per day were available during this period. These people were volunteers that were prepared to do just about any task. This included assisting in timber and walkway construction, obtaining plants from nurseries, painting, loading and unloading timber and plants from a truck, spreading mulch or gravel and any other odd jobs.

The days were long and it was hard work. Staff often started early and only finished after dark. The weather was good with no rain. Bad weather was probably one of the biggest risks factors associated with success at the show.

Prior to and during the set-up, several people were involved in a range of tasks that had to be done simultaneously. For instance taking care of publication approval, compiling plant lists, ensuring that the required information was provided to staff, arranging staff accommodation and rosters, and keeping staff updated with the latest information and progress.

Open for business

The Victorian Minister for Agriculture, The Honourable Robert Cameron MLA, opened the exhibit on the first morning of the show. Other speakers included Richard Barley, Divisional Director of the RBG and David Mathews, President of the NGIV. Ron Harris, Executive Director, Catchment and Agriculture Services, Department of Primary Industries, was the master of ceremonies at the official opening ceremony.

The show was open for a five-day period. Because of the long opening hours, each day was divided in approximately four-hour shifts to ensure staff were refreshed. A range of people was involved in staffing the display for several days in succession and this can be a tiring exercise. To be able to respond to questions from the public a range of reference literature was made available on site. These items were secured in a lockable container or removed from site when staff were not there. A visitors logbook was kept at the display where visitors could record their thoughts and comments.

The dismantling of the display took place over a period of three days and the site was handed back to the organisers in good condition.

RBG staff assisted visitors with plant selection advice and many home garden weed control enquiries. A major contribution by the RBG was the top quality site design by Andrew Laidlaw, the resident landscape architect. This was supported by the good plant knowledge represented in the RBG.

DPI staff were able to assist visitors with questions about weeds, invasive garden plants and environmental issues.

Compliance activities

DPI enforces the noxious weed provisions of the *Catchment and Land Protection Act 1994* and is also responsible for identifying and acting on new and emerging weeds. The MIFGS exhibit was an effective way for DPI to display and transfer this information to visitors. After obtaining agreement with the NGIV, information about declared State Prohibited Weeds was distributed to all exhibitors through IMG. This included a list of taxa and legal obligations concerning these noxious weeds. To ensure that compliance was discreet and did not impact on show activities, this activity took place before the show opened. During the compliance investigation, involving the inspection of all the show sites for declared State Prohibited Weeds, a good result was obtained with no live weeds encountered.

Members of the public visiting the exhibit reported occurrences of a number of noxious weeds which DPI staff were able to record and follow-up on after the show.

Cost

It is difficult to do an accurate costing because a large number of activities were performed as an in-kind contribution. In many cases volunteers contributed additional time (private and official). It is estimated that the cost involved in hosting the display would be at least one hundred thousand dollars with an additional fifty thousand dollars being contributed by sponsors in the form, for example, of plants on loan.

Visitors

A total of approximately 120 000 people visited MIFGS, an estimated one third being international tourists and one third from other Australian States. Feedback about the DPI exhibit from members of the public was overwhelmingly positive. The weed display in the midst of the nursery industry's premier showcase was a strong and positive way to convey messages, not only to the home gardener, but also to the industry and professional open space managers. From the DSE/DPI perspective the opportunity to engage with large numbers of gardeners was invaluable: the event enabled us to present weed awareness messages in positive ways, to receptive audiences. The comment, 'This exhibit is the best in the show, because it makes you think' (or words to that effect) was regularly heard.

At the peak visitor times during the show, an estimated 2000 visitors per hour passed through the 'Future Choice Garden Centre' exhibit.

The quotation that states 'Success doesn't happen by chance, it is the outcome of good planning, team work, commitment and a lot of hard work' is true in this case.

Acknowledgements

The huge commitment and passion of the DPI and RBG staff to make the display a success is acknowledged. The following DPI staff were involved in training, set-up, compliance, display, dismantling or other activities: Adam Kay, Anthony Wilson, Byron Crowe, Claire Norris, Drew Gracie, Donna Smithyman, Ian Faithful, Jaye Caldwell, John Weiss, Kristy Roche, Kate Blood, Les Bould, Linda Iaconis, Mark Watt, Marg McKenzie, Megan McCarthy, Michael Hansford, Natasha Baldyga, Penny Gillespie, Ryan Cooke, Sarah Holland Clift, Sarah Keel, Shane Bettess, Pamm Brittain, Tim Bloomfield and Trevor Hunt. I would like to thank Tony Lovick, Neil Smith and Rob McNally for their constructive contribution.

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The contribution of our partners and sponsors made the display a reality. The contribution of Michael Gainger and Robert Chin from the NGIV is appreciated. Involvement by the Weed Society of Victoria and Peter Martin from the Weeds CRC is acknowledged.

I would especially like to thank a colleague, Kate Blood, and the Project Manager, Rob Pelletier, for their enthusiasm and valued contribution to the event.

Nursery people aren't all environmental pests

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Introduction

Villainous vendors or careful conservationists?

The truth is probably somewhere in the middle.

For a long time the nursery industry has been an easy target for those in the burgeoning weed movement who are critical of us – but is this fair and justified? It may have been in the past but is it now?

The history of weeds in Australia is varied and yes we have contributed – but we are actually working very hard to stop the impact of weeds on our natural and built environments.

Where do weeds come from – a bit of history?

The nursery industry is often blamed for being the source of weed problems. We have been in the past but not through all of history as the following examples show.

a) Blackberry – one of our biggest weeds. Initially spread by Baron Von Mueller as a food source for drovers.
b) Prickly pears – brought to Australia by Captain Arthur Phillip on the 1st fleet to start a cochineal industry to dye the uniforms for the colonies' soldiers.
c) Chilean needle grass – introduced to Australia from South America (circa 1934) as a contaminant of sheep wool or fodder.
d) Bitou bush was planted along the NSW coast by the NSW Soil Conservation Service to reduce dune erosion and assist in post mining rehabilitation.
e) Garden introductions – of course, but not always.

For the first 100 years of Australia's history we did not really have a nursery industry. Plants were imported by early settlers and governments. Governments and other advisory people have been telling us to plant weeds for ages.

What is a weed now wasn't always!

History is littered with well intentioned people and organisations wreaking havoc on the environment. We have not always known, or even cared about the environment. It is only relatively recently that the general public has started taking an interest in weeds.

There are many examples of plants that were brought into Australia for use as crop plants, fodder, grains etc. that are now considered weeds. Many of these were imported and recommended by government departments. Is canola the next big weed? Would we have a soft timber industry without those *Pinus radiata* that have been known to jump the fence! What about olives?

Why pick on the nursery industry?

Why do the media pick on us?

As with all things we need to take our share of responsibility for the problems that we have caused. As an industry through we seem to be getting targeted. People like WWF, The Weekly Times, Weeds CRC and many others are unfairly targeting us. The headline grabbers often exaggerate or under-estimate the truth. Headline grabbers spread hysteria and are not useful (Figure 1).

Where do the numbers come from?

Let's put this into perspective – and be realistic. As explained above – the truth is often the first casualty in these emotionally sensitive environmental areas. Exaggeration is rampant. Here are some examples.

Press Release AUSTRALIA'S LANDSCAPE 'UNDER SIEGE' (5 January 2005)

> '…Few people seem to realise that the rate of landscape loss to introduced plants is accelerating,' warns Dr Rachel McFadyen, Chief Executive Officer of the Co-operative Research Centre for Australian Weed Management.
>
> 'Already more than 27 million hectares have been swamped by over 2500 foreign invasive plants, and new threats are emerging constantly as plant imports continue to rise.
>
> 'Besides the damage to native landscapes, weeds inflict a $4–5 billion loss on the economy, mainly through agriculture, and a growing toll of ill-health among people who suffer allergies, lung problems or poisoning,' she says.
>
> 'One way to look at this is that it takes almost the entire earnings of the gold industry just to pay for the harm done to our economy by weeds. And that takes no account of the harm done to the environment.'

Comment: this is very emotional language. Where does the estimate of $4–5 billion come from? 27 million hectares is a good number but what is its origin? Probably 90% of all plants sold in Australia are foreign plants.

Press Release: A KNOTTY PROBLEM FROM THE GARDEN (27 April 2005)

> '…Since blackberries now occupy an estimated 8 million hectares of southern Australia – arguably the nation's

Figure 1. Here are some examples from the Victorian Weekly Times Newspaper

largest plant threat – the concern over knotweed isn't exaggerated', says John Weiss. 'The plant has the potential to colonise the wetter areas of the southern third of the continent…'

Comment: to do this we would need to displace the other 100 or so weeds that take over the environment, pull down our cities and towns, pull up our roads and fill in our lakes and rivers.)

Let's try and use less rhetoric and work positively together. The nursery industry is a $6 billion industry employing about 30 000 people. Being negative towards us affects us. Why aren't you picking on the olive industry, pine plantation industry or even Agriculture because this is where the majority of real environmental weeds are coming from?

What is the Nursery Industry doing?

In Victoria the Nursery industry, in other states and nationally are working towards removing pest plants and Greening Australia. We all need to work together to solve this problem. We are doing our bit. Here are some examples.

Future choice garden centre at Melbourne International Flower and Garden Show

- Showcase at MIFGS
- Assisted with lists, concept, supply of plants
- Difficult to find 'weedy' plants
- Good relationship builder
- 120 000 spectators
- Offered alternatives

List of 50+ weeds – voluntary removal

- Developed list in partnership with Government
- Agreed to list of plants for voluntary removal
- Distributed information/list to industry
- First of many to come
- No problems with implementing

(for a list of voluntary banned pest plants see Appendix I)

Spreading the word

- Several articles in our GroundSwell Magazine
- Distribute list of declared weeds through magazine
- Talk about weeds to various industry bodies
- Nursery Papers on weeds and garden escapes
- Best Management Practice manual – weeds section
- Five minute environment checklist
- Regular weed column in Australian Horticulture? (Figure 2)

Sustainable Gardening Australia (SGA)

- SGA is a not for profit association totally committed to achieving real, continually improving and easily understood environmental solutions for gardeners
- Support of industry body
- Our biggest and best members are involved
- Weeds are a component of SGA Accreditation
- Nearly 30 and growing
- http://www.sgaonline.org.au
- Working on projects together

Other things we are doing/planning

- Assisting DPI and DSE with various weed initiatives (time consuming)
- 'Grow me Instead' brochure
- Future regular publication – Australian Horticulture
- On-going communication
- Part of the NGIA, national approach – driving this

In South Australia:

- Andreas Glanznig WWF – Speaks at State Conference
- 'Grow Me Instead' brochure in conjunction with Weeds CRC
- On-going involvement with government and other relevant stakeholders

National – NGIA

- On-going dialogue with relevant stakeholders e.g. CRC, Federal government departments etc.
- National Weeds Advisory Group – member
- National Invasive Species Framework – member
- Invited WWF to National Board meeting
- Work nationally through state NGIs and IDOs
- Nursery Industry EMS nearing completion
- Nursery Papers and other publications

Which list?

The biggest problem that we, as an industry face is knowing which plants are weeds and which list should we refer to. Is it realistic to expect every member to stop selling and growing every plant on every list when nobody can agree on which plants should be on a list. This is very difficult. So which list should we use?

- B.A. / WWF List – is this a good list?
- AQIS List
- State Govt – Declared noxious list
- WoNS (not all have legal standing)
- WoNS 2
- Local Government lists
- Local Landcare and Green groups lists
- Garden thugs/escapees lists
- Nursery Industry lists

Confusion reigns supreme! No wonder our members struggle. Maybe their needs to be only one list? Who will decide which is the right list though?

Back to basics – what is a weed?

Who defines a weed? The perception is that the 'weed industry' bureaucracy is growing almost as big as the problem itself. One of the key jobs of the regulators must be to help out in this area – not make it worse.

- Some plants known as weeds are only plants that people can grow e.g. north of divide
- Must have a basis in scientific fact
- Can not rush listings
- Just because it is a weed in one area of one part of the world does not mean it will be a weed here in Oz
- Sterile hybrids
- Not just because they are popular
- How do we as an industry know if it is a weed if the Government lets it in?
- Whose responsibility is it to define a weed? e.g. *Agapanthus* example

The Future – working smarter and harder

There must be a better way. We need to work better and smarter. Working together and educating must be better than slander, exaggeration and taking shots at each other. So how can we go forward? Here are some thoughts:

- Better communication – across all stakeholders

Figure 2. Nursery industry publications

- Working closer together – workshop example
- Which plants are weeds? – Sterile cultivars – proper scientific basis
- Which list do we use? Lets simplify this
- Don't play the blame game!
- Talk to me – or my counterparts in your states
- Considered education program

References and acknowledgements

The following resources were used in the preparation of this presentation:

- Weeds Australia website: http://www.weeds.org.au
- Weeds CRC – various publications, press releases and website: http://www.weeds.crc.org.au
- Enviroweeds
- Weekly Times – Various clippings and letters

Thank you to WSV for invitation to attend and speak, to the various nurseries that have contributed to this presentation and other stakeholders that I work with in this area that assisted us.

Appendix I. List of 50 plants voluntarily removed from sale

Botanical name	Common name
Acacia nilotica (L.) Willd. ex Delile*	Prickly acacia
Ambrosia L. spp.	All ragweeds
Annona glabra L.*	Pond apple
Anredera cordifolia (Ten.) Steenis	Madeira vine
Asparagus asparagoides (L.) Druce*	Bridal creeper
Bassia scoparia , *B. sieversiana* , *Kochia alata*, *K. scoparia* var. *culta, K. scoparia* var. *pubsecens* , *K. scoparia* var. *subvillosa* Moq., *K. scoparia* var. *trichophila* (Stapf), *K. sieversiana*, *K. trichophila* Stapf.	Kochia
Cabomba Aubl. spp. (all)*	Cabomba
Calystegia silvatica (Kit.) Griseb.	Greater bindweed
Carthamus glaucus M.Bieb.	Glaucus start thistle
Cenchrus incertus M.A.Curtis	Spiny bluegrass
Centaurea maculosa Lam.	Spotted knapweed
Chromolaena odorata (L.) R.M.King & H.Robinson	Siam weed
Cryptostegia grandiflora Roxb. ex R.Br.*	Rubber vine
Disa bracteata Sw.	African weed-orchid
Gymnocoronis spilanthoides DC.	Senegal tea
Hedera helix L.	English ivy
Hymenache amplexicaulis (Rudge) Nees*	Hymenache
Hypericum calycinum L. Grow under permit	Large flowered St John's wort
Hypericum canariense L.	Canary Island St John's wort
Hypericum humifusum L. Grow under permit	Trailing St John's wort
Lantana camara L.*	Lantana
Miconia Ruiz & Pav. spp.*	Miconia
Mimosa pigra L.*	Giant sensitive plant
Nassella (Trin.) Desv. spp.*	Needlegrass
Onopordum L. spp.	Onopordum thistles
Onopordum tauricum Willd.	Taurian thistle
Opuntia aurantiaca Lindl.	Tiger pear
Parkinsonia aculeata L.*	Parkinsonia
Rubus alceifolius Poir.	Giant bramble
Rubus argutus Link	Florida blackberry
Rubus rugosus J.E. Smith	Keriberry
Sagittaria graminea Michaux	Sagittaria
Sagittaria montevidensis Cham. & Schltdl.	Arrowhead
Sagittaria platyphylla (Engelm.) J.G.Sm.	Delta arrowhead
Sagittaria pygmaea Miq.	Dwarf arrowhead
Salix aegyptiaca L.*	Asian sallow
Salix alba L.*	White willow
Salix cinerea L.*	Common sallow
Salix exigua Nutt.*	Sandbar willow
Salix fragilis L.*	Crack willow
Salix glaucophylloides Fernald*	Dune willow
Salix humboltiana Willd.*	Pencil willow
Salix L. spp. (all except *S. babylonica* L., *S. calodendron* [= *S.* × *calodendron* Wimm. = *S. caprea* L. × *S. purpurea* L. × *S. viminalis* L.], *S.* × *reichardtii* A.Kern [= *S. caprea* L. × *S. cinerea* L.], *S. alba* var *caerulea*)*	Willow, sallow, osier
Salix matsudana Koidz.*	Tortured willow

Sustainable garden centre project

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The aim of the Sustainable Garden Centre environmental accreditation project is to provide retail garden businesses and home gardeners with a pathway to sustainability

Project development and structure

Sustainable Gardening Australia (SGA) worked with the University of Melbourne (Burnley Horticultural College), local government and retail nurseries across Melbourne for 18 months to develop and trial an environmental accreditation for retail garden centres that was industry relevant and customer focused. From the onset SGA recognised the important role local government played, the importance of aligning with council initiatives and the valuable role SGA could play in building communication pathways between retail nurseries and local government.

The working group identified six key areas of sustainability relevant to the gardening:

- Pesticides and herbicides
- Composting and organic waste recycling
- Water conservation
- Environmental weeds
- Indigenous plants
- Sustainable purchasing

SGA Sustainable Garden Centres have to demonstrate ongoing commitment to all the key areas of the project and to undergo an annual audit. To be an accredited member of SGA, garden centres have to:

- Develop policies and practices that meet the internal best practice guidelines of the project;
- Undergo staff training to ensure staff are giving reliable advice to home gardeners and;
- Pro-actively promote, educate and influence home gardeners to garden in a more sustainable manner by displaying the SGA ratings systems and education material.

Internal operations

To obtain accreditation garden centres are required to address numerous environmental issues relating to chemical and water use, waste and energy reduction and promotion of indigenous plants and renewable products. Specifically with regard to weeds nurseries must:

- Develop an Environmental Weed Policy and a Purchasing Policy
- Ensure no noxious weeds or DPI banned plants are sold
- Liaise with SGA and council to remove from sale the worst garden escapees of the local area
- Publicly display this list and include in staff manual and plant buyers guide
- Tag with an SGA Weed Warning label any other plants council may be concerned about
- Remove any weeds from the nursery display gardens e.g. car park
- Patrol the nursery boundary monthly for escapees

Sustainable Garden Centres are audited annually to encourage businesses to incrementally and continually improve their environmental performance.

Staff training

To achieve accreditation garden centre staff undertake a training course in sustainable gardening to ensure they are aware of the environmental issues and provide appropriate advice to customers. This training incorporates the free TAFE accredited Our Water Our Future Green Gardeners course developed and delivered by SGA with funding from Our Water Our Future, Melbourne Water and the Catchment Management Authorities. Within this training program there is a focus on the impact of weeds on the natural environment, the responsibility of the horticultural and gardening industries, identification of local environmental weeds and alternative plant species to recommend to customers.

Customer education material

The SGA working group has developed and trialled a number of customer education tools including posters displayed at the point of sale when the gardener is making a purchasing decision. SGA encourages the gardener to think about the issues and make a decision that will have a positive environmental impact beyond their backyard. Sustainable Garden Centres also distribute council publications on weeds and indigenous plants.

SGA has detailed information sheets on their website that customers are referred to as well a monthly magazine that focuses on a weed and alternative species each month. Twenty six mainstream garden centres are currently committed to the project.

Olives – new industry or environmental threat

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Summary The olive tree is known worldwide for its symbolism, aesthetics and gastronomic value. Unfortunately the olive have also naturalised and invaded native vegetation in many areas, reducing biodiversity.

The olive industry in Australia is rapidly developing with many groves being established in new areas. The increased number and distribution of olive groves threatens native vegetation. South Australia and Tasmania have addressed this issue by developing management strategies. Despite significant industry development in Victoria, the government and industry has not yet addressed the issue.

This paper considers the influence of the environment and potential management on olive dispersal and growth. This data was incorporated into distribution models which showed Victoria's climate and environment is well suited to olives. Unless properly managed, the current expansion in olives plantings will pose a very high risk to Victoria's remnant bushland.

It is recommended that: 1). The Victorian government and olive industry address the issue of feral olives; 2). A stakeholder group be formed to examine the issue; 3). An education and awareness campaign be implemented; 4). Risk management guidelines be developed for olive groves; 5). Existing and new feral olive trees be controlled; and 6). The potential for preventing new olive groves in high-risk areas using a weed risk assessment be further investigated.

Introduction

The olive tree (*Olea europaea* ssp. *europaea*) is known worldwide for its symbolism, aesthetics, hardiness and the gastronomic value of the olive fruit (drupe). The olive industry is currently undergoing a period of significant expansion in Australia. Large numbers of new olive groves have been established throughout the country, many of them in Victoria. The current industry expansion is in somewhat of a renaissance, as there have been past expansions and contractions in the olive industry, particularly in South Australia.

The early development and contraction of the olive industry resulted in olive seeds dispersing from abandoned groves, causing a major weed problem of feral olives. There is concern that if not properly managed, the current industry expansion with increased numbers and distribution of groves will provide a seed source for new generations of feral olives with a much wider distribution (Bass *et al.* 2004).

In response to this concern South Australia and Tasmania have initiated strategies to manage the risk of olives dispersing off farm. These have included education campaigns, grove registration, research activities, and the development of Weed Risk Assessments for the approval of new olive groves (APCC 1999, Hanson 2002).

Despite significant olive industry development in Victoria, the industry or government has not yet developed any management strategies for the issue of feral olives. The management strategies devised by South Australia and Tasmania could provide a guideline for developing strategies for Victoria. However, differing legislative and natural environments require a strategy specific to Victoria.

Present industry situation

The olive industry in Australia has rapidly developed in the past decade. The new and existing groves range in size from very small to large investment driven corporate groves (Kailis and Sweeney 2002). Most growers entering the industry are small, with farm diversification projects or hobby farms of less than 5000 trees (D'Emden 2001, Davies 2002). While estimations and surveys of olive tree numbers in Australia have ranged between 3.8–9.6 million trees (Table 1), there is a lack of accurate information about the size and distribution of the olive industry in Australia (Davies 2002, King 2004).

Victorian olive industry

There is little information about the current size and distribution of the industry in Victoria. Various estimates of industry size place the Victorian industry between 596 000 (ABS 2001) and 2.6 million (Sweeney 2002), (Table 1). Importantly, the census indicated a large number of recent plantings with 89% of the trees less than six years old (ABS 2001), suggesting many trees were yet to come into full production.

Olives are grown throughout Victoria with the ABS finding the largest concentration of olive trees is in the Swan Hill region (233 529). There are also large numbers of trees in the South Grampians (54 696), Horsham (54 013), Loddon (33 866), and Moira regions (32 252) (Figure 1). Current data sets (Table 1, Figure 1) are likely to underestimate the distribution of olive trees, as there have been significant plantings since the time of the census.

Olive ecological attributes

Rainfall

While it is considered commercial production of olives should receive between 700 to 1100 mm of water annually (Booth and Davies 1996). Feral olives are able to grow, reproduce and invade new areas with much lower annual rainfall, being highly invasive where annual rainfall is 500–800 mm (Cooke 1989, Parsons and Cuthbertson 1992, Muyt 2001) but capable of surviving in regions with less than 400 mm annual rainfall (Crossman *et al.* 2002), but

Table 1. Estimations of tree numbers in Australia

	Tree numbers from 2000/2001 census[A]	Tree numbers based on nursery sales and orders 1990–2002[B]	Approximate olive tree numbers as of 2001[C]	Sales as at June 2002 + orders for 2002–2003[D]
VIC	596 040	1 561 677	2 300 000	2 657 416
NSW	785 965	1 926 117	2 000 000	2 209 050
SA	856 443	1 255 792	1 500 000	1 767 519
WA	843 989	1 602 790	1 300 000	1 418 240
QLD	746 429	1 096 520	1 200 000	1 241 020
TAS	53 864	107 730	170 000	170 799
NT		2 300	5 000	2 300
ACT	1 700		Included in NSW	
Unknown		100 000		100 100
Australia	3 884 432	7 652 926	8 475 000	9 566 344

[A] (ABS 2001); [B] (RIRDC 2002); [C] (Miller 2002 in Kailis and Considine 2002); [D] (Sweeney 2002)

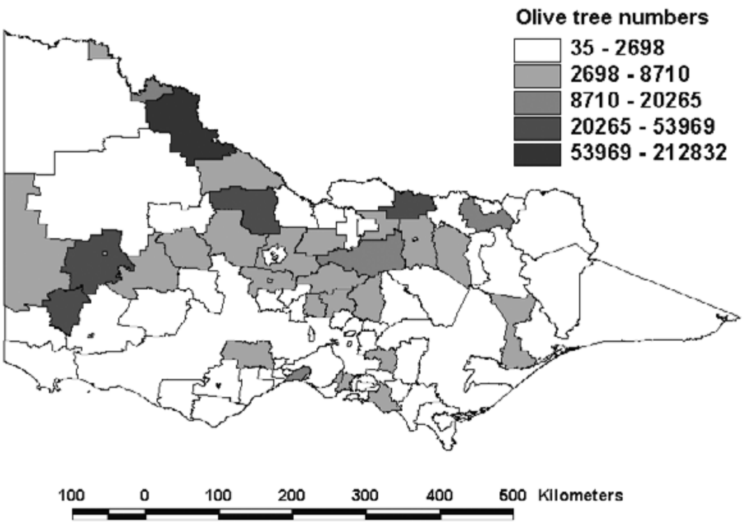

Figure 1. Victorian olive tree numbers by Local Government Area from the 2000/2001 census (ABS 2001)

this may be associated with run-off (Muyt 2001) or abnormally wet seasons (Spennemann and Allen 2000).

Temperature
A vernalisation temperature of approximately 12°C average daily temperature is required for flowering and fruit set to occur (Denney and McEachern 1983). Growth of olives can occur up to 33°C, with mature tree entering dormancy above this (Renowden 1999). Temperatures below zero will damage tree extremities(Renowden 1999) but temperatures need to be below −5°C to kill young seedlings and less than −10°C for large mature trees (Sibbett and Osgood 1994), with a LD_{50} of three-year-old trees ranged between −11.39°C to −18.16°C, depending on the cultivar (Bartolozzi and Fontanazza 1999).

Soil characteristics
Olives are capable of growing on hilly and rocky areas and will generally grow in any soil type, with the exception of pure sands or clays (Burr 1999). The soil pH_{CaCl2} parameters for suitable for olive production range between 5 and 8.5 (Sibbett and Osgood 1994, Burr 1999), though have been observed growing as a weed, in quite acidic soils(<5 pH_{water}) (Hamilton 1999). The olive is a moderately salt tolerate tree (Connell and Catlin 1994), with soil salinity greater than 8.4 dS m^{-1} unsuitable for commercial olive production (Burr 1999).

Olive dispersal

Birds are considered the main dispersal mechanism for feral olives. While the common starling is generally recognised as the main avian vector for olive dispersal numerous bird species have been seen to feed on olives, including emus (Cleland 1952, Black 1965, Forde 1986, Mladovan 1998, Spennemann and Allen 2000). Whether the birds can ingest the olive depends on olive size (Fabbri *et al.* 2004) and the gape size of the bird (Rey *et al.* 1997).

The main non-avian vectors are foxes (Lowe 1982, Paton *et al.* 1988). Unlike most bird predation, foxes are likely to be long distance vectors of olive seeds (Burr 1999), with a potential dispersal range up to 5 km (Spennemann and Allen 1998). Kangaroos have also been reported as feeding on olive fruits (Burr 1999). Other possible dispersal vectors of olives include mice (*Mus musculus*), rats (*Rattus rattus, R. noregicus*), flying foxes (*Pteropus* sp.), sugar squirrels (*Petaurus breviceps*), possums (*Pseudocheirus; Trichosurus*), rabbits (*Oryctolagus cuniculus*), goats (*Capra hircus*), sheep (*Ovis aries*) and wombats (*Wombatus ursinus*) (Spennemann and Allen 1998). Farm animals including pigs, cattle and poultry will eat olive seeds and could contribute to dispersal (Tompson 1888, in Spennemann and Allen 1998).

Management options to reduce dispersal

Vector management
Effective bird management in orchards use many different methods such as visually scaring (scarecrows, reflective mirrors, bird silhouettes or kites),auditory methods (bangers or other explosive devices) can be used to cause fear, disorientation, disrupt communication and to mimic distress calls (Sinclair 1999). Population reduction by shooting birds is generally an inefficient control measure, but can be used successfully to reinforce auditory control methods. Emus can be controlled by frequent harassing (Temby 2003). They can also be excluded by installing a sloping electric fence (APCC 1999, Temby 2003) or an extra high non-electric fence (APCC 1999).

Alternatively, is to utilise birds perching habits to ensure dispersal is close to the orchard. The South Australian APPC (1999) code of practice for olive trees, recommends a 25–50m olive free amelioration zone, for monitoring and fire control and a 50–200m buffer zone within the property boundary. The required width of the buffer zone depends on the number of perching sites (APCC 1999), as the aim of the buffer zone is to encourage feeding birds to perch and drop the seed near the orchard.

As most bird damage is done when alternative food sources are scarce (Feare 1980), providing alternative food sources could reduce bird predation of olives (Feare 1980, Sinclair 1999). This requires knowledge of the nutrition requirements and feeding habits of different age and sex groups (Feare 1980) and the availability of alternative food sources.

The most effective control is physically excluding birds from orchards by the use of netting. The cost of netting means it is generally only appropriate to high value crops with a high level of fruit loss (Sinclair 1999, Bomford and Sinclair 2002). The cost of netting varies between $15 000 to $30 000 per ha (APCC 1999) at least tripling the present, establishment costs (Trapnell and Carmichael 1998, Burgess 1999, Kailis and Considine 2002).

Effective fox management requires a group of landholders conducting a widespread baiting program (APCC 1999).

Harvesting
Greater efficiencies in harvesting reducing the amount of fruit left on the trees or on the ground is required. Hand harvesting is more effect in getting the majority of fruit (up to 95%) compared to mechanical harvesting (65–80%), but can be improved by either using chemical loosening agents (80–95%) or if followed by hand picking (99%) (Booth and Davies 1996, ABC 2003).

Increasing fruit size
As smaller olive seeds are likely to be swallowed by a greater number of birds, thereby dispersing the seeds (Sinclair 1999), the growing of larger size varieties should be encouraged. Thinning the number of olives shortly after fruit set will also increase the size of fruit (Maranto and Krueger 1994, Martin *et al.* 1994). Similarly pruning can also be used to adjust the levels of fruit on the tree, with less fruit the large fruit size (Fowler 1940).

Time of ripening
Unevenness in ripening is likely to result in a smaller harvesting efficiency (Burr 1999)with more fruit remaining on the tree, which could be eaten and dispersed. As variety influences maturity time, having a region with similar varieties will

leave only a small window of opportunity for food sources to vectors, reducing build up of vectors over time.

Victoria at risk

The computer program CLIMATE was used to analyse the potential distribution of olives based on climatic suitability. Weather data utilised by the program was weather station data from the Mediterranean region where olives originated from, and weather stations matching the FIS locations of feral olives in Victoria (DSE 2004) were added to the data. Weather stations were removed where a) temperatures below −5°C, b) Stations with annual rainfall below 350 mm and c) Stations above 45°N.

The Mediterranean based CLIMATE map of Victorian suitability was joined in Arcview to the vegetation data from of land classes where olives could establish (Crossman *et al.* 2002) and included: Lowland grassland, grassy woodland, dry sclerophyll forest, dry sclerophyll woodland, riparian vegetation and rock outcrop vegetation, but excluded grazing and cropping land use areas. The CLIMATE map for the Mediterranean locations was also joined in Arcview to a layer of roads in Victoria supplied by the Department of Primary Industries Frankston.

The CLIMATE prediction for Victoria using all naturalised locations suggests that the majority of Victoria's climate is very highly suitable for olives. However after factoring in land use (i.e. discounting grazing and cropping land use areas), it is the area of remnant vegetation that is most at risk particularly in the central and Gippsland areas (Figure 2). When this prediction is compared with recorded sites of olive invasion in Victoria these sites occur outside of the suitable vegetation (Figure 2). Many of these sites are likely to have occurred in non-arable areas such as roadsides or small reserves that are not included in the vegetative map.

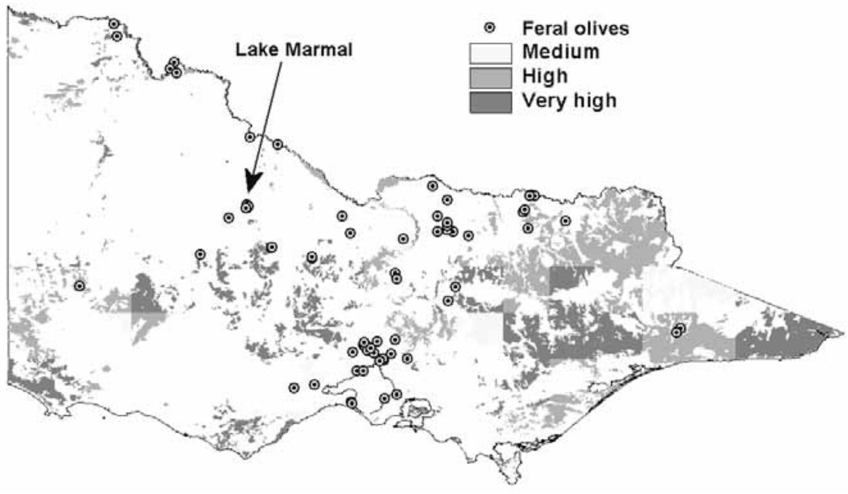

Figure 2. Climatic and vegetative suitability of *Olea europaea* L. in Victoria from CLIMATE modelling of Mediterranean locations overlayed with recorded sites of olive invasion

Recommendations

The continued development of the Victorian olive industry will have major economic and social benefits for the state, particularly in rural areas. However, from the evidence presented in this paper it can be concluded that olives in Victoria will pose a serious environmental weed risk if they are not properly managed.

1. Victorian government and olive industry must address the issue of feral olives.
2. A stakeholder group must be formed to examine strategies for reducing weed risk.
3. Implementation of an education and awareness campaign.
4. Risk management guidelines must be developed for olive groves.
5. Control of feral olives
6. Establishment of new olives should be prevented in high-risk areas.
7. An effective grove registrar must be established.

Victorian government and olive industry involvement

The conflict of interest between the potential economic and cultural benefits of olives versus the potential negative environmental externalities, suggests that the Victorian government and olive industry must address the issue of feral olives. If the government was not to address the issue of feral olives they would be disregarding their own visions of 'sustainable development' and 'protecting the environment for future generations' (DPC 2001). Addressing the issue of feral olives may provide a precedent and lessons for resolving future weedy conflicts of interest.

Victoria is currently well behind other Australian states in tackling the issue of feral olives despite the olive industry developing significantly in recent years. The olive industry in South Australia and to a lesser extent Tasmania, have set a precedent in the control of feral olives. Their strategies such as an education campaign, industry code of practice and grove database would be relatively easy to implement in Victoria.

Formation of stakeholder group

The way forward is for the Victorian government and industry to form a stakeholder group to examine the options for reducing the weed risk of olives. It must widely incorporate all stakeholders in the olive industry including ornamental growers, as their involvement and ownership in of the process is likely to increase their cooperation with strategies developed from the group.

Education and awareness campaign

An education and awareness campaign must be implemented. At present, cultivated and even feral olives tend to be perceived as good plants. Many small growers are likely to be unaware of the weed threat of olives. Although such an education program may only have limited success in reducing the risk of olives spreading in the short to medium term, the increased awareness of the issue would over a longer-term, increase the acceptance and success of other initiatives such as a code of practice. Lessons on involving the industry and public could be learnt from the South Australian and Tasmanian education campaigns for feral olives or more general campaigns such as Weedbusters.

Risk management guidelines

Guidelines for olive growers on reducing the risk and harm caused by dispersal of olives must be developed. The actual form of such guidelines should be decided by the stakeholder group but could be a Code of Practice or incorporated into Environmental Management Systems for the olive industry. Experience from other states has shown a poor level of cooperation with voluntary measures. Stronger incentives and promotion are needed for such guidelines to be adopted by growers.

Control of feral olives

The long non-reproductive period of juvenile feral trees presents a good opportunity to control these trees before they disperse seed. Controlling existing feral trees must be given a much greater priority than they are presently as it these feral trees that produce smaller seed which pose a much greater risk of dispersal than cultivated fruits. Feral olives could be controlled regionally or locally, however as olives appear to pose a weed risk throughout the state, a statewide approach should be adopted. Although the current Victorian noxious weed legislation doesn't currently have the capacity to differentiate between commercial and feral plants, as the South Australian legislation does, it is recommended that unharvested or feral olives should be declared a noxious weed, requiring control and a legally enforceable requirement to control or remove unharvested groves.

Olives in high-risk areas.

The single most effective method to prevent invasion of feral olives into ecologically sensitive areas is by not allowing high-risk groves to be established near those areas. This could be done in Victoria, as it has been in South Australia by developing a Weed Risk Assessment for new olive groves. Such a Weed Risk Assessment would need to assess the likelihood of dispersal and the harm caused by successful dispersal. The South Australian model provides a good example where groves assessed as higher risk are more restricted.

A detailed study of dispersal from commercial groves would benefit both the development of a WRA and code of practice. The study should include historical studies of distances and pattern of dispersal and current studies of dispersal, examining the dispersal characteristics of commercial groves, particularly the relationship between management, drupe size and dispersal. Some of this information may arise from current and planned research activities around the Dookie district by the University of Melbourne (Hamilton personal communication 2004).

Grove registration

A complete grove register is particularly important for groves in high-risk areas as it would provide information for implementing monitoring and control programs. The experience from South Australia and Tasmania suggest voluntary grove registers are unlikely to be effective in Victoria, without significant incentives. Victoria should investigate the potential for compulsory registration or compiling a register of existing groves using techniques such as remote sensing or drive by surveys.

A National approach

There have been calls for a national approach to the problem of feral olives (Bass *et al.* 2004) and a levy to help fund olive removal (ABC News 2003). Initiatives such as an education program led by the Australian Olive Association would have long-term benefits and should be implemented. The Adoption a similar weed management strategy to other states (e.g. WRA and COP), would be beneficial in presenting a united effort to tackle the issue.

Conclusion

Victoria is well suited to grow olives as is demonstrated by the increase in the number of orchards being established. This suitability also presents a risk to the native vegetation as olives have proven to be a major invasive species in Australia and overseas. It is imperative that both the olive industry and the Victorian government implement strategies to stop or at least minimise off farm dispersal of olives, while allowing for the expansion of this industry.

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Aquatic weeds of national significance – coming to a waterway near you!

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Abstract Early detection of the aquatic Weeds of National Significance (WoNS) is essential for successful eradication or containment. Unfortunately this concept has not been widely adopted in Australia, resulting in these and many other aquatic weed species proliferating largely unnoticed at many locations.

Cabomba (*Cabomba caroliniana*), one of the aquatic WoNS, poses a serious threat to waterways in all States and Territories. Attractive, hardy and easy to grow, ably describes this plant that enjoyed immense popularity with aquarium and fishpond enthusiasts. It's widely believed that this plant was deliberately planted in waterways to meet retail demand and many such plantings may remain undiscovered today, posing a `serious risk to waterways.

Keywords Aquatic weeds, cabomba, early detection, waterways.

Introduction

The aquatic Weeds of National Significance (WoNS) include alligator weed (*Alternanthera philoxeroides*), cabomba (*Cabomba caroliniana*) and salvinia (*Salvinia molesta*), each an aquatic plant from South America. These species cause considerable environmental and economic impacts and have potential to spread to waterways in all states and territories. This paper will outline the threat of the aquatic Weeds of National Significance, using cabomba as a case study and will highlight processes and benefits for implementing aquatic WoNS early detection procedures.

What is cabomba?

Cabomba, a submerged aquatic plant native to parts of both North and South America, is a hardy perennial that favours slow moving or still waterbodies. Although cabomba flowers it is known to only reproduce vegetatively, although there are anecdotal reports of seeding populations in the Northern Territory. It tolerates a wide range of water temperatures, including tropical and cool temperate waters. CLIMEX modelling suggests its potential distribution includes all states and territories with excellent habitat conditions in eastern and southern Australia (ARMCANZ 2000).

Cabomba was introduced to Australia for the aquarium trade and by the mid 1980s naturalised populations of cabomba were been discovered. Such infestations were either the result of aquatic plant traders deliberately seeding waterways for commercial purposes or through aquarium dumpings. Infestations of cabomba have since been discovered at various sites on coastal Queensland and NSW from Cairns to Sydney, Katoomba NSW, Darwin and the nearby Darwin River, and Lake Nagambie and Lake Benalla in Victoria.

These infestations occupy only a fraction of its potential range. It's feared that due to the plants submerged and hard to detect nature many infestations are yet to be discovered so its true distribution could be much greater than what is currently known.

The cabomba threat

Cabomba is a WoNS due to its invasiveness, potential to spread and its potential economic, social and environmental impacts (Thorp and Lynch 2000). Cabomba tends to invade slow moving or ponded waterways where it can form dense underwater thickets. Such thickets can:

- dangerously interfere with swimming and boating activities
- deplete oxygen and light levels in the water, which reduces fish stocks
- replace native aquatic plants
- clog irrigation channels and water intakes
- increase water treatment costs.

In addition cabomba is proving to be a difficult plant to manage. Herbicide applications are difficult due to its submerged nature and currently there are no biological controls. Mechanical harvesting and lowering of water bodies are feasible but are expensive.

The problematic nature of cabomba and its status as a WoNS has seen the plant banned from sale in all states and territories except Victoria. The ongoing legal trade of cabomba in Victoria poses an unnecessary risk of further cabomba infestations eventuating through either plant trading or dumped aquarium plants in Victoria but in all states and territories.

The following two case studies illustrate the problematic nature of this aquatic WoNS.

Case study 1 – Impacts of cabomba on Northern Territory waterways

Since its detection in the Northern Territory (NT) in 1997 in a man made lake, cabomba has proven to be a difficult plant to manage. All attempts at control using various physical methods including hand-pulling, draining the lake, dredging the lake and shading infestations failed over the next four years. In 2002 a single application of 2,4-D n-butyl ester plus diatomaceous earth resulted in the disappearance of the species from the lake which has been confirmed by monitoring the site on a monthly basis since then.

In October 2004 cabomba was again recorded in the NT, however this time it was found in a natural and pristine waterway over an 11 km stretch of the Darwin River. A massive publicity and awareness campaign immediately following this resulted in a further 13 sites being positively identified in backyards, ponds and fish tanks in suburban Darwin, with one record 200 km south at Pine Creek.

The Darwin river site is complex from the point of management due to the wide range of land use groups and land tenures in addition to the river being a potable water supply. A herbicide control program commenced late in 2004, with three treatments occurring before the on set of the Wet Season in late December. Only one live plant was found on December 17 2004, however by July 2005 cabomba had recovered to approximately 60% of the infestation level mapped prior to treatment. Further control operations are scheduled to recommence in August with priority given to fine tuning application techniques as further developments occur.

Case Study 2 – Sunshine Coast, South-East Queensland

Cabomba was first noticed in Lake Macdonald and the Ewen Maddock Dam in 1991. At the time these two impoundments were the major potable water supplies for Noosa and Caloundra Shires, respectively.

Various methods have been used in the fight against this most tenacious of aquatic bullies. At Ewen Maddock dam, mechanical harvesting, draw down, and the current method of using a venturi (or underwater vacuum cleaner), operated by divers, have achieved some degree of control but at considerable economic cost. Cost as at June 2005 was $176.00 per hour to operate.

At Lake Macdonald, in the Noosa hinterland, cabomba grows in water up to

10 metres deep, with foliage increasing towards the light (surface). This foliage prevents light from reaching the floor of the Lake resulting in the decimation of a once vibrant native aquatic plant population. Where healthy clumps of *Potamogeton crispus* and *Vallisneria nana* once thrived, the area is now an underwater desert. Watching underwater video transects is depressing, as well as boring… pitch black, and nothing, apart from cabomba. This South American bully has drastically reduced the ecological diversity of this water body.

Adding to these ecological impacts was the need to ban swimming and boating activities in the lake due to safety concerns and to reduce the risk of the plant spreading. Other recreational activities such as sailing, canoeing and fishing are all activities hampered by cabomba.

Managing the Lake Macdonald infestation is an expensive and ongoing task, made more difficult due to it being a potable water supply (thus herbicides are not an option). A purpose built aquatic harvester has actively cut and removed cabomba from the lake for the last four years. At its peak, the harvester was removing up to nine tons of cut Cabomba per day. Due to heavy metal concerns (notably manganese at 5400 mg kg^{-1}) harvested Cabomba is classified as contaminated waste and requires disposal at landfill sites, thus increasing treatment costs.

Unsuccessful attempts to reintroduce native plants to help manage cabomba were made by the Lake Macdonald Catchment Care Group, and Caloundra Council (Ewen Maddock Dam). Whilst establishment was successful, predation by birds and other aquatic animals severely limited the long-term survival of these introductions.

How early detection programs can help

Early detection and treatment of cabomba and other aquatic weed infestations is an essential preventative measure that can help avoid the problems listed previously. Containment or eradication of submerged aquatic weeds such as cabomba are only possible if infestations are detected and treated whilst small (generally less than 1 ha in size). Early detection efforts increase the likelihood of successful eradication or containment whilst populations are still low, resulting in significant long term cost savings and protection of downstream aquatic habitat (National Invasive Species Council 2003).

Early detection can involve:

1. active detection programs, and
2. passive detection programs.

Active detection programs involve weed control authorities methodically surveying designated areas for prioritised aquatic weeds. In Australia, methodologies for undertaking such surveys have been developed that provide effective detection tools whilst meeting end user requirements in terms of minimal time and skill levels required (Watts 2003, NAWMG 2005). Such methodologies provide a process to:

1. identify and prioritise high risk aquatic weeds,
2. identifying high risk sites of aquatic weed invasion and establishment,
3. inspecting high risk sites,
4. data collection, and
5. post reconnaissance survey tasks.

These methodologies are also simple enough to allow participation from existing volunteer weed detection networks or community organisations such as Waterwatch. With minimal training and provision of identification aids, volunteers can increase the effectiveness of established active detection programs.

Passive detection programs involve people reporting infestations they fortuitously detect as they conduct other activities. Such programs can be established by increasing awareness and identification skills amongst those people most likely to notice an aquatic weed incursion. They include natural resource management staff, fishing and boating enthusiasts, Waterwatch and other community groups.

Early detection of aquatic weeds is a relatively new concept in Australia with only few existing efforts, mostly conducted at local scales. However, implementing early detection programs is a key national priority listed in the National Cabomba strategy and for the National Aquatic Weeds Management Group. It is hoped that through the Defeating the Weeds Menace program adequate resources can help establish such programs in areas of Australia thought to be at high risk of aquatic weed invasion. Once established, such programs will require long term support and commitment from weed control authorities, weed detection networks and community groups.

Conclusion

Despite its limited distribution cabomba, a WoNS, poses significant management challenges to weed control authorities where established populations exist. Its significant impacts and submerged habitat, rapid growth and hidden nature make it an extremely difficult plant to effectively manage. National management is also not helped by the fact that it can still be traded legally in Victoria.

A lesson learnt from infestations throughout Australia is the important role early detection programs could play in preventing future cabomba and other aquatic weed outbreaks. Methodologies for aquatic weed early detection are available. Long term benefits of their implementation will out way their costs and will help preserve our waterways.

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Operation rapid response – dealing with the potential incursion of branched broomrape (*Orobanche ramosa* Linnaeus) into Victoria, Australia

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Summary The Victorian Government is placing a high priority on potential, new and emerging weeds. Preventing the establishment of serious weeds is a worthwhile government investment. It saves money, protects the environment and may reduce the impact on human health.

The Department of Primary Industries (DPI), and the Department of Sustainability and Environment (DSE) have developed the Weed Alert Rapid Response program to target potential, new and emerging weeds in Victoria. The main focus is on surveillance, collection, identification, assessment and response. A network of Weed Spotters has been established to look for new weeds and report them when found. More intensive surveillance programs are being conducted for serious potential weeds.

An outbreak of the parasitic weed branched broomrape (*Orobanche ramosa*) in the Murray Bridge region of South Australia is threatening agricultural production in Victoria. Trace-back operations in South Australia have identified 34 Victorian properties linked to the South Australia infestation. To stop this potential incursion, the Victorian Government has set up an "Operation Rapid Response – Branched Broomrape Team" in much the same way as a team is put together to deal with natural disasters. This team has overseen the surveillance for this weed in Victoria and raised awareness of the problem with key stakeholders and the Victorian community.

Keywords Branched broomrape, *Orobanche ramosa*, eradication, weed alert, weed incursion, weed surveillance.

Introduction

Historically, weed management priorities have been dictated by weed economics. Weed policy was directed by the number of weed complaints government departments received from farmers. This meant that by the time action happened, the weed was already out of control and beyond eradication. More recently, weed science has provided more information on the potential distributions and impacts of new and emerging weeds (Kriticos and Randall 2001). It has become evident that governments can get much better value by either preventing weed species coming into Australia or by identifying new weed species very early in their colonisation phase and targeting their suppression or eradication. Today's management pays attention to the principle of 'prevention is better than cure' as opposed to the past philosophy of 'treating weed problems as they arise' (Csurhes and Edwards 1998).

The recent identification of new outbreaks of branched broomrape, *Orobanche ramosa* Linnaeus in South Australia has highlighted the importance of pro-active weed alerts and rapid responses in Victoria. *O. ramosa* is an obligate root parasite of a wide range of broad-leaved plants and its distribution extends from central Europe, the Middle East and northern Africa. It has been introduced to a number of other regions, including South Africa, Mali, Australia, Cuba and several sites in Central America and the USA (Parker and Riches 1993). The potential hosts of *O. ramosa* in Australia have been listed by Virtue *et al.* (2002) and include species such as canola, cabbage, tomato, potato, carrot, coriander, vetch, faba bean, lupin, chickpea, lucerne, burr medic, annual white clover, lettuce, safflower and sunflower. It has also been found attacking various weeds and native herbs. An economic assessment of the potential costs of *O. ramosa* to Australia has estimated that if left uncontrolled, infestations could cost Australia $240.7 million within five years and as much as $2.1 billion within 25 years, with the main impacts on oilseed, pulse and vegetable cropping and through rejection of exports such as cereal grains contaminated with broomrape seed (Milne 2000).

The history of *O. ramosa* introduction and spread in Australia is described in Jupp *et al.* 1992. The infestation is located in the Murray Bridge area of South Australia and extends over an area of approximately 70 km by 70 km. In 2005, infestations in this region are confined to an area of approximately 6500 ha with 457 properties under quarantine (Nick Secomb personal communication). There is a nationally funded eradication and containment program for this region costing approximately $2 million per annum, supported by the Federal and State Governments and industry. It has seen extensive surveys, tracebacks, implementation of quarantine (Jupp *et al.* 1992), research into herbicides (Mathews 2002), and research into its host range (Virtue *et al.* 2002). Concurrently, ongoing research is being carried out on fumigation, seed decay, identification (a genetic probe, sniffer dogs), vectors, lifecycle and seed dispersal. Through the strict eradication and containment program in South Australia, approximately 32% of paddocks infested with *O. ramosa* in 2000 have remained free of *O. ramosa* through host denial (Nick Secomb personal communication).

All broomrape (*Orobanche*) species are prohibited imports to Australia and have largely been kept out by quarantine controls, but the seeds could easily enter undetected. The Australian Quarantine and Inspection Service (AQIS) is responsible for screening and vetting plant and plant product imports to ensure new weeds are not introduced. For example, AQIS is responsible for monitoring the 52 000 aircraft that arrive annually, carrying in excess of 7.3 million passengers and aircrew and 1.8 million airfreight containers. Intercepting each and every illegal item and contaminant is impossible. At seaports Australia wide, 10 000 ships dock annually carrying 1 million cargo containers, of which approximately 5% are checked (Anon. 1999). Many of our trading partners prohibit all broomrapes, so Australian export markets will be severely affected if these plants become widely established. Branched broomrape is a declared exotic disease under the Victorian *Plant Health and Plant Products Act 1995* and is a State Prohibited Weed under the Victorian *Catchment and Land Protection Act of 1994*.

Materials and methods

Upon receiving notification in 1999 of the outbreaks of *O. ramosa* in South Australia and trace-backs (links to infected properties through movement of produce, stock, machinery or other materials) to Victorian properties to infested areas in South Australia, the Victorian DPI called a meeting to develop a plan of how Victoria would respond. It was decided that branched broomrape should be treated like an emergency (i.e. bushfires) and a 'Branched Broomrape Operation Rapid Response Team' was set up. The team was structured according to the Australian Interservice Incident Management System – Incident Control System. As such the team was composed of a program leader (controller), a planning manager, a logistics manager and a communications manager.

The program manager oversaw and coordinated the entire program. The planning manager dealt with issues such as political support, management structures, frequently asked questions, what other States were doing, timing, trace forwards and staff training needs. The logistics manager dealt with ordering equipment, databases and management of the budget. The communications manager drafted a communications plan, identified and briefed regional media staff, organised press releases, printed and distributed identification material and briefed stakeholders. The operations manager identified operational staff, organised training, examined operational hygiene, organised staff authorisations and how to inform and work with the land owners.

The draft rapid response program was evaluated during the early stages of operation through a risk management process that examined all the tasks within this project and identified those that required active management. Planning and obtaining adequate resources for implementation of the plan were identified as the most important tasks. Inspections of properties were undertaken as has been described in Jupp *et al.* 2002.

1n 2002, the Victorian Department of Primary Industries started the development of a Weed Alert Rapid Response Plan (WARR) for potential, new and emerging weeds. The Plan guides further developments in surveillance, collection, identification, assessment and rapid response. It ensures the timely implementation of effective management measures for the protection of Victorian environments and industries and other social values. The WARR plan is consistent with various National and State policies and strategies and fits within a policy framework hierarchy within Victoria. The importance of biosecurity management is well recognised by government agencies across Australia and internationally. The WARR Plan was launched in 2005. The plan defines the reporting relationships and responsibilities of those involved and 'Operation Rapid Response – Branched Broomrape' now falls under its guidance in Victoria.

To ensure sufficient preparedness for future weed incursions, various networks and documents are being prepared to supplement the WARR plan. These include a communication strategy, contingency plans, weed collection guidelines, a hygiene and disposal protocol and a compensation protocol. The plan will significantly enhance the effectiveness of any weed incursion response.

Various individual positions and groups or committees have new responsibilities in Victoria as part of the plan. These include the DPI/DSE Pest Management Coordinating Committee (PMCC), a Weed Assessment Panel, Weed Incursion Management Teams, and appointment of the Project Leader WARR, Implementation Officer WARR and Weed Compliance Officer. In the field, Weed Alert Contact Officers are being put in place to deal with new incursions. The WARR plan defines their reporting relationships and responsibilities. The National Herbarium of Victoria is responsible for formal identification of weed specimens.

A network of people who can carry out weed surveillance, recognition and collection has been formed called the Weed Alert Network. These 'Weed Spotters' including community group members, officers of State and local governments and members of the public will be supported with training opportunities and an email discussion group. They will be encouraged to deliver specimens of potential, new and emerging weeds to the Herbarium for formal identification via the field-based Weed Alert Contact Officers.

When a new weed incursion is discovered, the weed will undergo a risk and threat assessment by the Weed Assessment Panel and an appropriate type of response (high, medium, low) will be recommended to the PMCC and the appropriate responses put into action. This rapid response plan can be and is being used as a model for reporting and acting upon weed and other incursions in Victoria, nationally and overseas.

Results

The number of Victorian properties inspected for branched broomrape is shown in Table 1. After consultation with South Australia, six of the previously surveyed properties were excluded from the 2004 surveys. These had been surveyed for at least three years without the plant being detected and also they were perceived to pose a low risk of harbouring branched broomrape because of their location, soil type, link type etc. After five years of detailed surveys of Victorian properties linked to *O. ramosa* infestations in South Australia, no *O. ramosa* has been found in Victoria. The fact that the rapid response team have found several clover broomrape, *O. minor* specimens while searching for *O. ramosa,* provides confidence that the search procedures were effective (Brian Dowley, DPI Victoria, personal communication). The number of properties requiring repeated surveying will fall dramatically if further inspections demonstrate the absence of O. ramosa and quarantine measures prevent any new linkages to Victoria from the infected area.

A branched broomrape incursion contingency flowchart has need developed for Victoria (Figure 1) In the event of an incursion being found, this flowchart details what and when responses will take place, who will undertake them and also describes the lines of communication required for the response. Being prepared in advance facilitates quick and decisive actions to deal with serious incursions.

To enhance the potential surveillance coverage of branched broomrape, the network of over 600 registered Weed Spotters can be asked to look for and report incursions. The Cooperative Research Centre for Australian Weed Management (Weeds CRC), in association with DPI, is now using the Victorian model for a Weed Spotter network and piloting it in parts of Queensland. It may then be applied across Australia.

Discussion

Failure to find branched broomrape in areas of Victoria identified most at risk may only provide a temporary reprieve, but during this time planning and research has enabled strategies to be put in place to minimise damage should it be found. Victoria needs to ensure all land managers are aware of how to identify branched broomrape, so it can be immediately recognised and acted upon. The WARR program is a critically important component of this process. The Victorian government in collaboration with industry should also invest in determining the best fumigation techniques should the plant becomes established in Victoria. The current branched broomrape fumigation program in South Australia relies on methyl bromide and currently costs in excess of $1.5 million annually. Methyl bromide will be phased out of production because of environmental concerns by 2008. A proactive research and awareness program will help keep Victoria free of branched broomrape.

Table 1. Surveys of traceback properties in Victoria

Year	Properties surveyed	Area surveyed (ha)	*O. ramosa* plants found
2000	7	6 827	0
2001	27	17 774	0
2002	34	20 992	0
2003	34	20 992	0
2004	28	17 807	0

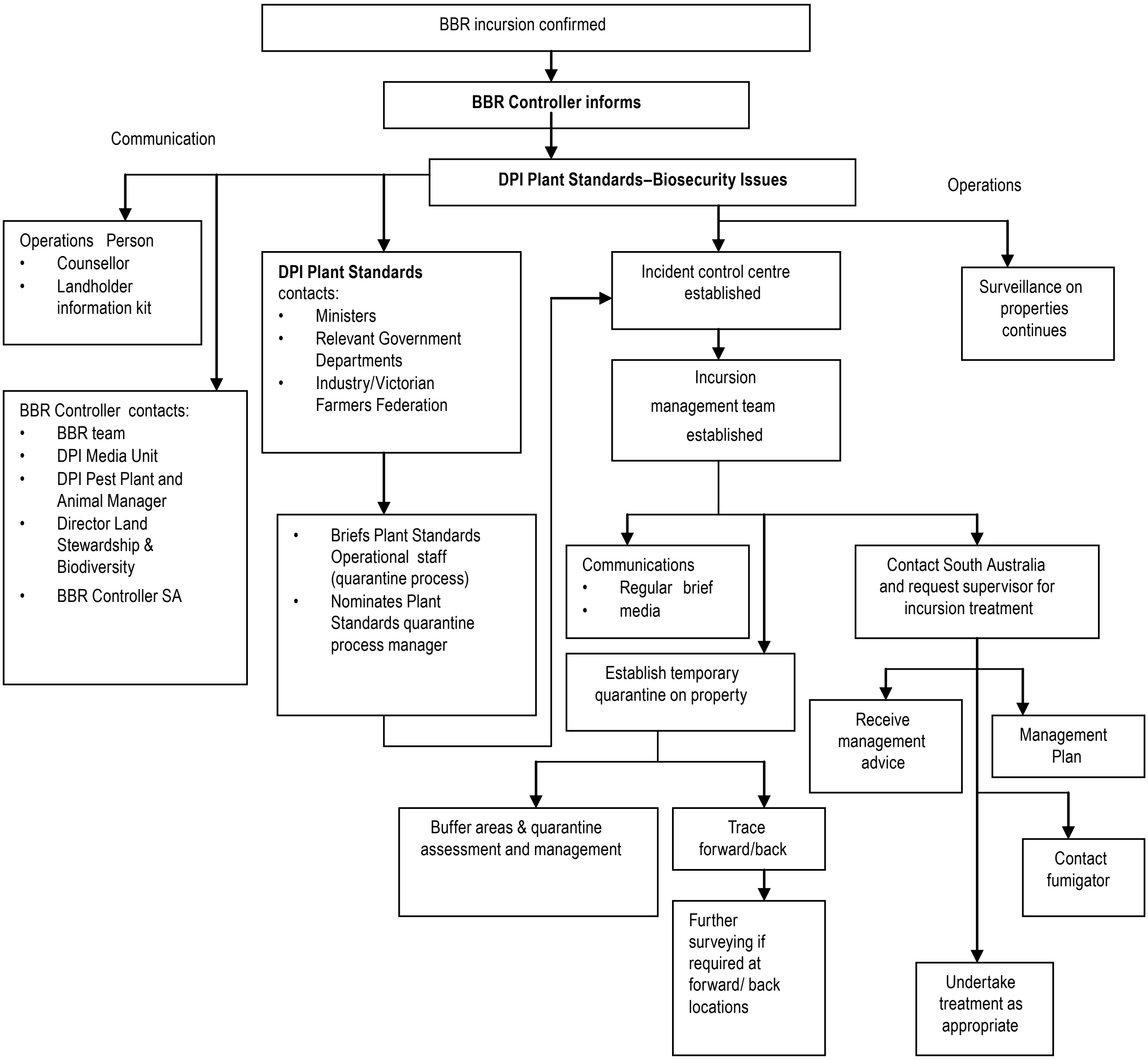

Figure 1. A branched broomrape incursion contingency flowchart

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SESSION 4
Integrated weed management (concurrent)

Chilean needle grass (*Nassella neesiana*) – integrated grazing for success

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Chilean needle grass (*Nassella neesiana*, CNG) is able to over-run pastures resulting in canopy cover of up to 60%. Such infestations can lead to a substantial reduction in livestock carrying capacity as the grass produces large numbers of unpalatable flower stalks and sharp seeds that pose a risk to animal welfare, particularly sheep. A large scale grazing study was initiated over spring 2004 to compare the ability of set stocked or rotationally grazed sheep and cattle, to reduce CNG seed production, as well as to monitor the effects on animal production and the botanical composition of the pasture regrowth.

Sheep (Suffolk X ewes and lambs) and cattle (Angus cows and calves) were grazed in separate paddocks stocked at 12 DSE ha^{-1} in a set stock or simple rotational system. Simple rotational treatments consisted of a four paddock time based rotation. Rotation length at the start of spring was eight weeks and was reduced to four weeks by the end of spring.

Grazing significantly reduced the amount of standing panicle seed ($P = 0.015$), and stem cleistogene seed ($P = 0.015$) when compared with the ungrazed controls. Within the grazed treatments, cattle grazed significantly ($P = 0.043$) more CNG panicle seeds compared with sheep. Pasture regrowth of grazed treatments had significantly less CNG dry matter than ungrazed treatments in early spring ($P = 0.039$, day 56) although there was no difference later in spring. Animals in the trial gained weight satisfactorily. Cattle gained significantly more ($P = 0.015$) weight than the sheep during the first month although this trend did not continue. The method of grazing, whether set stocked or rotational, did not significantly affect any of the parameters listed above.

Grazing significantly reduced the number of both CNG panicle and stem seeds whilst changing early spring regrowth to a more palatable composition. Managed grazing with cattle could potentially be used therefore to reduce the amount of CNG seeds entering the soil seedbank whilst not compromising animal productivity or welfare.

Enviromark: a system for integrated weed management along roadsides

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Summary This paper introduces Enviromark, a system that has been developed, in partnership with road managers, to overcome problems in managing roadside weeds. Enviromark is not just a series of markers on roadsides, but an integrated system that delivers practical information on what to manage where, to the people on the ground managing roadsides.

Keywords Enviromark, roadsides, environmental management system

Introduction
Managing weeds on roadsides is a difficult task. There are so many weeds but some are more significant than others. Some are spread by road maintenance activities and some look like native plants. Many roadside marker systems have been developed to mark weeds, and there is information available on how to manage weeds, but very often the right information, on what to manage how and where, does not get through to people working on the ground.

Greening Australia has developed an integrated environmental management system for mapping, marking and managing weeds and significant environments. Called Enviromark, it can help organisations to observe their responsibilities under weed management legislation and local and regional natural resource management strategies. Enviromark allows weed management to be prioritised and enables road management plans to be enacted. This paper outlines the issues that Enviromark addresses and describes how the system works, focusing on its application to weeds on roadsides.

Background
Enviromark was developed and road-tested over five years, by Greening Australia with the Tasmanian State Department of Infrastructure, Energy and Resources and several Tasmanian councils, with input from other corridor managers. Initially called the Tasmanian Roadside Vegetation Marker System, positive feedback led to a name change to Enviromark so that the system can be applied Australia-wide. Enviromark is now managed as a licensed product by Greening Australia on a fee-for-service basis.

The issues
Many organisations undertake work on roadsides and different organisations own and manage different areas, so who's job is it to manage the weeds? Weeds thrive in disturbed roadside ground and spread along road reserves. Adjacent land can be threatened by the weeds on road reserves. Information on how to manage the weeds is out there, but often this is not communicated to, or is not in a useful form for, the people who actually work on roadsides.

Road corridors can also contain threatened species and their habitat or other significant vegetation. Sometimes roadsides contain the most significant remnants of native vegetation in a region.

Many roadside marker systems have been invented over the years. Also much roadside mapping of vegetation has been done, and many roads have management plans. However cases of weeds being spread by roadside slashing, spoil full of weed seeds being moved and threatened species being damaged continue.

Unlike previous marker systems, Enviromark translates existing maps, plans and strategies into on-ground actions, informing field crews on how to operate within marked areas, so they do not need to be botanists or ecologists to improve roadside management.

Who is using Enviromark?
Under the Tackling Weeds on Private Land Initiative several Victorian councils are taking up Enviromark to manage roadside weeds. VicRoads is also setting up a trial. A couple of councils in Tasmania and Victoria (Clarence City and Indigo) are already using Enviromark to manage Weeds of National Significance. The system is also being used by the Tasmanian State roads department to manage weeds (and threatened species) and is likely to be taken up by other councils and corridor managers. The use of Enviromark has resulted in the Tasmanian main roads department and a local council working together for integrated management of a Weed of National Significance across jurisdictional boundaries.

The Process
The first step is for the road or corridor manager to make decisions regarding the priority issues and locations to be managed by Enviromark, for example which weeds or threatened species, over what area. This decision will depend on resources, existing mapping, priorities, funding opportunities, obligations and the level of existing information on corridor management.

Next an agreement is signed between the corridor manager and Greening Australia, setting out who provides what and the timeframe and budget. A licence agreement is signed also, to ensure that Enviromark is used properly. After this the road manager and Greening Australia decide on codes, prepare specifications and run training. There are many cost options depending on how much the road or corridor manager wishes to do and what information they have already available. Monitoring and evaluation is done yearly.

System overview
Enviromark uses a range of tools and can be applied at different levels, as priorities and resources allow. The components are;

- Field markers
- Specifications
- Training
- User guide
- Mapping database
- Monitoring

The field markers identify where important weeds or other significant vegetation occurs on the ground. The field markers have a code that relates to a particular specification. Specification sheets outline a particular management regime which can be applied to a particular weed, or group of weeds. These specifications detail how road management activities are to be performed in each area marked with a particular code.

For the system to work there must be training for the on-the-ground crews and supervisors, and anyone else working within the marked areas. A user guide is produced for the training, detailing which issues are covered and how the Enviromark system works in each project area. There also needs to be regular monitoring of the system to make sure it is being used effectively. There is an optional database that holds inventory information on roadside weed infestations and their management and can be used to generate road-map reports.

The field markers
Field markers show the location on the roadside of different management areas and have links to information on the appropriate management response. Information is coded on the markers with colours, symbols and codes, as demonstrated below.

The field markers are designed to be easily recognisable from a slow moving vehicle. Standard white or coloured guide posts are marked with vinyl stickers (50 ×

153 mm) as the recommended option (Figure 1), although the stickers can also be attached to a semi-flexible backing which can then be attached to electricity poles, guard rails or fence posts. Figure 2 shows the elements of the field markers and their arrangement. There are a range of main markers available for different applications, described in detail below.

Pest Species Area marker

Management areas marked with this symbol (Figure 3), contain pest species of plants or animals that can be spread by common roadside management activities. It is important to note that this marker is not used to identify all roadside weeds. This is because not all species are spread by roadside management activities and some species are more significant than others. These markers only identify those species and occurrences where hygiene measures are likely to reduce their spread and where the application of hygiene measures is practical.

The purpose of this marker is to minimise the further spread of the pest species through routine road management activities and to direct activities to remove the pest species. To achieve this the directions for working in these areas focus on managing the hygiene of works personnel, machinery and associated materials.

The label below the main marker (Figure 4) refers to the specification relevant to that management area. The code labels for the root rot fungus and Chilean needle grass are shown below.

Chilean needle grass is a major pest species occurring on roadsides in Victoria, New South Wales, the ACT and found recently in South Australia, Queensland and Tasmania. Roadwork hygiene has a major influence on its spread. This species would be marked with the Pest Species Area marker.

Other main markers

Enviromark can be used to manage any significant vegetation. Below are examples of other main markers and specification link codes created to manage particular issues (Figure 5). Other markers could be developed to cover different issues.

Markers for specific actions

Stockpile and Parking Area marker

These markers are used to direct vehicles to appropriate parking and stockpiling areas. The markers should be used in areas that do not have pest species, threatened species or significant habitat that could be damaged by parking or stockpiling.

This marker (Figure 6) can also be used for temporary construction areas. A set zone for the movement of construction vehicle can be defined or designated using this marker. This should minimise any unnecessary damage or disturbance.

Figure 1. An example of a Pest Species Area field marker

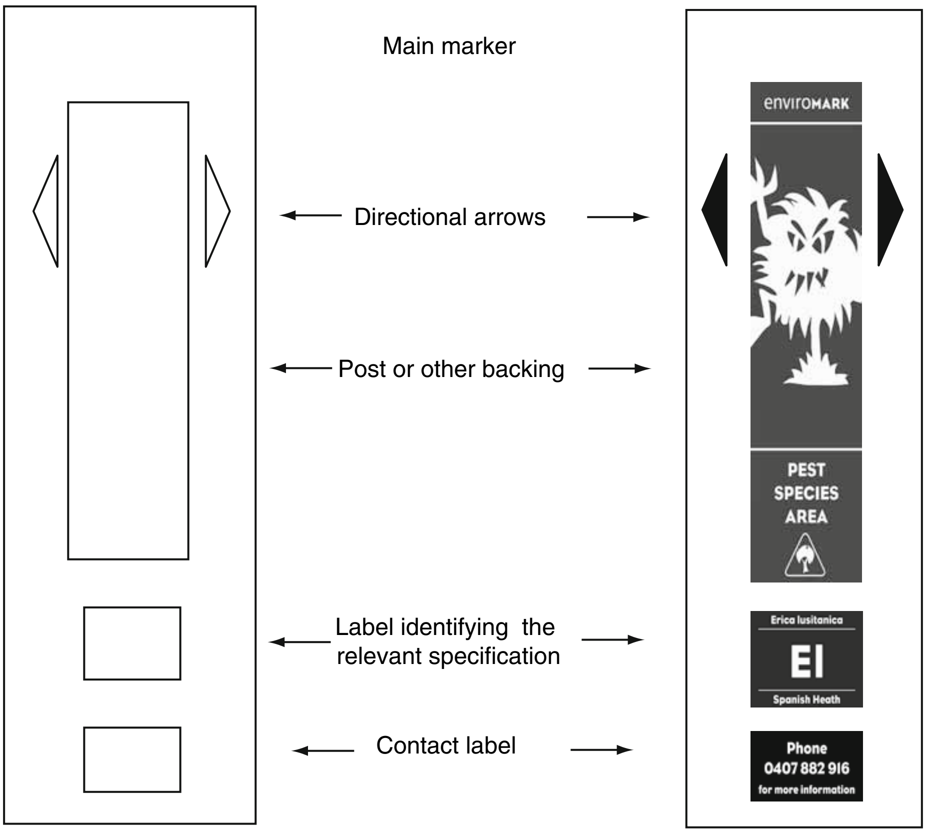


Figure 2. The elements of the field markers and their arrangement

Figure 3. The Pest Species Area main marker

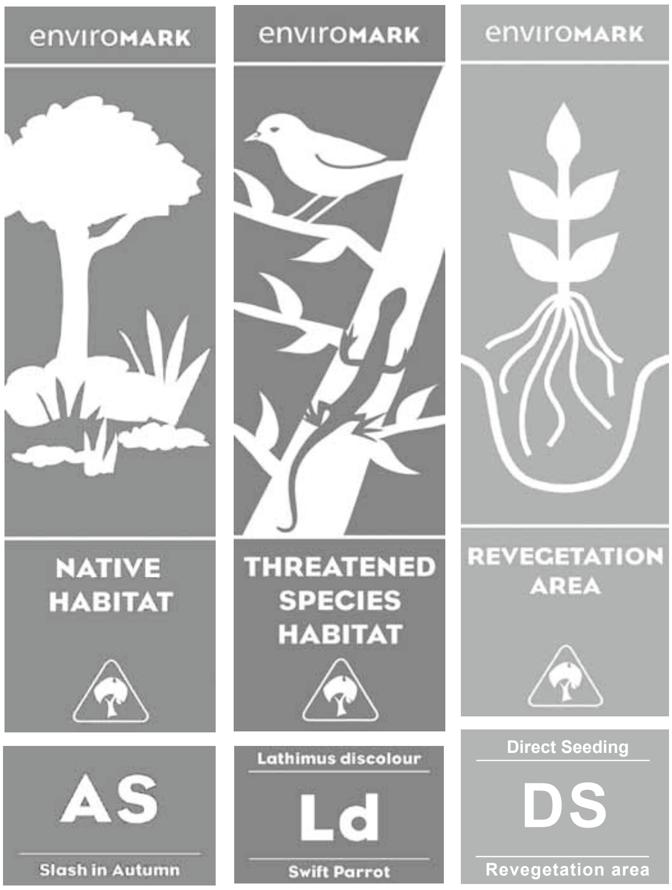


Figure 5. Examples of other Enviromark main markers

Figure 4. Examples of pest species code stickers

No herbicide marker

The purpose of this marker (Figure 7) is to prevent damage to non-target significant species or areas. These may be in the actual marked area or in adjacent areas where translocation of the pesticide is likely due to wind or water movement. The marker can also be used around human areas where herbicide spraying is not desirable, such as near organic farming enterprises or adjacent to schools.

The capability exists with this marker to add a label that specifies the actual type of chemical that is prohibited, thereby allowing the use of other herbicides or pesticides that do not pose a risk.

The contact label

The contact label contains the phone number of the organisation implementing Enviromark. This provides a source of further information on the markers. The number must be one that is monitored during most working hours.

Directional arrows

Directional arrows should be stuck on the marker posts to indicate the location, with respect to the marker post, of the management area to which the marker refers.

Marker placement

A note of safety: The placement of markers and the associated management regimes are not to compromise safety or the reasonable functioning of the road corridor at any time. The determination of management practices and placement of markers is to be done in consultation with road managers and their input is sought in making guidelines practical and safe.

Field marker stickers can be placed on dedicated guide posts, either at the back of the road reserve, or in line with existing road furniture.

The standard specifications

This is the crux of Enviromark; the management regime that accompanies the field markers. For each code on the label on the field markers there is a corresponding specification, which sets out the management regime for the marked area. The specification sets out specific management actions, listed by activity such as slashing, drain cleaning and grading. Figures 8 and 9 give examples of a pest species and a threatened species specification. The specification is an A4 sheet that is to be carried in the glove box of all vehicles working in the marked management area with that code.

Specifications for weeds generally focus on hygiene measures that prevent the spread of weeds. For example, when mowing in areas of Chilean needle grass, parts of the grass, including seeds, will end up on top of the mower. Hence it is essential that the machine is cleaned of plant material before leaving a weed-infested site. The actions set out in the specification must be practical and road managers and supervisors need to be consulted during specification preparation to ensure a management regime that can and will be followed. The management regime must allow for the safe use and maintenance of the road and furniture. Changing maintenance regimes will have implications for works programs that need to be planned.

The specification sets out a management regime and it may be the case that several weed species can be managed by one management regime. Thus for example a grassy weeds code and specification could be prepared. It may be more practical to mark and specify actions for areas that are weed-free, and manage to maintain those, than to focus on the weed-infested areas.

Training

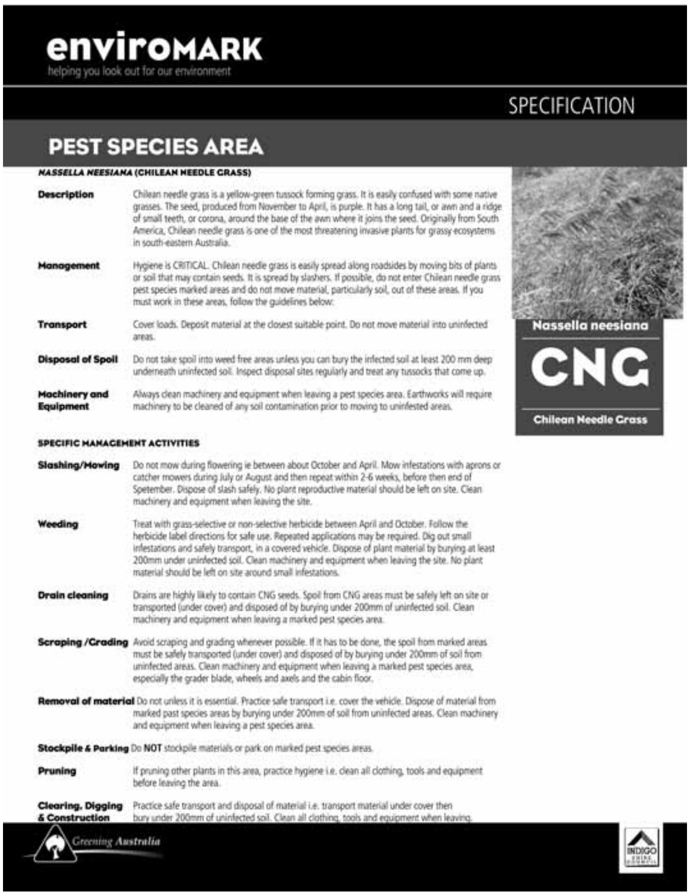
For Enviromark to work there must be training. Training needs to result in road works crews knowing what the field markers are, where they are and having the right specification. They may need particular equipment, such as brush-down or wash-down equipment or mower covers, to undertake the actions required when working in marked areas. Also the supervisors and other relevant people in the road management authority should attend. Changes in works schedules required by the altered management regimes need to be considered and approved. The training should involve looking at field markers in place.

The Database

The Enviromark database is a purpose built database for storing and displaying

Figure 6. The Stockpile and Parking Area main marker

Figure 7. The No Herbicide Spraying main marker



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SPECIFICATION

PEST SPECIES AREA

NASSELLA NEESIANA (CHILEAN NEEDLE GRASS)

Description	Chilean needle grass is a yellow-green tussock forming grass. It is easily confused with some native grasses. The seed, produced from November to April, is purple. It has a long tail, or awn and a ridge of small teeth, or corona, around the base of the awn where it joins the seed. Originally from South America, Chilean needle grass is one of the most threatening invasive plants for grassy ecosystems in south-eastern Australia.
Management	Hygiene is CRITICAL. Chilean needle grass is easily spread along roadsides by moving bits of plants or soil that may contain seeds. It is spread by slashers. If possible, do not enter Chilean needle grass pest species marked areas and do not move material, particularly soil, out of these areas. If you must work in these areas, follow the guidelines below:
Transport	Cover loads. Deposit material at the closest suitable point. Do not move material into uninfected areas.
Disposal of Spoil	Do not take spoil into weed free areas unless you can bury the infected soil at least 200 mm deep underneath uninfected soil. Inspect disposal sites regularly and treat any tussocks that come up.
Machinery and Equipment	Always clean machinery and equipment when leaving a pest species area. Earthworks will require machinery to be cleaned of any soil contamination prior to moving to uninfested areas.

Nassella neesiana
CNG
Chilean Needle Grass

SPECIFIC MANAGEMENT ACTIVITIES

Slashing/Mowing	Do not mow during flowering ie between about October and April. Mow infestations with aprons or catcher mowers during July or August and then repeat within 2-6 weeks, before then end of Spetember. Dispose of slash safely. No plant reproductive material should be left on site. Clean machinery and equipment when leaving the site.
Weeding	Treat with grass-selective or non-selective herbicide between April and October. Follow the herbicide label directions for safe use. Repeated applications may be required. Dig out small infestations and safely transport, in a covered vehicle. Dispose of plant material by buying at least 200mm under uninfected soil. Clean machinery and equipment when leaving the site. No plant material should be left on site around small infestations.
Drain cleaning	Drains are highly likely to contain CNG seeds. Spoil from CNG areas must be safely left on site or transported (under cover) and disposed of by burying under 200mm of uninfected soil. Clean machinery and equipment when leaving a marked pest species area.
Scraping /Grading	Avoid scraping and grading whenever possible. If it has to be done, the spoil from marked areas must be safely transported (under cover) and disposed of by burying under 200mm of soil from uninfected areas. Clean machinery and equipment when leaving a marked pest species area, especially the grader blade, wheels and axels and the cabin floor.
Removal of material	Do not unless it is essential. Practice safe transport i.e. cover the vehicle. Dispose of material from marked past species areas by burying under 200mm of soil from uninfected areas. Clean machinery and equipment when leaving a pest species area.
Stockpile & Parking	Do **NOT** stockpile materials or park on marked pest species areas.
Pruning	If pruning other plants in this area, practice hygiene i.e. clean all clothing, tools and equipment before leaving the area.
Clearing, Digging & Construction	Practice safe transport and disposal of material i.e. transport material under cover then bury under 200mm of uninfected soil. Clean all clothing, tools and equipment when leaving.

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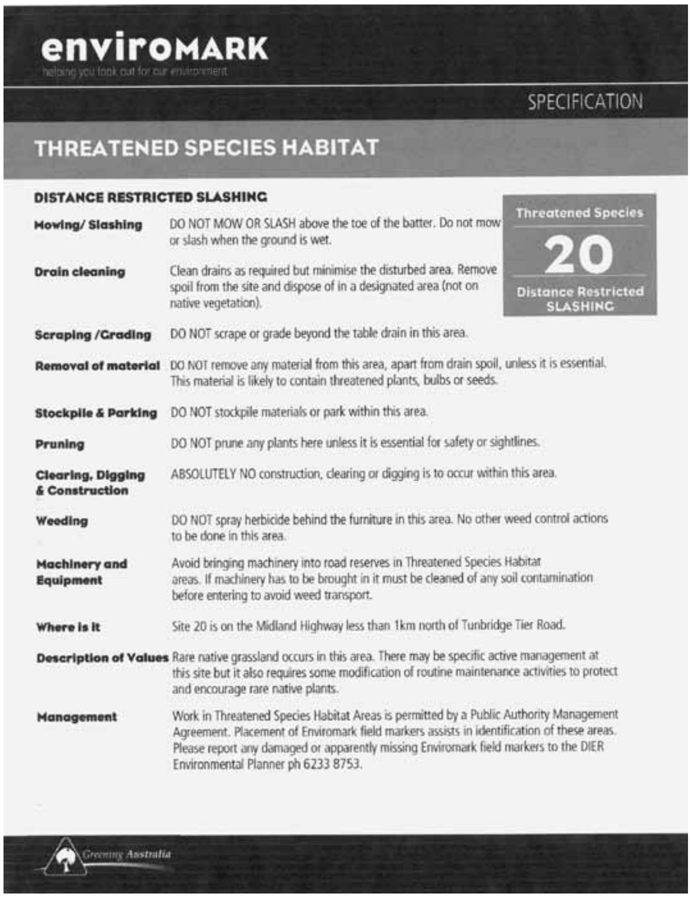
INDIGO

Figure 8. Specification for Chilean needle grass



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SPECIFICATION

THREATENED SPECIES HABITAT

DISTANCE RESTRICTED SLASHING

Threatened Species
20
Distance Restricted SLASHING

Mowing/ Slashing	DO NOT MOW OR SLASH above the toe of the batter. Do not mow or slash when the ground is wet.
Drain cleaning	Clean drains as required but minimise the disturbed area. Remove spoil from the site and dispose of in a designated area (not on native vegetation).
Scraping /Grading	DO NOT scrape or grade beyond the table drain in this area.
Removal of material	DO NOT remove any material from this area, apart from drain spoil, unless it is essential. This material is likely to contain threatened plants, bulbs or seeds.
Stockpile & Parking	DO NOT stockpile materials or park within this area.
Pruning	DO NOT prune any plants here unless it is essential for safety or sightlines.
Clearing, Digging & Construction	ABSOLUTELY NO construction, clearing or digging is to occur within this area.
Weeding	DO NOT spray herbicide behind the furniture in this area. No other weed control actions to be done in this area.
Machinery and Equipment	Avoid bringing machinery into road reserves in Threatened Species Habitat areas. If machinery has to be brought in it must be cleaned of any soil contamination before entering to avoid weed transport.
Where is it	Site 20 is on the Midland Highway less than 1km north of Tunbridge Tier Road.
Description of Values	Rare native grassland occurs in this area. There may be specific active management at this site but it also requires some modification of routine maintenance activities to protect and encourage rare native plants.
Management	Work in Threatened Species Habitat Areas is permitted by a Public Authority Management Agreement. Placement of Enviromark field markers assists in identification of these areas. Please report any damaged or apparently missing Enviromark field markers to the DIER Environmental Planner ph 6233 8753.

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Figure 9. A grassland threatened species specification

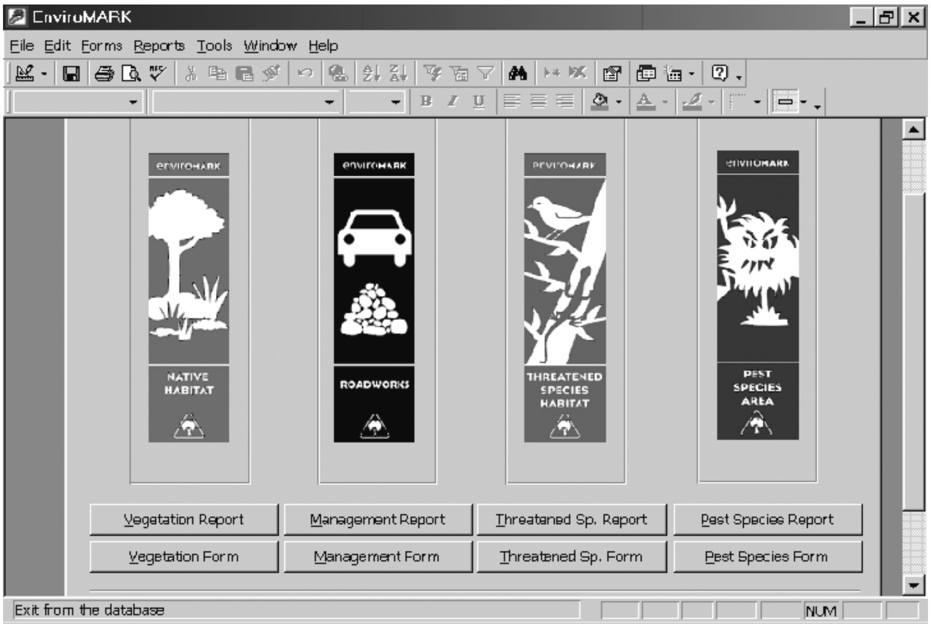

Figure 10. The main panel for the Enviromark database

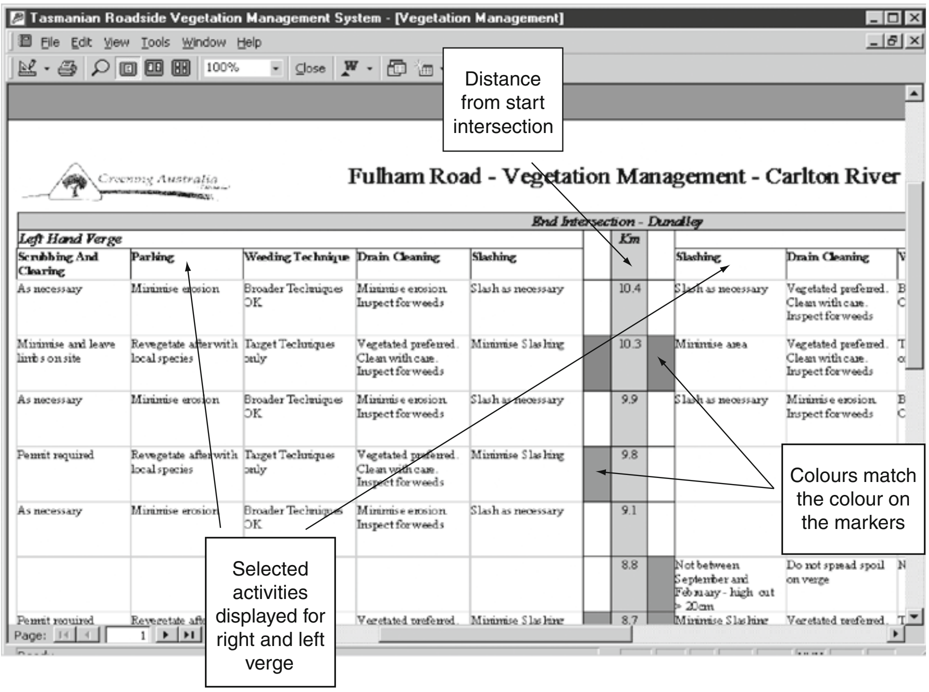

Figure 11. Schematic road maps generated by the Enviromark database. The central column represents the road with distance in kilometres from the start intersection shown where management areas start and finish. The column either side displays the colour that matches the colour on the roadside marker. Thus, red areas indicate Threatened Species Habitat Areas, green are Native Habitat Areas and purple are Pest Species Areas. On both sides are displayed the management activities selected and instructions on how that activity should be performed within that area

roadside vegetation and management information. It consists of a data entry and a display facility (Figure 10). The former is used for collecting inventory information on roadside vegetation and storing the locations and their associated management regimes. The display facility allows selected information to be displayed in schematic road maps (Figure 11). In this way a user can create maps for the area they are working in, for the job they are doing, as needed.

Descriptions of vegetation and management regimes are mostly entered via pick lists to ensure they are standardised. The database was developed in Access to provide mapping capability without the need for GIS expertise.

Monitoring

Monitoring system use

Each year the use of the Enviromark system needs to be reassessed, to check that it is being used properly, that the markers are in place and undamaged and that the problem(s) for which it was implemented are still being adequately addressed and still require the prescribed management, within the marked areas. The aim is to look for ways of improving the system and its use.

After five years the whole project should be reassessed and it is likely that the roadsides will need to be re-mapped. Hopefully there will be less weeds to manage and you have an informed and empowered road workforce that is making a difference to managing significant areas on roadsides.

For more information, contact Christine Corbett, Greening Australia Tasmania, 110 Hampden Road, Battery Point, Phone 03 6223 6377, or see our web page for more information www.greeningaustralia.org.au/GA/TAS/OnGroundAction/

Delivering strategic conservation outcomes through the integrated management of bitou bush, a Weed of National Significance

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Abstract Weeds pose the greatest threat to Australian biodiversity after land clearing. However, knowledge of the specific biodiversity threatened by weeds is currently inadequate, despite many major weed strategies aiming to reduce such impacts (e.g. the National Weeds Strategy). Thus, it is extremely important to obtain detailed information on the biodiversity threatened by weeds. A new approach adopted for the management of bitou bush (*Chrysanthemoides monilifera* subsp. *monilifera* (DC.) T.Norl.) in NSW provides a methodology for determining biodiversity at risk and a framework for reducing the impacts of weeds to biodiversity. This approach could be adopted for other widespread weeds, such as the Weeds of National Significance (WoNS), to enable targeted weed management for conservation purposes. The development of this approach required a strategic framework, such as the WoNS program, to gain access to on-ground networks across varying land tenures, and stakeholders. These networks provided valuable information during the planning stages, and are crucial for effective implementation of this approach.

Introduction

The severity of the impacts of invasive species (i.e. weeds and pest animals) to global biodiversity has been widely acknowledged (see IUCN 2000). While the impacts of invasive species on biodiversity can be documented through interactions like competition by weeds and predation by introduced carnivores (e.g. foxes), detailed information on the actual species impacted upon is not readily available (see Downey *et al.* 2004, also see below). This lack of data has contributed to a historically poor linkage between invasive species management and biodiversity conservation, especially from an on-ground perspective (Mahon 2000, Downey 2003). Reasons for this include: (i) invasive species management has not been aligned with available information on invasive species impacts to biodiversity (Mahon 2000); (ii) information on the species directly impacted by each invasive species is inadequate (Downey 2004); (iii) the varied legislative requirements for invasive species management – i.e. some species are listed under a range of Acts (e.g. Threatened Species Conservation and Noxious Weeds Acts), while others are not listed under any Acts (see Downey 2003); and, (iv) the separate historical management approaches of these two disciplines (Saunders *et al*. 1995, Downey 2003) .

Assessment of the impact of weeds to biodiversity

Historically, attempts to assess the impacts or risks of weed invasions to biodiversity have either been through specific scientific investigation (e.g. Weiss and Noble 1984a,b, French and Zubovic 1997, Matarczyk 1999, Vranjic *et al.* 2000) or reviews of such studies (e.g. Grice *et al.* 2004, Vidler 2004). To provide a more comprehensive assessment, recent work has focused on an examination of threatened species databases (see Coutts-Smith and Downey in press), as well as systematic reviews and consultation with stakeholders who have specific working knowledge of weeds and native species (DEC 2004, Downey 2004). These new approaches have significantly increased the number of species considered to be at risk from weed invasion. For example, a review by Vidler (2004) found 41 species threatened by weeds in Australia, while Coutts-Smith and Downey (in press) increased this number by an order of magnitude for NSW alone, using this new approach. Although, this study examined weeds collectively using existing datasets, a similar result was also achieved using the systematic review and consultation approach for a single weed species. The result of which was that the number of species threatened by bitou bush in NSW was found to be 25 times higher than previously recorded (see Downey 2004).

Here we outline the process/approach used to determine the species at risk from bitou bush in NSW and investigate the possibility of adopting this process for other target weeds (i.e. WoNS species). The other new approach is outlined in Coutts-Smith and Downey (in press). We also describe how information gained from these processes can be used to improve weed management strategies and deliver strategic outcomes at a national level through the WoNS program.

The Bitou Bush Threat Abatement Plan approach

In 1999, the 'invasion of native plant communities by bitou bush and boneseed' was listed as a Key Threatening Process (KTP) under the NSW *Threatened Species Conservation Act 1995*. This listing required the development of a Threat Abatement Plan (TAP) to abate, ameliorate or eliminate the threat posed by bitou bush to native plant communities. Prior to the development of the TAP, the number of species reported to be threatened by bitou bush was six (ARMCANZ *et al.* 2000). Given that bitou bush occupied approximately 80% of the NSW coastline (Thomas and Leys 2002), the number of species threatened was presumed to be much greater than six. A more accurate reflection of the species at risk was needed to meet the objectives of the TAP. To achieve this, a systematic review was undertaken which involved wide consultation and a series of workshops with botanists, weed managers and scientists to consider all species potentially at risk. A draft list of species at risk was then modelled to develop a set of priority species and circulated for wider comment and subsequent revision – attributes considered in the model were: (i) invasibility of the habitat, (ii) distribution of native species compared to that of bitou bush, (iii) native species susceptibility to invasion, and (iv) native species ability to persist in the environment. Information was then gathered from known locations with the distribution of these species to determine priority sites for control. This approach forms the basis of the draft NSW Bitou Bush Threat Abatement Plan (Bitou TAP; see DEC 2004) and has led to the identification of approximately 150 species and nine ecological communities at risk from bitou bush invasion in NSW. The Bitou TAP also identifies priority sites where the control of bitou bush will result in significant benefits for conservation, independent of land tenure (see Downey 2004).

Applying the TAP approach to other weeds

The TAP approach was developed for one of Australia's 20 worst weeds. It is not possible to develop a TAP for each environmental weed in Australia; however it may be feasible to develop a TAP for each of the Weeds of National Significance (WoNS).

Weeds of National Significance

In 1997, the Australian Government launched the National Weeds Strategy (NWS: ARMCANZ *et al.* 1997) to help deliver strategic and consistent weed management of weeds throughout Australia. One of the three goals in the strategy is to 'reduce the impact of existing weed problems of national significance'. To meet this goal, a list of nationally significant weeds was needed (Objective 2.2 of the NWS). Twenty Weeds of National Significance (WoNS) were identified from an initial list of 71 weeds (see Thorp and Lynch 2000). The WoNS include environmental, agricultural and aquatic weeds. Since the initiation of the WoNS programs, significant work has been directed at WoNS management, including the development of a National Management Strategy for each WoNS. These National Strategies describe a range of impacts attributed to weed invasions, including: (i) environmental, (ii) agricultural, (iii) economic, and (iv) human health impacts. Impacts to biodiversity, or environmental impacts, can be either direct (e.g. competition) or through modification of ecosystem processes (e.g. alteration of disturbance regimes like fire (see Gordon 1998, Mack and D'Antonio 1998)).

Despite the goal of the NWS to reduce the impact of WoNS, little has been done to establish the individual impact of these weeds, particularly to biodiversity. Here we examined information and actions on the impacts to biodiversity for each of the 20 WoNS as presented in the National Strategies (see ARMCANZ *et al*. (2000a–g, 2001a–l, 2003). For the purposes of this review, only actions with specific reference to biodiversity/conservation were examined. Many of the National WoNS Strategies do not identify the biodiversity at risk in a manner that can be used to deliver effective management (see Table 1). For example, many of the WoNS only provided information at a generalised level (i.e. grasslands are at risk from invasion). In addition, a specific section on minimising impacts (or similar wording) within the strategic framework (i.e. objectives and actions) was not included in some of the national strategies (see Table 1). One Strategy, viz. athel pine, did not include any action for reducing the impacts to biodiversity (Table 1). While in many cases the reduction of impacts is implied, it is not clearly identified in some of the strategies. Thus, if we are to meet the goal of the NWS, an assessment of the impacts to biodiversity is needed for the WoNS, especially those that are classified as environmental weeds.

Listing WoNS as key threatening processes (see Downey and Leys 2004) can result in significant increases in our knowledge of the species at risk as highlighted by Downey (2004). The listing of specific WoNS as KTPs is an action in four national strategies viz. bridal creeper, cabomba,

Table 1. The biodiversity identified at risk, and information on the associated actions to reduced such impacts as outlined in the 20 WoNS strategies[A]

Weed of National Significance	Weed type[B]	Number of threatened species reported	Number of threatened ecological communities reported	Number of other biodiversity values reported to be impacted (e.g. grasslands)	Summary on impacts[D]	Section in strategic plan (section 2) on mimising impacts[D]	Number of actions relating to reducing impacts to biodiversity. Total number of actions outlined in brackets
alligator weed	Aq/Ag	0	0	1	yes (1.3)	no	3 (50)
athel pine	Ag/E	0	0	6	yes (1.3)	no	0 (43)
bitou bush/ boneseed	E	19	2	7	yes (1.3)	yes (2.2)	6 (38)
blackberry	E/Ag	0	0	0[C]	yes (1.3)	no	1 (23)
bridal creeper	E	1	0	1	no[E]	yes (2.3)	7 (71)
cabomba	Aq	0	0	5	no[E]	yes (2.3)	2 (49)
Chilean needle grass	Ag	3	0	3	yes (1.3)	no	2 (36)
gorse	E/Ag	0	0	2	no[E]	no	2 (46)
hymenachne	Aq/Ag	0	0	2	no[E]	yes (2.2)	1 (40)
lantana	E/Ag	5	0	67	no[E]	yes (2.1)	1 (42)
mesquite	E/Ag	0	0	2	no[E]	yes (2.2)	1 (78)
mimosa	E/Ag	2	0	4	yes (1.3)	yes (2.4)	2 (48)
parkinsonia	Ag/E	0	1	19	no[E]	no	3 (64)
parthenium weed	Ag/E	0	0	4	no[E]	yes (2.3)	2 (40)
pond apple	E	5	0	32	no[E]	no[F]	3 (72)
prickly acacia	E/Ag	25	0	1	no[E]	yes (2.2)	2 (60)
rubber vine	E/Ag	4	13	15	no[E]	yes (2.2)	1 (51)
salvinia	Aq	0	0	5	yes (1.3)	yes (2.3)	3 (45)
serrated tussock	Ag/E	0	0	0	yes (1.2)	yes (2.2)	2 (18)
willows	E/Ag	1	1	3[C]	no[E]	no	3 (41)

[A] Information derived from ARMCANZ *et al.* (2000a–g, 2001a–l, 2003)
[B] Ag = agricultural weed, E = environmental weed, Aq = aquatic weed
[C] Mention of widespread 'impacts' without references to specific species or ecological communities
[D] Number in parentheses are section numbers in the National Strategy
[E] No section entitled impacts, rather information on impacts is contained under a section entitled 'Weed of National Significance'
[F] Not mentioned, however there is a section entitled '2.1 alert the community to the impact and seriousness of pond apple'

mimosa and pond apple (see Table 2), while bitou bush/boneseed is already listed in NSW (see above).

The threat abatement planning approach can be used to increase knowledge of the species at risk (see Downey 2004). While identification of the species at risk is a crucial component of a TAP, additional components are required for effective implementation of a TAP, which include: (i) understanding where those species at risk occur with respect to the distribution of the weed; (ii) involving all stakeholders in the management of priority species at priority sites; (iii) creating site-specific management plans for each site, and; (iv) ensuring holistic weed management continues at all priority sites. This approach is being developed for bitou bush in NSW through the Bitou TAP (see DEC 2004).

Bitou bush and boneseed WoNS program

Bitou bush and boneseed (*Chrysanthemoides monilifera* subsp. *rotundata* (L.) T.Norl.) were identified as one of the WoNS (Thorp and Lynch 2000). Following this determination, the NSW National Parks and Wildlife Service (now part of the Department of Environment and Conservation) agreed to act as the host agency for the national program. A National Strategy was developed (see ARMCANZ *et al.* 2000) and a National Coordinator appointed to administer actions within the Strategy. To date, significant progress has been made towards actions outlined in the National Strategy, however, significant work is still needed to tackle the impact of bitou bush and boneseed throughout Australia. Through the National Coordinator, the bitou bush and boneseed WoNS program can foster effective weed management and conservation outcomes nationally by coordinating integrated weed management (IWM) and planning activities across states, regions and land tenures. This coordinated approach is highlighted through a number of key strategies, one of which is the draft NSW Bitou Threat Abatement Plan (TAP).

The Bitou TAP has established an integrated approach to weed management using best-practice principles to deliver conservation outcomes to those species most at risk. The threat abatement planning process outlined in the Bitou TAP may provide a good premise for achieving biodiversity conservation outcomes through IWM principles aimed at reducing the distribution, abundance and biodiversity impacts, which could be adopted more broadly.

Applying this approach to other WoNS species

The Bitou TAP approach, of identifying the species/biodiversity at risk and priority locations to enable the greatest conservation benefits, could be adopted for WoNS. For example, the Bitou TAP approach was trialled recently for lantana in northern NSW/southern Queensland, in conjunction with the National Lantana Coordinator. Results of this trial are very promising, with a significant increase in the number of species at risk (i.e. from 21 to over 160 species). Despite a few minor modifications, this trial indicated that the Bitou TAP approach appears to work for lantana. Thus, further examination is warranted to see if the Bitou TAP approach can be applied more broadly to other WoNS.

Summary

Improving our understanding of the biodiversity threatened by weeds has significant implications for managing weeds. For example specific conservation outcomes can be established within weed management strategies (e.g. control of bitou bush to protect littoral rainforests). The Bitou TAP identifies the species at risk as well as establishing a framework for delivering on-ground conservation outcomes. Based on our experiences during the development and implementation of the Bitou TAP, this approach could be used as a mechanism to reduce the impacts of other WoNS to biodiversity.

Acknowledgements

Comments by Aaron Coutts-Smith and Andrew Leys on an earlier version were greatly appreciated.

References

ARMCANZ (Agriculture and Resource Management Council of Australia and New Zealand), ANZECC (Australian and New Zealand Environmental and Conservation Council) and Forestry Ministers (1997). The National Weeds Strategy: A strategic approach to weed problems of national significance. (Commonwealth of Australia, Canberra).

ARMCANZ (Agriculture and Resource Management Council of Australia and New Zealand), ANZECC (Australian and New Zealand Environmental and Conservation Council) and Forestry Ministers (2000a). Weeds of National Significance Alligator Weed (*Alternanthera philoxeroides*) Strategic Plan. (National Weeds Strategy Executive Committee, Launceston).

ARMCANZ (Agriculture and Resource Management Council of Australia and New Zealand), ANZECC (Australian and New Zealand Environmental and Conservation Council) and Forestry Ministers (2000b). Weeds of National Significance Bitou Bush and Boneseed (*Chrysanthemoides monilifera* ssp. *rotundata* and *monilifera*) Strategic Plan. (National Weeds Strategy Executive Committee, Launceston).

ARMCANZ (Agriculture and Resource Management Council of Australia and New Zealand), ANZECC (Australian and New Zealand Environmental and Conservation Council) and Forestry Ministers (2000c). Weeds of National Significance Cabomba (*Cabomba caroliniana*) Strategic Plan. (National Weeds Strategy Executive Committee, Launceston).

Table 2. Specific actions relating to listing WoNS as KTPs in the 20 National Strategies [A]

Weed of National Significance	Strategy in plan relating to reducing impacts to biodiversity	Actions in plan relating to reducing current impacts to biodiversity
bridal creeper	2.1.3 – apply for bridal creeper to be listed as a Key Threatening Process under Commonwealth environment legislation	Prepare a submission to Environment Australia
cabomba	2.3.4 – quantify the impacts of cabomba	Identify if cabomba is a threatening process under federal biodiversity legislation
mimosa	2.2 – implement land management strategies that decrease the susceptibility of land to mimosa invasion	Present the case for recognising mimosa as a key threatening process under the *Endangered Species Protection Act 1992*
pond apple	2.1.3 – nominate pond apple as a key threatening process	Collate information required to nominate the impacts of pond apple invasions to Environment Australia as a key threatening process under Commonwealth legislation

[A] Information derived from ARMCANZ *et al.* (2000c, 2000e, 2001c, 2000i)

ARMCANZ (Agriculture and Resource Management Council of Australia and New Zealand), ANZECC (Australian and New Zealand Environmental and Conservation Council) and Forestry Ministers (2000d). Weeds of National Significance Hymenachne (*Hymenachne amplexicaulis*) Strategic Plan. (National Weeds Strategy Executive Committee, Launceston).

ARMCANZ (Agriculture and Resource Management Council of Australia and New Zealand), ANZECC (Australian and New Zealand Environmental and Conservation Council) and Forestry Ministers (2000e). Weeds of National Significance Mimosa (*Mimosa pigra*) Strategic Plan. (National Weeds Strategy Executive Committee, Launceston).

ARMCANZ (Agriculture and Resource Management Council of Australia and New Zealand), ANZECC (Australian and New Zealand Environmental and Conservation Council) and Forestry Ministers (2000f). Weeds of National Significance Salvinia (*Salvinia molesta*) Strategic Plan. (National Weeds Strategy Executive Committee, Launceston).

ARMCANZ (Agriculture and Resource Management Council of Australia and New Zealand), ANZECC (Australian and New Zealand Environmental and Conservation Council) and Forestry Ministers (2000g). Weeds of National Significance Serrated Tussock (*Nassella trichotoma*) Strategic Plan. (National Weeds Strategy Executive Committee, Launceston).

ARMCANZ (Agriculture and Resource Management Council of Australia and New Zealand), ANZECC (Australian and New Zealand Environmental and Conservation Council) and Forestry Ministers (2001a). Weeds of National Significance Athel Pine (*Tamarix aphylla*) Strategic Plan. (National Weeds Strategy Executive Committee, Launceston).

ARMCANZ (Agriculture and Resource Management Council of Australia and New Zealand), ANZECC (Australian and New Zealand Environmental and Conservation Council) and Forestry Ministers (2001b). Weeds of National Significance Blackberry (*Rubus fruticosus* L. agg.) Strategic Plan. (National Weeds Strategy Executive Committee, Launceston).

ARMCANZ (Agriculture and Resource Management Council of Australia and New Zealand), ANZECC (Australian and New Zealand Environmental and Conservation Council) and Forestry Ministers (2001c). Weeds of National Significance Bridal Creeper (*Asparagus asparagoides*) Strategic Plan. (National Weeds Strategy Executive Committee, Launceston).

ARMCANZ (Agriculture and Resource Management Council of Australia and New Zealand), ANZECC (Australian and New Zealand Environmental and Conservation Council) and Forestry Ministers (2001d). Weeds of National Significance Chilean Needle Grass (*Nassella neesiana*) Strategic Plan. (National Weeds Strategy Executive Committee, Launceston).

ARMCANZ (Agriculture and Resource Management Council of Australia and New Zealand), ANZECC (Australian and New Zealand Environmental and Conservation Council) and Forestry Ministers (2001e). Weeds of National Significance Lantana (*Lantana camara*) Strategic Plan. (National Weeds Strategy Executive Committee, Launceston).

ARMCANZ (Agriculture and Resource Management Council of Australia and New Zealand), ANZECC (Australian and New Zealand Environmental and Conservation Council) and Forestry Ministers (2001f). Weeds of National Significance Mesquite (*Prosopis* species) Strategic Plan. (National Weeds Strategy Executive Committee, Launceston).

ARMCANZ (Agriculture and Resource Management Council of Australia and New Zealand), ANZECC (Australian and New Zealand Environmental and Conservation Council) and Forestry Ministers (2001g). Weeds of National Significance Parkinsonia (*Parkinsonia aculeata*) Strategic Plan. (National Weeds Strategy Executive Committee, Launceston).

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Gorse task force

Jeanette Bellchambers, Gorse Task Force, RMB 1250, Shelford, Victoria 3329

In general, it is pretty much, a take it or leave it attitude with weeds in our community.

The situation of weeds abounding in many locations creates much discussion and inevitably, they are always someone else's problem and responsibility.

Some of the most common weed statements that we are all familiar with are:

- It is the Governments problem because we used to have those people who came along and sprayed the roadside weeds regularly.
- It is a neighbours problem, because they are quite neglectful and seem to do nothing about a particular problem weed.
- It is a Local Government problem, because we didn't have those weeds in our locality until there was that heavy machinery work, the movement of gravel or re-sheeting of the road.
- Not to mention the state of many Crown Land Reserves – so why doesn't Landcare do something about that!

Gorse Task Force

Gorse was deliberately introduced into Australia in the early 1800s and used extensively for hedgerows and has grown out along hundreds of kilometres of fence line. Eventually it invaded many stream and river locations and as a legacy of extensive mining around Ballarat, in any disturbed areas of soil, it readily established. So comfortable was the Ballarat locality with gorse, that the Ballarat region was possibly the largest operating maze of roadside and riparian gorse.

In 1998 a small but representative group, mainly the central highland Local Government region, a number of Landcare groups, some really committed people and the then Department Natural Resources and Environment (DNRE) formed the community driven – Ballarat Region Gorse Task Force (BRGTF).

Looking back on our early achievements…

These were very optimistic times, with a small budget of about $50 000, which enabled two facilitators working part time, 2–3 days per week and considerable DNRE operational support. Each year our primary funding source has been Second Generation funding from the State Government's Victorian Landcare Program. The task had begun, tackling the huge infestations of gorse in the Ballarat region.

In 1999, a Gorse Control Strategy was developed, one of the main aims is to increase community awareness of responsibility and possible control options – thereby, overall reducing infestations of gorse. The two principle goals of the strategy are:

1. Reduce overall extent of gorse within the GTF area by 25% within five years (2000 ha).
2. Reduce the extent of gorse by 15% within five years on all roadsides and waterways (1000 ha).

Ballarat Region Gorse Task Force, as it was then known, focuses on targeted agricultural areas that are nominated by Landcare groups. A small financial incentive is paid to the landholder, towards gorse clearance costs in roadside and riparian locations; as this delivers the greatest public benefit in reducing the spread of seed, but removal of gorse on the landholders adjoining property is at their own expense.

The facilitation component of Task Force operation is an important part of the interaction and guidance process. This enables the two parties to develop a Work Plan Agreement (WPA) which is an agreement between the facilitator and landholder about how and when the work is to be achieved. This agreement allows latitude and is considerate of the landholder's circumstances – it is usually preceded by letters, individual contact and the actual WPA allows at least 2–3 months for the control work.

With support from Corangamite, Glenelg /Hopkins, and North Central CMAs a co-operative roadside program was established that involved Local Government areas around Ballarat and in some cases dollars were matched by that shire, increasing roadside outcomes.

Change began to occur…

In 2001, Gorse Control Strategy was adopted as an Interim Statewide Strategy for Victoria after the BRGTF committee successfully gained Weeds of National Significance (WoNS) funding of $615 000 for 2002–2004 years of operation.

Part of this funding enabled a greater emphasis on removing Gorse from the Ballarat region and really accelerated our Ballarat program. WoNS funding benefited many other strategic locations across the state, allowing GTF to target gorse infestations from the South Australian border, across to Gippsland. The Gorse Task Force (GTF) now named because of this statewide approach managed the WoNS process.

Weeds of National Significance and DSE Good Neighbour program allow work to be achieved on public land and 75 ha of public land is under long term gorse control as a result. The GTF encourages projects to involve all land managers whether freehold, linear managers such as Vic Rail and Vic Roads, DSE and Parks Victoria.

During the time of GTF operation 1782.2 ha of gorse has been treated from 121 708 ha of agricultural land in the South West region, involving 6500 properties and a similar number of landholders.

An extremely rewarding result for the GTF Committee who are representatives from the 40 Landcare groups, three CMA regions of Corangamite, Glenelg/Hopkins and North Central and the six Local Government areas of Golden Plains, Ballarat, Ararat, Hepburn, Pyrenees and Moorabool.

Clearly, additional change has occurred outside of target areas because of the influence of target area work. This supports the fact that, while we do nothing there will be no change, we stay 'comfortable' with weeds in our environment, but when change occurs it inspires others to do something about their weeds!

In July 2004, the GTF invested in the evaluation of the Gorse Control Strategy (GCS) with the evaluation split into two distinct components:

1. The use of an independent consultant to provide the GTF a clear picture of its partners and stakeholders satisfaction with current programs, and to highlight issues with these programs that need to be addressed.
2. A desktop study to determine progress towards the key actions outlined in the GCS.

The GTF has evolved over the five years, adapting to the complexities of funding changes, improving the operational process with Landcare groups and harnessing new partners in the task of gorse reduction.

However, it has not been all clear sailing!

Gorse Task Force is constantly challenged by the lack of clarity with *The Catchment and Land Protection Act* (*CaLP Act*) and in particular the roadside responsibility issue for regionally controlled weeds on undeclared roads. We have been able to advance this situation with funding from the Department of Sustainability and Environment for an Interim Roadside Program. This has enabled six Local Government regions to arrange control work on priority roadsides and protect previous investment in these locations.

Each year the uncertainty of continuing funding is disruptive to our programs. Considerable legal training for facilitators working under the *CaLP Act*, short-term tenure and twelve-month employment arrangements do not deliver the best return for the dollars invested.

The GTF has also realised that when work is undertaken in an area, return and possible follow-up of that area, must remain for several years to achieve permanent change.

As well as those who invest in our work, we also want the best outcome for the dollars invested; weeds are possibly our greatest Natural Resource Management challenge and need long term support and focus. The GTF realises there is much more work still to be done, but it is possible to see considerable change in and around Ballarat

To secure the process…

Weed action needs to be fair but **F.I.E.R.C.E.** and most of these six components have helped the GTF deliver success!

Facilitation – one on one with landholders, facilitators work with many community members who are not necessarily Landcare members. Facilitators work with Landcare executive committees to estimate gorse infestations and calculate incentive payments, this helps build human capacity at many levels and has helped to lessen the burden on Landcare groups.

Information – there has been an increasing number of calls to DPI requesting information on gorse control and many requests for assistance in urban and small township areas. Urban areas are presently not the focus of the Gorse Control Strategy and the restrictions of funding limit control work to designated areas. The GTF are presently supporting the feasibility of an existing Local Government By Law, that could assist the clean up of gorse in township locations.
In 2001, GTF printed 30 000 brochures (sponsored by Dow AgriServices) detailing the options for gorse control, (not just chemical) – so great was the demand, we had to get another 20 000 printed!

Education – about changing the landscape from weed encroachment and the apathy that allows it to happen. This is the interaction fore front that can inform of productivity benefits and establishes the continuity of regular weed control. In partnership with Keith Turnbull Research Institute, GTF have assisted the Weed Warriors program that has operated the gorse spider mite breeding and release program involving school children at many schools.

Responsibility, this requires an attitude change, a responsibility to the landscape, to our many unique ecosystems, our neighbours and the broader region.

Compliance – from the first knock on the door, letter or phone contact, the landholder becomes part of the compliance process. This is what the community wants – everyone being involved, 'not just a scattergun approach'.

Enforcement – in fairness to the work planned, delivered and those of the community who accept the challenge and do the work, enforcement is a necessary push for a minority. Often it is only the threat of enforcement that gets the work done.

F.I.E.R.C.E. is the acronym for – everyone desiring and working towards the goal of weed eradication. The benefit is that, all the stakeholders desire the same outcome – we all want a reduction in weed infestations.

Because weeds are everyone's problem!

To achieve this united outcome requires an integrated approach. We need stronger partnerships with State and Local Government, Catchment Management Authorities, Landcare and the broader community, to work towards this goal.

Every partner needs to be sending out the same message, encouraging better land management, which delivers productivity benefits but most importantly, enforces landowner responsibility.

Weed Warriors – engaging and empowering the community

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Summary Weed Warriors is a community engagement and empowerment program that focuses on joining together regional stakeholders, local schools and community groups to tackle local weed problems.

The program is a proud Victorian initiative, commencing as a pilot program in 2001 and representing the culmination of almost ten years experience of DPI/DSE researchers, catchment management and extension officers and land managers. In 2002, the program was launched nationally through the support of the CRC for Australian Weed Management, and to date over 180 networks of participants across Australia are proud to call themselves Weed Warriors.

Keywords Weed Warriors, biological control, community engagement and empowerment.

Introduction - what is Weed Warriors?

Weed Warriors is an innovative national community engagement program, supported by the Department of Primary Industries and the Cooperative Research Centre for Australian Weed Management that aims to enhance community awareness of and involvement in local weed issues.

The programs focus is on linking school students, the land managers of the near future, with a network of regional stakeholders and community groups, and empowering and engaging them all in weed management through a series of ongoing practical hands-on experiences based on biological control. (Biological control is the management of a weed using natural enemies from the weed's country of origin). The experiences are designed to take the program participants beyond knowledge to action and help to encourage a sense of connection to and responsibility for their natural environment.

Through the program, school students are given the unique opportunity to participate in real life weed research and control programs within and beyond the classroom. As Weed Warriors students become actively involved in the management of a local weed problem when they take on the task of breeding, in their classroom, a biological control agent required for the research and control program.

As part of the program, students are provided with an insectary and a colony of agents, and are taught the skills needed to breed them. The students then take on the role of 'weed scientists' and turn their classroom into a mini 'research institute' as they investigate and research the relationship between living things by direct observation and active participation. After rearing the agents for a period of time, the students release them at weed infestations localised to the school in collaboration with the network of regional stakeholders and community groups, helping to make a valuable contribution towards addressing a weed problem in their own community.

The structure of the Weed Warriors program

The Weed Warriors program is designed to run for at least four weeks and consists of an initial classroom session, the breeding phase and concludes with a field-based activity. A follow-up activity is recommended six to twelve months after the conclusion of the program.

The initial classroom session

The initial classroom session is usually of one hour duration and is aimed at increasing the student's knowledge of weed related issues, linked both to their local community and a wider context and introducing them to various weed management tools including biological control. The initial classroom session is supported by visits from members of the local community and those willing to act as mentors to the students.

Through the initial classroom session, students are taught the skills needed to breed the biological control agents for the chosen target weed. The weed species targeted and biological control agent reared will depend on what weed problems occur in the local area and the availability of agents for those weeds.

The breeding phase

The breeding phase of the Weed Warriors program generally lasts four to six weeks. During this time students become responsible for the breeding of the biological control agents and making basic observations about the biological control agent's life cycle and its impact on the target weed. Duties include watering and providing quantities of the weed to act as a food source. The agents chosen for the program are highly visible in their impact and students are encouraged to measure their observable impact and report on what they find.

The field-based activity

The field-based activity is usually of two hours duration and centres on the release of the classroom reared biological control agents at a suitable weed infestation localised to the school. Media attendance at the event is encouraged as is attendance by parents and other interested parties. Through participating in the release event, students are given an opportunity to relate their classroom-based learning to a real-world experience.

The follow-up activity

An important follow-up activity is to involve the students in monitoring the establishment and spread of the biological control agents at the release site at least six or twelve months after their release.

The logic behind the Weed Warriors program

Weed Warriors represents a departure away from traditional education and awareness programs towards a new

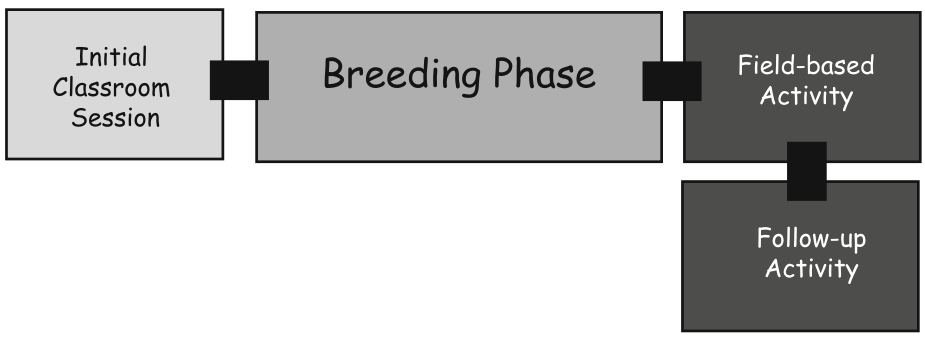

Figure 1. The structure of the national Weed Warriors program

	Anticipated Impact
Change in **SEE** conditions :	What change in **S**ocial, **E**nvironmental and **E**conomic conditions do you want to see as a result of the program?
Practice Change	What change in the participant's adoption of improved practices is required to bring about an 'end result' – a change in SEE conditions?
KASA Change	What change associated with participating in the program is needed in participants': **K**nowledge, **A**ttitudes, **S**kills, **A**spirations to bring about practice change?
Reactions	**How do people feel as a result of participating in the program?**
Participants	What are the characteristics of the people who are targeted for participation the program?
Activities	What activities (strategies, methods, events and communication efforts) will be used in the program to involve participants?
Resources	What resources (time, money, staff (including volunteers) will be used to plan, promote, implement, monitor and evaluate the program?

Adapted from the Program Evaluation Training Course Handbook, DPI 2005

Figure 2. A Bennett's Hierarchy highlighting the reactions category as the causal link between activity and change

methodology emphasising empowerment. Traditional education programs generally operate in the area of intellect and strive to increase the knowledge and understanding of a particular issue or set of issues. The Weed Warriors program acknowledges that increasing people's awareness of an issue without empowering them with the practical tools needed to become part of the solution to the problem can leave people feeling overwhelmed and disconnected, often leading to inactivity and at worst, apathy.

Consequently the Weed Warriors program is designed to take people from knowledge to action and encourages participants to develop a sense of connection to and responsibility for local places that is critical to bringing about lasting change.

A deeper understanding of how Weed Warriors works requires an investigation into the logic that underpins the program. While developing the Weed Warriors model significant thinking was employed to map the anticipated cause and effect relationship between the program's activities and the desired 'end result', in this case, a change in the way weeds impact on social, environmental and economic conditions in Australia.

The logic behind the Weeds Warriors' program was described using a Bennett's Hierarchy (Bennett and Rockwell 2002). Figure 2 illustrates the lay-out of the Bennett's Hierarchy used and illustrates the type of questions that were asked and answered in defining the core drivers of the Weed Warriors program.

Bennett's Hierarchy suggests that the skeleton of program design should acknowledge that we employ resources to generate activity for people to participate in and support the following assumption. Participants will develop a reaction associated with participating in the program's activities and that this reaction can lead to a change in their attitudes and behaviour.

The causal link between activity and change in a program lies in the realm of 'reactions', and of all the phases of a program, the generation of a reaction in participants is the most powerful catalyst and the most difficult to control. Program evaluators acknowledge that it is within the realm of reactions that 'miracles' occur, meaning that the invaluable contribution reactions make to the ultimate success of our programs is often elusive and little understood. Importantly the Weed Warriors program has developed an effective vehicle to harness this potent phenomenon.

The key to success?

Arguably the key to the success of the Weed Warriors program lies in its ability to consistently generate strong reactions in a diverse range of people. Building Weed Warriors on sound program logic has ensured that the program was developed with inherent empathy with the needs of program participants and is flexible and dynamic enough to ensure outcomes for a wide range of stakeholder groups.

Intensive evaluation of participants in the Weed Warriors program seeks to both quantify and qualify the way they react to the program, and to identify the change in their KASA as a result of Weed Warriors.

In the course of the Weed Warriors evaluation, program participants are asked to describe their reactions to the program by answering the following questions:

I found the Weed Warriors program *personally*:

Unrewarding ____2____3____ Very Rewarding

I found Weed Warriors program *professionally*:

Unrewarding ____2____3____ Very Rewarding

Importantly, 100% of all program participants surveyed (n=40 people) found the program professionally and **personally** very rewarding. Work is continuing to monitor how this positive reaction links to practice change and ultimately to 'end results'.

However the Weed Warriors program is designed to translate this strong emotive response into community empowerment and sustainable stakeholder engagement. While the program recognises children as the land managers of the near future it acknowledges that the development of regional stakeholder networks to facilitate and support their involvement in the classroom rearing and release of biological control agents is a powerful tool to achieve practice change in a diverse stakeholder group.

Conclusion

The national Weed Warriors program has proved itself an effective vehicle for engaging both students and the community in local weed management issues.

Its interactive approach has allowed students and the community to gain greater understanding and appreciation for the environment in which they live and the impact weeds have on it and us. The strength of the program lies in the development of supportive and mutually beneficial Weed Warriors networks of enthusiasm, experience and expertise to help create a program driven by empowered and engaged stakeholders.

Evidence based verses community driven Weed Action Plans

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Abstract Meeting expectations are the key to the success of any plan of action. All forms of investment are based on achieving a return on those resources invested through some form of change. If Weed Action Plans are to provide the basis for investment in weed management they must be able to demonstrate how they will meet expectations and provide return on investment. Community driven plans have the strength of ownership but may be susceptible if the outcomes they seek are not achievable. Evidence based plans provide the logic for weed management but may not represent the aspirations of the community in the location to which they apply. The success of any plan is dependent on the resources that are available to implement it, the likelihood of success and the acceptance of those stakeholders involved. All Weed Action Plans need to incorporate the ownership of the community based on logical and achievable outcomes.

Introduction

What are Weed Action Plans? In Australia at present there are a range of documents that could be classified as weed action plans. The various state and federal legislations that have provisions to deal with species of plants considered to be weeds are a form of action plan. The various state and federal strategies such as the National Weeds Strategy and in this state, the Victorian Pest Management Framework and the associated Victorian Weed Management Strategy, could be considered as weed action plans. At the regional level Catchment Management Authority Regional Weed Action Plans also comply with the definition. Species based strategies such as those for serrated tussock, gorse, blackberry, ragwort, and Chilean needle grass are also action plans for weeds. Localised programs that are articulated within a document of some form can also be defined as weed action plans as such.

The basis of most of these plans has been that they have been developed because the community has identified the need to strategically plan and implement weed management programs. The majority of these plans have been developed by the community on what they perceived are the species of plants that present the greatest threat and have the most impact. In recent times there has been the recognition for the need to base decisions about weed management around assessing the actual threat that these plants present through a vigorous understanding of the plant's capacity to invade and cause impact. This thinking has been clarified through the Victorian Weed Management Strategy (VWMS) under the Victorian Pest Management Framework with key objectives being to 'assess the threat and risk posed by new plant species with weed potential' and to 'assess the current and potential impact of existing weed problems in Victoria'. Strategic action nine of the VWMS is to assess the benefits and costs of weed management. The required action to achieve this is to 'develop a decision-making process for investment in weed management that considers economic, environmental and social values'.

Background

Australia's first noxious weed legislation was enacted in South Australia in 1851 through an 'Act for Preventing the Further Spread of the Scotch Thistle' (Parsons and Cuthbertson 1992).

In Victoria over recent years weed management has taken a more strategic focus, this focus has been articulated through the development of weed action plans. Prior to this approach being adopted weed management was very much the responsibility of the individual land manager, with the consequence of their management and its associated impact, not being considered by the community as a whole. Government intervention on behalf of the community occurred through the provisions of noxious weeds legislation where land managers could be required to comply with managing species of plants declared under such legislation.

In Victoria the first concerted effort to develop regionally based weed action plans occurred at the turn of last century. The provisions of the Catchment and Land Protection Act state that a Catchment Management Authority has the function to prepare a regional catchment strategy for the region and to co-ordinate and monitor its implementation. Regional Weed Action Plans were seen by government to be an appropriate mechanism to ensure that the weeds deemed by the community of that region to present the greatest threat to the values of that region, were dealt with in a strategic, cost-effective manner.

Discussion

With all the effort that has been put into managing weeds in Australia since European settlement, why are weeds still a problem? There are believed to be about 2700 naturalised species of non-native plants in this country. Thirty percent of these (798) are considered to be a major problem (Groves *et al*. 2003). Introduced plants are perceived in different ways by different individuals, what is seen as being a useful plant by one individual or group is seen as a serious threat by others.

Perceptions of individuals, groups and the community provide the drivers as to why plants are considered weeds. To rural communities plants that effect primary industries such as agriculture, horticulture, animal production and forestry reduce economic output and have a direct effect on those communities are considered to be weeds. Users of waterways, irrigation and drainage systems consider plants that hinder fishing, reduce flows, effect water quality and effect habitats to be weeds. Plants that effect human or animal welfare are considered by those affected to be weeds. Plants that are fire hazards, reduce aesthetic values, impede visibility or cause structural damage are considered to be weeds. Plants that adversely affect the integrity, conservation value or diversity of natural ecosystems are viewed as weeds within that context.

A plant is not necessarily a weed in all circumstances, it is only when it is having an adverse impact that its weedy attributes comes to the fore. Some plant species have this propensity in a number of situations due to their physiology (spiny or injurious), their habit (smothering) or their biochemistry (odour, poisonous, allergenic) and these are generally considered our worst weeds. On the other hand some plants only cause impact in certain situations, so if they are not occurring in locations where they can cause this impact or have the potential to cause impact, they are not necessarily weeds.

Given that not all introduced plant species are weeds and that some plant species are only considered to be weeds when they cause an impact on something that an individual or the community values, for Weed Action Plans to be effective they need to consider this. Another consideration is that weeds need to be managed to minimise their impact and that all forms of management have a cost, then utilising the available resources to manage them in the most cost-effective, efficient manner should be the outcome sought by any Weed Action Plan. A Weed Action Plan that does not consider these factors will be unlikely to succeed.

What then is a community driven Weed Action Plan and how is it different to an evidence based plan? Traditionally, community driven plans concentrate on dealing with weeds that the community perceives as being a threat to the things they value, i.e. Paterson's curse is a serious weed that has invaded large areas of Australia therefore we need to deal with it. These plans usually apply to a geographic region or to a particular species of plant. They are generally developed by a group of individuals who have a common need and are embraced by those involved in their development. When large segments of the community or the majority of the population from a geographic area are involved, these plans can be powerful drivers for change.

Evidence based plans tend to use decision support processes based on robust information to decide when interventions against weeds need to take place. Such evidence can come from science (invasiveness, suitable climate, suitable situations, vulnerability of ecosystems to invasion), economics (cost to production, cost to manage, cost-benefit) and social values (recreation, amenity, cultural). The major strength of these plans is that they can readily justify investment and clarify benefit to investors.

Government has increasingly applied the 'beneficiary pays' principle for assigning the costs of natural resource rehabilitation programs, including weed control. The principle states that the costs are assigned to the beneficiaries, be they private individuals or the local or national community. It is generally held that investment in weed management by the government should not seek to replace private investment, but should seek to leverage private investment to ensure a coordinated approach to weed management can be implemented so that the spread of weed populations is reduced.

There are significant public benefits from government investment in weed management – if such investment can make a difference in the rate at which weed populations spread through time. Every hectare invaded by weeds cause economic and environmental losses. This in turn has important social implications – reduced opportunities for wealth creation or investment opportunities in regional communities.

As the community's representative governments:

- Invest in weed management strategies that minimise the likelihood of new weed infestations from outside Victoria to the extent that the net gain to Victoria is maximised.
- Address market failure that leads to landowners not investing in weed management strategies in other land areas.
- Identify community outcomes where government investment is justified – based on assessment of private, industry and public beneficiaries.

Comment

The development of community driven plans can be vulnerable to being influenced by any prejudices of those who are involved in such development. Development of community driven plans are also vulnerable to being manipulated by sectors of the community to leverage individual gain through funding or other forms of resource allocation.

Alternatively, if the community do not have ownership of evidence based plans or are not supportive of the logic used, then these plans can be seen as an imposition and may not be supported. The notion of 'managing' weeds as opposed to 'eradicating' them is often against what the community has been conditioned to and is a culture that can be difficult to change.

Conclusion

There are pros and cons to both forms of Weed Action Plans and neither should be mutually exclusive. The strength of community driven plans is that if appropriate consultation occurs and the community to which these plans refer to is supportive then ownership by those practitioners who will play a major role in their implementation will greatly enhance the prospects of success. These communities must ensure that the outcomes they are seeking through the implementation of these plans are achievable within the constraints of available resources.

Evidence based plans provide a sound basis on what action to take over time and can be used to ascertain the resources that are required, but if the community to which these plans apply do not have ownership, then these too are vulnerable to failure.

Well-developed management plans should lay the foundations for a successful weed management program. Weed management plans can provide the following benefits:

- identification of the underlying causes of the weed problem(s) and associated issues,
- establishing priorities,
- identification of best management practices to address the causes of the weed problem(s),
- outlining the preferred outcomes from any action,
- increased coordination amongst stakeholders,
- community involvement and commitment,
- identification and acceptance of roles and the allocation of responsibilities,
- improved resource allocation, and
- increased monitoring and evaluation of actions.

Successful weed management requires a coordinated, strategic approach which can be more readily achieved through the widespread adoption of weed management plans. Planning provides the mechanism for integration and management of weed issues within a wider natural resource management context by addressing the causes, and not just the symptoms, of weed problems (LWBC undated).

Ideally a mixture of evidence based and community driven processes is the best approach to development and implementation.

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Understanding and managing weed effects on establishment of native tree seedlings in riparian zones

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Summary This paper reports early results of a field experiment in which cover of two exotic weed species was modified to examine the effect on seedling establishment of two native tree species. The weeds were blackberry (*Rubus fruticosus* agg.) and blue periwinkle (*Vinca major*). Both commonly form extensive near-monocultures in riparian zones. Blackwood (*Acacia melanoxylon*) and manna gum (*Eucalyptus viminalis*) were the native tree species. Experiments were set up in October 2004 at six riparian sites in southern Victoria. Three sites were used for each weed. Treatments consisting of 0, 40, 80 or 120 cm diameter gaps in the weed cover were planted with seedlings of either blackwood or manna gum. Once created the gaps were allowed to close up without further interference. There were six replicate plots of each treatment per site, giving a total of 48 plots per site.

Overall survival to March of manna gum (30%) was much less than that of blackwood (74%). There were very highly significant effects of tree species and gap size and a significant influence of weed species. Initial seedling size had no significant influence on survival. Generally seedlings of both species were taller at blue periwinkle sites than at blackberry sites, across all gap sizes. Gap size was a significant factor for height of blackwoods but not for manna gums, however there were only three gap sizes for manna gum heights, due to death of all manna gums in zero gap plots. Results from the remainder of the experiment will be useful for prioritisation of weed species for management. The results will also define the minimum weed-free space that must be created when planting different native trees

Introduction

The riparian zone is the interface between terrestrial and freshwater systems and can be defined as 'the area of land that adjoins, regularly influences, or is influenced by, a river' (DNRE 2002). In Victoria, as elsewhere in Australia, riparian vegetation communities have been degraded by a number of processes, and are particularly vulnerable to invasion by environmental weeds in comparison with other habitats (Humphries *et al.* 1991, Carr *et al.* 1992). The frequency of natural disturbance that creates the mosaic of habitats within the riparian zone is thought to contribute to the high invasibility of riparian communities by exotic species (Naiman and Decamps 1997).

It is often stated that weed species prevent the recruitment of native trees and shrubs in various habitats (e.g. Randall 1996, Muyt 2001), but empirical evidence to support such claims is often lacking. In riparian habitats, understanding the impact that weeds have on the recruitment of native trees is further limited by the paucity of information relating to the natural recruitment processes of key overstorey species. A study of weed cover and native seedling occurrence at riparian sites in Victoria (Ede *et al.* 2004) found that contrary to expectations, the abundant riparian weed blackberry (*Rubus fruticosus* agg.) did not appear to influence the abundance of native tree seedlings. Furthermore, high cover of some exotic groundcover plants was in fact associated with finding greater numbers of native tree seedlings. One reason for these findings could be that data were collected at a site (3000–4000 m^2) scale, whilst the assumed competition between exotic weeds and native tree seedlings occurs at a smaller scale.

This paper reports early results of an ongoing field experiment in which cover of two exotic weed species was modified and the responses of two species of native tree seedling examined. The weed species chosen were the shrub blackberry and the perennial herb blue periwinkle (*Vinca major*). Both of these species commonly form extensive near-monocultures in riparian zones. Blackwood (*Acacia melanoxylon*) and manna gum (*Eucalyptus viminalis*) were the native tree species used. Both of these trees are common in riparian vegetation but have very different phenologies. The objectives were to determine how different levels of weed cover affected the survival and growth of the native tree seedlings, whether the weeds differed in their effects and whether the two native tree species differed in their susceptibilities to competition from weeds.

Materials and methods

The experiments were set up at six riparian sites in southern Victoria, five in Gippsland and one on the Mornington peninsula. Three sites were used for blackberry and the remaining three for blue periwinkle. Experimental areas were chosen that as far as possible contained only the weed species of interest. With the exception of one blackberry site all had a canopy of mature native trees. Potential plot locations were marked out at each site and then assigned at random to one of eight treatments in a totally randomised design. Treatments were clearing of 0, 40, 80 or 120 cm diameter gaps in the weed cover, which were then planted with two seedlings of either blackwood or manna gum. One seedling of each pair was designated the primary plant for the plot and the other was a reserve plant to be used only in case of death of the primary plant. Due to a shortage of suitable blackwood seedlings not all blackwood plots had reserve seedlings. There were six replicate plots of each treatment at every site, giving a total of 48 plots per site. Seedlings had been purchased from a commercial nursery and were selected for uniform size and appearance. When planted in October 2004 mean the height of manna gum seedlings was 10.7 cm (range 6 to 20) and for blackwoods 7.6 cm (4 to 16). Remaining backup plants were removed in January 2005 unless the primary plant in the plot was dead, which happened in only six of 288 plots. Only data from primary plants are considered here.

Gaps in blackberry cover were created by cutting canes around a central marker to create a gap of the required diameter, with any canes arising within the plot cut at ground level. Root material was not removed because the resultant disturbance would have been excessive due to the deep rooting habit of blackberry. Since blackberry canes can grow up to 7 m in a single growing season it was considered that removal of root material within the plots would in any case have little effect on the rate of gap closure. Blue periwinkle gaps were created similarly but in this case the much shallower roots were removed. Once created the gaps were allowed to close up without further interference.

Seedlings were watered in and then covered with wire mesh guards to exclude browsing. No further watering was provided. Survival and height growth were recorded in November and December 2004 and January and March 2005. On each occasion remaining gap size was assessed by measuring the total remaining gap (any lengths greater than 10 cm) along four equally spaced diameters.

Number of surviving tree seedlings were analysed by logistic regression and seedling height data by analysis of variance after natural logarithm transformation.

Results

Seedling survival

Initial survival was good in all treatments and the majority of mortality occurred from January onwards. Overall survival to March of manna gum (30%) was much less than that of blackwood (74%). Figure 1a shows survival in different gaps sizes at blackberry sites. A third of the blackwood seedlings survived even without any gap in the weed canopy and when any size of gap was created, blackwood seedling survival exceeded 70%; in 120 cm gaps almost all blackwood seedlings survived. All manna gum seedlings died in zero gap blackberry plots, and survival progressively increased with increasing gap size up to 50% in 120 cm gaps.

Survival of both tree species was better at blue periwinkle sites (Figure 1b). Two thirds of blackwood seedlings survived even with no gap and this increased to almost 80% in a 40 cm gap. Manna gum survival was much lower with once again no survivors in zero gap plots and only around a third surviving in 40 or 80 cm gaps. However in 120 cm diameter gaps almost 90% of manna gums survived.

Within each group of three sites with the same weed there was no effect of site on tree seedling survival. Site was therefore removed as a factor in the analysis. There were very highly significant effects of tree species and gap size (P = 0.000) and significant influence of the weed species (P = 0.010). Initial tree seedling size had no significant influence on survival. When each tree species was considered separately, the weed species they had been planted into was not significant for blackwood and was only marginally significant for manna gum (P = 0.049).

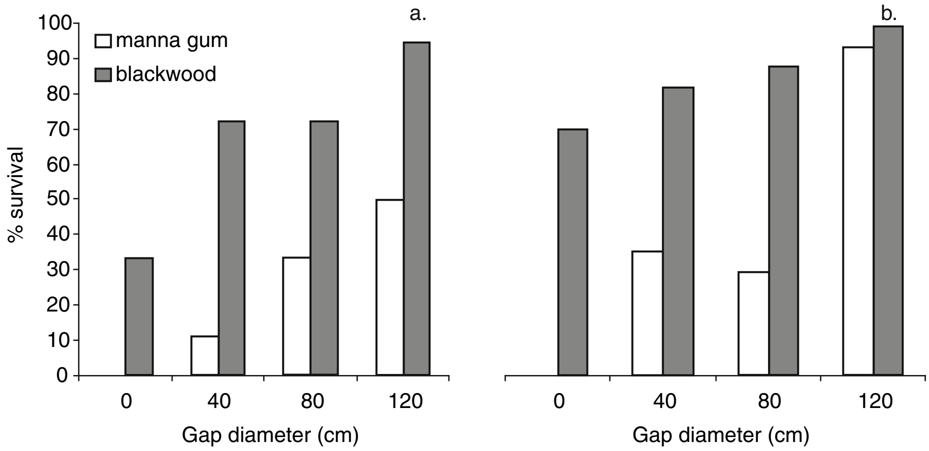

Figure 1. Percent survival of tree seedlings planted into (a) blackberry and (b) blue periwinkle

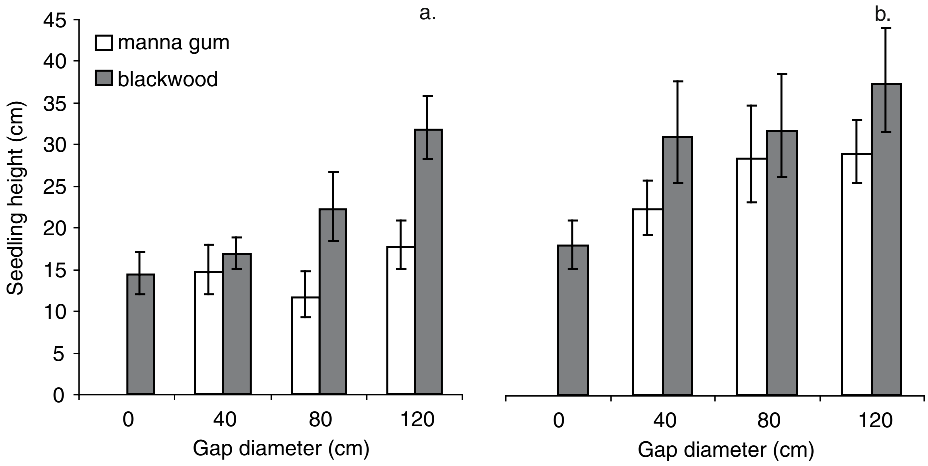

Figure 2. Mean heights (with standard errors) of tree seedlings planted into (a) blackberry and (b) blue periwinkle. Figures are back-transformed from logged data

Height growth

Seedling heights at blackberry sites are shown in Figure 2a. Blackwood seedlings were taller than manna gum seedlings in 80 and 120 cm gaps. Whilst blackwood seedlings tended to be taller as gap size increased this was not evident for manna gum seedlings. Figure 2b shows seedling heights at blue periwinkle sites. Blackwood seedlings appeared to be suppressed in zero gap plots but of a similar height in all other gap sizes. There was a tendency for blackwood seedlings in 80 and 120 cm gaps to be larger than the corresponding manna gum seedlings, but this was less strong than at blackberry sites. Generally seedlings of both species were taller at blue periwinkle sites than at blackberry sites (Table 1), across all gap sizes.

Table 1 shows the factors that had significant effects on seedling height. Unsurprisingly initial seedling height affected March height of both tree species and weed species was also a significant effect on both tree species. There was significant variation in height of both species due to differences amongst the three sites of each weed species. The site effect for both tree species was strongly influenced by poor growth at the Mornington peninsula blackberry site, where the overstorey of native trees was denser than at other sites.

Gap size was a significant factor for blackwoods but not for manna gums, but it is important to note that a much smaller number of plots still contained live manna gums (45 plots compared to 107 blackwood plots) and also that there were only three gap sizes for manna gum height measurements, due to death of all manna gums in zero gap plots.

Discussion and conclusions

The results from this trial which was designed to investigate the effect of weed competition on individual seedling survival and growth are consistent with blackberry suppressing growth and survival of

Table 1a. Anova of log-transformed blackwood seedling height.

	df	F	P
Gap size	3	9.8	0.000
Initial height	1	14.6	0.000
Weed species	1	6.5	0.012
Sites within weed species	4	4.4	0.002
Error	97		

Table 1b. Anova of log-transformed manna gum seedling height.

	df	F	P
Gap size	2	2.8	0.076
Initial height	1	9.1	0.005
Weed species	1	10.1	0.003
Sites within weed species	4	2.9	0.037
Error	36		

both tree species more than blue periwinkle and with manna gum seedlings being more susceptible to weed effects than blackwood. These findings support opinions from land managers that blackwoods are relatively tolerant of weed competition. It is too early to determine whether the seedlings that survived to March 2005 will establish successfully. Blue periwinkle at these sites is generally less than 0.5 m tall, so some of the larger seedlings are now above the level of the weed canopy and appear to have a good prospect of establishing. However at one blue periwinkle site the climbing exotic weed cape ivy (*Delairea odorata*) may prevent this.

Seedlings planted into blackberry benefited from the summer of 2004–05 being a good year for the blackberry rust fungus (*Phragmidium violaceum*) which caused significant defoliation from mid summer onwards at all three blackberry sites. Thus although gaps in the blackberry cover initially closed over quite rapidly, in some cases the plots then became less shaded as the season went on. No seedlings have yet overtopped blackberry and their survival may be determined by whether they can do so in spring 2005 before renewed blackberry growth shades them out. Shading appears to be the major factor determining outcomes in this field experiment. A glasshouse experiment is currently underway to examine the response of these two tree species to different levels of shade to see whether our assumption that blackwood is much more shade tolerant than manna gum is correct.

The ability of young tree seedlings, particularly blackwoods, to survive and grow in small or zero gaps in blue periwinkle may explain the observation during our earlier survey (Ede *et al*. 2004) of native tree recruitment coexisting with high cover of exotic herb weeds such as blue periwinkle. Seedlings that survived to March in blackberry in this experiment may well die once blackberry growth resumes, because they are all still well below the height of the weed. If this proves to be the case there would appear to be a contradiction between this experiment and the observation from the survey that amount of blackberry cover does not affect number of native tree seedlings. Several explanations are possible, including that within the 3000 to 4000 m^2 sites surveyed there was sufficient space not occupied by blackberry for tree seedlings to establish in reasonable numbers; an explanation supported by the fact that blackberry cover in the survey never exceeded 65% of a site. Thus perhaps at a small scale tree seedlings cannot establish within blackberry thickets, but at a larger scale sufficient gaps exist in blackberry cover for seedling establishment. If the results from the remainder of the experiment confirm that blackberry has worse consequences for tree seedlings than blue periwinkle this information will be useful for prioritisation of weed management. The results will also assist in deciding the minimum weed-free space that must be created for different native trees if it is intended to augment native tree recruitment with small-scale planting within weedy riparian zones.

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SESSION 5
Successful monitoring

Monitoring weed eradication programs and evaluating performance

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Eradication is a management strategy that has considerable appeal because of its potential to provide substantial benefits when invading pest organisms are eliminated. Eradication programs for weeds that develop persistent seed populations will require relatively long-term funding and institutional commitment by comparison with those targeting other pest organisms. Such programs typically require 10 years or more to complete. A procedure for the evaluation of eradication programs is required to distinguish potentially successful programs from those that are destined to become indefinite control efforts.

There are three basic criteria by which progress towards the weed eradication objective may be evaluated. The most fundamental of these is the delimitation criterion, which relates to the degree of knowledge of the total extent of a weed incursion. The other two criteria (containment and extinction) relate to the prevention of further spread of an incursion and the elimination of individual infestations, respectively. Assessing conformity to the containment criterion is problematic owing to practical difficulties in demonstrating containment failure. However, if containment failure does occur, it will be reflected by increasing total area of infestation, hence will be covered by the delimitation criterion. The delimitation and extinction criteria are examined with regard to eradication programs targeting kochia (*Bassia scoparia* (L.) A.J. Scott), skeleton weed (*Chondrilla juncea* L.) (both in Western Australia) and branched broomrape (*Orobanche ramosa* L.) in South Australia.

A scoring system for the evaluation of progress towards the eradication objective is presented. This system takes into account five-year trends in cumulative infested area, the detection ratio (infested area detected/area searched) and the average distance between new infestations and known infestations. It also includes an extinction score, which is a composite of the percentage of infestations in the monitoring phase (no plants detected for at least 12 months) and the percentage of infestations eradicated. The system is applied to the previously successful eradication program targeting bitterweed (*Helenium amarum* L.) and to the ongoing program targeting branched broomrape. The data required for this scoring system are fairly simple.

Using geospatial technologies to map and monitor environmental weeds

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Summary Since development of the first geospatial technologies (remote sensing, GIS and GPS), there has been considerable interest in their application to weed management. Remote sensing in particular has been presented as a cost-effective means for mapping and monitoring weeds, with the ability to obtain complete spatial coverage and repeat acquisition over time. Whilst there has been considerable progress in this area for detecting and mapping and agricultural weeds, the practical application to environmental weeds remains uncertain.

This paper addresses the question of whether remote sensing can be used successfully to map and monitor environmental weeds in Australia, including discussion specific to Victorian conditions. Two components are presented: a review of the current use of remote sensing for mapping and monitoring environmental weeds in Australia, and a case study using remote sensing to map and monitor a single environmental weed in south-west Victoria.

Although not suitable for all species and conditions, it is concluded that current remote sensing technologies can be used successfully in weed mapping, provided careful consideration is made in matching imagery to the species and mapping environment. Recent advances in technology may greatly increase our ability to do this, the main limit now being cost. The operational use of remote sensing for weed monitoring is yet to be realised in Australia; however, Australian pilot studies and overseas examples indicate considerable possibilities.

Introduction

Weed mapping and monitoring are both recognised as key steps in strategic weed management. Weed mapping is generally carried out as a single assessment that aims to identify and delineate weed populations on the ground (Dewey and Anderson 2004, Cooksey 2002). It is used for assessing the severity of infestation, planning management strategies, and allocating resources. Weed monitoring on the other hand aims to repeatedly and consistently map weed populations over time in order to detect change (Dewey and Anderson 2004, Cooksey 2002), and is generally used for assessing the effectiveness of weed control strategies.

Demand for accurate weed mapping and monitoring data is great as government and funding agencies increasingly need to prioritise weed control and assesses management outcomes. Yet mapping and monitoring are often neglected from weed management programs due to the difficulties of obtaining adequate spatial and temporal information on weed location. Traditional weed mapping methods such as on ground surveying or questionnaires are time consuming and expensive (Pitt and Miller 1988, McGowen *et al.* 2001, Grice 2004), and as a result are often limited in extent and coverage.

Remote sensing and other geospatial technologies have greatly enhanced our ability to map land features and land cover change. Remote sensing provides a cost effective means of obtaining data over extensive areas, and has the advantage of complete coverage and temporal repetition. Operational use of remote sensing in Australia for large scale mapping and monitoring has already been taken up in areas such as broadscale vegetation assessment and salinity monitoring (Wallace *et al.* 2004).

Unlike the ready uptake in other areas of natural resource management, remote sensing has not been widely used in weed management (McGowen *et al.* 2001). Uncertainties remain over its practicality due to past technical difficulties with single-species mapping (McGowen 2001, Lass *et al.* 2005). This is highlighted in titles of recent agricultural-based papers on the subject, including 'Is the application of remote sensing to weed mapping just 'S-pie in the sky?' and 'Remote sensing for broadscale weed mapping – is it possible?' (Bulman 2000, McGowen *et al.* 2001). Whilst there was much promise for weed mapping applications when remote imagery first emerged, there have since been lingering doubts over its widespread applicability for this purpose. Can remote sensing, combined with associated geospatial technologies, be useful in practice for weed mapping and monitoring in Australia? Are there many successful examples of this? What factors influence mapping success?

This paper attempts to answer some of these questions. Firstly, a review will be presented on the application of remote sensing to environmental weed mapping and monitoring in Australia. The species, study conditions, methods and levels of success will be discussed. A case study will then be presented to explore the choices involved in method selection in practice. Finally, implications for future applications will be discussed, and an attempt made at answering the broader question: Can remote sensing can be used successfully in mapping and monitoring environmental weeds in Australia?

The role of geospatial technologies in weed mapping and monitoring

Geospatial technologies refer collectively to remote sensing, Geographic Positioning Systems (GPS), and Geographic Information Systems (GIS). All of these technologies may play an independent or combined role in weed management.

Remote sensing may be operationally defined as the acquisition of image data from a remote airborne or satellite platform. The primary use of remote sensing in weed management is to collect data from which weed distribution information can be extracted to create weed maps. A wide range of imagery is available with varying spatial coverage (area), spatial resolution (smallest image unit), and spectral resolution (number of recorded spectral bands in different regions of the electromagnetic spectrum) (Table 1). For a weed species to be accurately mapped using remotely sensed imagery, it must be spectrally distinct from surrounding land cover types, and the characteristics of the imagery must be such that this difference can be detected (Bulman 2000, McGowen *et al.* 2001). A complete review of remote sensing principles and their application to weed mapping may be found in Bulman (2000) and Lass *et al.* (2005).

A Geographic Positioning System (GPS) is a hand held unit which can accurately identify geographic position on the ground. In weed management, GPS units are used by managers to record point locations of weed infestations or control efforts in the field, which can then be uploaded into a computer for storage and analysis (Tucker personal communication, Honan personal communication.). The accuracy of GPS units can vary considerably according to price and the presence or absence of differential correction (i.e. removal of noise signals introduced by the US Army to reduce positional accuracy). Top of the range units with differential correction can now obtain sub-meter accuracies, although some cheaper units (less than AU$500) can achieve accuracies of within 10 m or better. A number of GPS units have

Table 1. Examples of remotely sensed imagery in Australia potentially useful for weed mapping (adapted from Lass *et al.* 2005)

Imagery	Type	Spatial resolution	Spectral resolution (bands)
Landsat MSS#	Multi-spectral satellite	80 m	3 colour (green, red, NIR)
Landsat ETM*	Multi-spectral satellite	30 m colour 15 m pan	7 colour (blue to infrared) 1 panchromatic
SPOT 4	Multi-spectral satellite	20 m colour	3 colour (green, red, NIR)
SPOT 5	Multi-spectral satellite	5 m colour 2.5 m pan	3 colour (green, red, NIR) 1 panchromatic
EO1 – ALI	Multi-spectral satellite	30 m thermal 10 m pan	10 colour 1 panchromatic
Quickbird	High resolution multi-spectral satellite	2.4 m colour 0.6 m pan	4 colour (blue, green, red, NIR) 1 panchromatic
IKONOS	High resolution multi-spectral satellite	4 m colour 1 m pan	4 colour (blue, green, red, NIR) 1 panchromatic
EO1 – Hyperion	Hyperspectral satellite	30 m	220 colour
Multispectral video or still camera	Multispectral airborne	0.25 – 4 m	3 – 8 colour, user choice
AVIRIS	Hyperspectral airborne	4 m and 20 m	224 colour
ITRES – CASI	Hyperspectral airborne	0.5 – 10 m	User programmed

No longer collects current data (since 1992)

* A scan line correction malfunction in May 2003 means data is less useable

also been customised specifically for weed mapping (Kolomeitz personal communication).

A Geographic Information System (GIS) is a computer based system for storing, displaying and analysing geographically referenced data. In weed management, GIS is useful as a framework for handling spatially referenced weed information. A range of GIS frameworks exist, from those allowing complex spatial analysis (ArcGIS and MapInfo), down to basic systems suitable for use by non-technical groups e.g. Streets Ahead and Catchman (Emeny 2004). A number of GIS-like programs are currently being used in state level weed management, including the Pest Management Information System in Victoria (Backholer 2000) and PestInfo in Queensland (Bryant and Lockton 2003). Although not strictly GIS, these programs all allow for the integration of spatially referenced information.

The greatest benefit of geospatial technologies comes through their integration. The use of GIS in planning weed control programs can benefit enormously from information obtained in a spatially referenced format using GPS or remote sensing. Remote sensing can also benefit through the use of GPS in assessing mapping accuracy on the ground, and the use of GIS for analysing weed spatial patterns or change over time.

Review of remote sensing as a tool for environmental weed mapping and monitoring in Australia

A search of available literature and consultation with field experts revealed 28 environmental weeds across 19 studies in which remote sensing was applied for mapping or monitoring in Australia (Tables 2 and 3). The characteristics of these studies in terms of species, mapping environment, methods and levels of success are reviewed.

Species and study conditions

Of the 28 environmental weeds to which remote sensing has been applied in Australia, 17 were successfully detected using at least one type of imagery and method (Table 2). Two studies mapped more than one species simultaneously (McGowen *et al.* 2001, Crossman and Kochergen 2002), and a number of weeds were mapped in more than one study (*Acacia longifolia* var. *sophorae*, *Cryptostegia grandiflora*, *Echium plantagineum*, *Mimosa pigra*, *Rubus fruticosis*). Most species mapped are either trees or shrubs (14 out of 17 successful attempts). Three of the four successfully mapped grasses/herbs were in open agricultural settings.

Successful mapping environments included mixed (e.g. native vegetation/rural/urban) (Frazier 1998, Bowman 2000, Crossman and Kochergen 2002, Emeny *et al.* 2005, Cuneo personal communication), open grassland/agricultural (Ullah *et al.* 1989a, Brown and Carter 1998, Bulman 2000, McGowen *et al.* 2001, Robinson and Metternitch 2005), and riparian/wetland (Catt and Thiranongnarong 1992, Kastanis and Cranfield 1992, Abbott *et al.* 1999, McIntyre *et al.* 2002, Ticehurst *et al.* 2003). There were no examples in pure forest environments or closed woodlands, although in some cases these made up a smaller component of the study area (e.g. Frazier 1998, Emeny *et al.* 2005, Crossman and Bass 2002). In all cases, species mapped were either present in the canopy or mapped in relatively open environments. More than half of the species listed in Table 2 are serious or very serious environmental weeds under Victorian conditions.

Unsuccessful attempts (Table 3) were mostly from the same studies and species represented in Table 2, but using different imagery. Nine are from the study reported in Crossman and Kochergen 2002 (Crossman and Bass 2002), which successfully mapped six other species.

Virtually all 18 studies were single event mapping attempts with the primary aim of testing remote sensing technologies for future mapping or monitoring. Only three had the primary aim of assessing current weed extent and distribution to inform management or for analysing weed distribution patterns (Crossman and Kochergen 2002, Emeny *et al.* 2005, Cuneo personal communication). The only temporal mapping attempts were those by Brown and Carter (1998) and Robinson and Metternicht (2005), who mapped the historical spread of weed species. Bulman (2000) attempted to repeat mapping by Ullah *et al.* 1989a of Patterson's curse using Landsat TM to test its operational use in monitoring, however was unsuccessful. Strikingly, there were no operational examples of remote sensing in environmental weed monitoring.

Methods – selected imagery and scale

Most of the reviewed studies used traditional image sources for weed mapping, such as medium resolution satellite data (mainly Landsat) and aerial photography (see Tables 2 and 3). There are currently no published studies in Australia which have used new high resolution multispectral imagery, such as SPOT 5, Quickbird or IKONOS. Additionally, only two Australian studies have made use of new hyperspectral airborne imagery (Bulman 2000, Ticehurst *et al.* 2003), and only one of hyperspectral satellite data (Ticehurst *et al.* 2003). The only other imagery used included airborne video (Frazier 1998, Abbott *et al.* 1999), which is often used as a

Table 2. Successful attempts at mapping environmental weeds using remotely sensed imagery in Australia (using at least one method)

Species name	Growth form	Reference/s	Imagery used	Accuracy rate/s (where given)
Annona glabra	Tree	Ticehurst *et al*. 2003	Hymap, Hyperion, Landsat	Not stated, some success
Fraxinus rotundifolia ssp. *rotundifolia*[VS]	Tree	Crossman and Kochergen 2002	High resolution CIR aerial photos	Producer's: 79% User's: 35%
Mesquite	Tree	Robinson and Metternicht 2005	Panchromatic aerial photos	Not stated, considered successful
Mimosa pigra	Tree	Fitzpatrick *et al*.1988; McIntyre *et al*. 2002	Landsat TM, MASTER, aerial photography	88% detection of dense stands using Landsat TM
Olea europaea ssp. *europaea*[S]	Tree	Crossman and Kochergen 2002	High resolution CIR aerial photography	Producer's: 93% User's: 63%
Olea europaea ssp. *cuspidate*	Tree	Cuneo personal communication.	Landsat ETM	To be assessed, considered successful
Pinus radiata[VS]	Tree	Crossman and Kochergen 2002	High resolution CIR aerial photography	Producer's: 65% User's: 73%
Acacia longifolia var. *sophorae*[VS]	Shrub	Race and Rollings 1992, Emeny *et al*. 2005	Landsat TM and ETM	Producer's: 71–89% User's: 82–92%
Acacia nilotica	Shrub	Brown and Carter 1998	Conventional aerial photographs (pan and colour)	Not stated, considered successful
Crataegus monogyna[VS]	Shrub	Crossman and Kochergen 2002	High resolution CIR aerial photography	Producer's: 73% User's: 62%
Genista monspessulana[VS]	Shrub	Crossman and Kochergen 2002	High resolution CIR aerial photography	Producer's: 89% User's: 96%
Rubus fruticosis[VS]	Shrub	Ullah *et al*. 1989b, Frazier 1998, Crossman and Kochergen 2002	High resolution CIR aerial photography, airborne videography	Producer's: 79–97% User's: 43–100%
Cryptostegia grandiflora	Shrub	Kastanis and Cranfield 1992, Abbott *et al*. 1999	Landsat TM, multispectral airborne video	Overall: 63–89%
Echium plantagineum[S]	Herb	Ullah *et al*. 1989a, Bulman 2000	Landsat TM, CASI	Not stated, considered successful
Onopordum acanthium	Herb	McGowen *et al*. 2001	Landsat ETM	Overall 80–86%
Brachiaria mutica	Grass	Catt and Thirarongnarong 1992	High resolution CIR aerial photography	Not stated, considered successful
Nassella trichotoma[VS]	Grass	McGowen *et al*. 2001	Landsat ETM	Overall: 72–82%

[VS] = Very serious threat to one or more vegetation formations in Victoria (Carr *et al*. 1992)
[S] = Serious threat to one or more vegetation formations in Victoria (Carr *et al*. 1992)

cheaper alternative to aerial photography (Abbott *et al*. 1999).

Most studies were conducted over local to sub-regional scales in the range of 1000s to 10 000s of hectares. Only two were less than 1000 ha in extent, both of which were pilot studies for testing remote sensing methods (Frazier 1998, Ticehurst *et al*.2003). There were also only two attempts at mapping areas of more than 100 000 ha (Ticehurst *et al*. 2003, Emeny *et al*. 2005).

Not surprisingly, most studies mapping large extents (greater than 50 000 ha) used coarse resolution imagery (Figure 1). However, the opposite was not always true. Whilst many small scaled studies used fine resolution data, some also tried to use coarse resolution imagery (shown in the top left corner of Figure 1). Interestingly, most unsuccessful attempts occurred using this combination. With

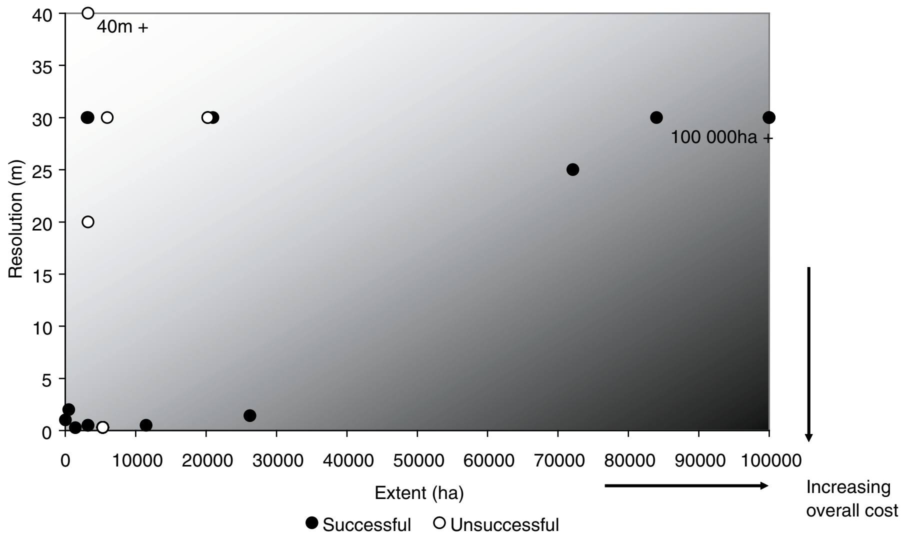

Figure 1. Association between study area extent, imagery resolution and success of mapping in Australian examples of using remote sensing for weed mapping

Table 3. Unsuccessful attempts at mapping environmental weeds using remotely sensed imagery in Australia

Species	Reference	Imagery used	Stated reasons
Brachiaria mutica	Catt and Thirarongnarong 1992	Landsat MSS, SPOT	Not stated
Chrysanthemoides monilifera	Crossman and Bass 2002	High resolution CIR aerial photos	Understorey species
Cyrnara cardunculus	Crossman and Bass 2002	High resolution CIR aerial photos	Scale of imagery relative to species
Cytisus scoparius	Crossman and Bass 2002	High resolution CIR aerial photos	Scale of imagery relative to species, time of year
Echium plantagineum	Bulman (2000)	Landsat TM	Coarse resolution
Lavandula stoechas	Crossman and Bass 2002	High resolution CIR aerial photos	Scale of imagery relative to species, time of year
Leptospermum laevigatum	Bennett and Ogleby (1994)	Landsat TM	Coarse imagery resolution, similar reflectance to other species, variable cover of target
Mimosa pigra	McIntyre *et al*. 2002	TopSAR and fused TopSAR/Landsat	Spectral similarity to other species
Pinus halepensis	Crossman and Bass 2002	High resolution CIR aerial photos	Not stated
Rhamnus alaternus	Crossman and Bass 2002	High resolution CIR aerial photos	Understorey species
Rosa canina	Crossman and Bass 2002	High resolution CIR aerial photos	Understorey species
Rosa rubiginosa	Crossman and Bass 2002	High resolution CIR aerial photos	Understorey species
Ulex europaeus	Crossman and Bass 2002	High resolution CIR aerial photos	Understorey species

the exception of species unsuccessfully mapped by Crossman and Bass (2002), all other unsuccessful attempts in Table 3 used coarse resolution imagery over small scales, and this was stated as a primary cause for failed mapping.

Methods – extracting weed data

Weed mapping from remotely sensed data generally falls into two categories: digital (computer assisted techniques), and manual (photo interpretation). Digital techniques are further categorised into image enhancements, unsupervised classification and supervised classification. Image enhancements adjust the information displayed from images in a way that highlights particular features. Unsupervised and supervised classifications are methods of categorising individual pixels into groups based on spectral similarity, and can give quantitative estimates of per land cover category. Unsupervised class is a more automated procedure with limited input from the analysis until after it has been run. Supervised classification on the other hand allows the analyst to 'train' the processing algorithm to identify land features of interest.

The methods used to extract weed data in Australian remote sensing examples cover all of the above mapping categories, with many trialling more than one method. There were slightly more examples of the less interactive methods of image enhancement and unsupervised classification than the more involved supervised classifications, the later however being generally more successful. Two studies successfully used manual techniques (Frazier 1998, Brown and Carter 1998), both of which coincided with relatively small study areas (42 ha and 1469 ha). Only two attempts were made at incorporating ancillary GIS data to improve mapping results (Abbott *et al*. 1999, Ticehurst *et al*. 2003). Both found a significant improvement in mapping results over the standard classification methods, with Abbott *et al*. (1999) achieving accuracies of 6% to 11% over standard supervised classification.

Assessment of mapping success

'Success' of weed mapping using remote sensing may in simple terms be defined as the degree to which results fit the intended purpose. However, a number of quantitative methods exist for assessing mapping accuracy using remote sensing (Congalton 1991). These include overall, producer's and user's accuracies, which are all calculated from an 'error matrix' comparing mapping results to 'true' land cover on the ground (Congalton 1991). Overall accuracy indicates mapping success across all land cover categories. Producer's accuracy, stated in terms of weed detection, refers to the percentage of weed presence on the ground accurately identified as weed on the image. User's accuracy then refers to the percentage of weed presence shown in the classified map which is actually weed on the ground. Quantative assessment of mapping results is important, as it gives the end user an indication of reliability of results.

Only in 11 of the reviewed studies was mapping accuracy quantitatively assessed, and only seven of those reported using an error matrix. Three did not estimate mapping accuracy at all, the remaining studies using visual or qualitative means. Most studies however gave some indication of 'success' for the stated purpose.

Where quantified, successful mapping attempts ranged in accuracy from 71% to 97% for producer's, and 35% to 100% for user's accuracies (Table 2). The most successful mapping attempts from the producer's point of view were for *Olea europaea* ssp. *europaea* (Crossman and Kochergen 2002) and *Rubus fruticosis* (Frazier 1998). The most successful mapping attempts from the user's point of view were *Acacia longifolia* var. *sophorae* (Race and Rollings 1992), *Genista monspessulana* (Crossman and Kochergen 2002) and *Rubus fruticosis* (Frazier 1998). Unsuccessful attempts did not quantify accuracy. Attributed causes for failed attempts (other than spatial resolution) included spectral similarity to other species, time of year (phenological stage of species not distinct from surrounds), and obstruction by overstorey species (Table 3).

In summary, it appears that remote sensing has been used with some success in mapping a number of environmental weeds in Australia. A review of current applications indicates that species with larger growth forms and environments where the target species is present in the canopy are more suited to mapping using the applied techniques. Almost all applications to date have used traditional imagery types such as aerial photography or medium resolution satellite imagery, mainly applied over local to sub-regional scales. Most studies applied some form of digital processing to extract weed data, with manual techniques only practical at very small scales. The lack of quantitative assessment and consistency in accuracy reporting makes comparison between studies difficult; however, an obvious cause of unsuccessful mapping was use of imagery with a

Table 4. Comparison of study conditions, method requirements and choice of imagery used for mapping and monitoring *Acacia longifolia* var. *sophorae* in south-west Victoria

		Part A: Regional Mapping	Part B: Local monitoring
Study conditions	Use of data	Assessment of weed extent and distribution, environmental correlates, predictive modelling	Change detection, rate of spread, pattern of spread, proximal causes in invasion process
	Extent	360 000 ha	1281 ha
	Vegetation type	Various – including woodland, forest, heathland, grassland	Invaded grassland
	Method requirements	Low cost/unit area, ability to detect in multiple environments, minimal preprocessing	Archival data (preferably pre-dating invasion in 1960s), detail (detect individuals)
Choice of imagery	Selected imagery	Landsat ETM satellite imagery	Conventional aerial photography (colour, black and white)
	Imagery resolution	30 m	2 m
	Cost of imagery	$950 <$0.01 per ha	$255.00 $0.19 per ha (approx.)
	Benefits of imagery chosen	Large spatial coverage, cost effective, minimal pre-processing	High spatial resolution, can detect individual plants, long historical archive
	Limitations of imagery chosen	Coarse spatial resolution, cannot measure density or individual plants, small infestations not detected	Low spectral resolution, expensive over large areas, considerable pre-processing, limited to non-treed environments
Results	Success	81% (User's 82%, Producer's 71%)	Not quantitatively assessed yet, however preliminary results are good. Some issues with edge pixels and image alignment

spatial or spectral resolution inappropriate for detecting target weed patches. Other stated reasons for unsuccessful mapping also related to imagery limitations, such as inability to detect small or understorey species. It is concluded that mapping success lies in part in matching of appropriate imagery to study conditions. The following case study uses a working example to demonstrate the choices made in matching imagery to study conditions in practice.

Case study: Mapping and monitoring *Acacia longifolia* var. *sophorae* in south-west Victoria

This case study is set in south-west Victoria and focuses on the species *Acacia longifolia* var. *sophorae*. *A. longifolia* var. *sophorae* is an Australian native dune coloniser that has become invasive in a number of vegetation types in the study area, outside its previous range. It is considered a serious environmental weed in much of the region. *A. longifolia* lends itself to remote mapping due to its large size (up to 30m in diameter), tendency to form large pure stands, and distinctive bright green foliage compared to surrounding species.

The case study consisted of two distinct components. Firstly the mapping of current regional distribution of *A. longifolia* (Part A), and secondly an analysis of historical spread of *A. longifolia* at a localised scale (Part B).

Table 4 indicates the different study conditions of Part A and B; resulting data requirements; and choice of imagery and imagery characteristics to match these conditions. The larger area and range of environments in Part A meant imagery was required with minimal cost per unit area, minimal pre-processing, and the ability to detect *A. longifolia* across a range of environments. The characteristics of Landsat ETM 7 made it suitable for this purpose (Table 4). The common limitation of relatively coarse spatial resolution of this imagery was not an issue in this case as the aim was to map broad distribution patterns.

The need to detect temporal patterns of weed spread and attribute proximal causes in Part B mean archival data was required over regular intervals, preferably with at least one image pre-dating the initial invasion (1960s), and sufficient detail to detect individual plants. Conventional aerial photographs were selected in this case, as these represent the only available imagery dating prior to the 1960s. Seven images were available for the study area over the past 55 years, including one from 1947. With a scanned resolution of approximately 1 m, the aerial photos gave the detail required to detect individual plants. Whilst aerial photos have low spectral resolution, the open nature of the study area and growth form of the invading species meant plants were readily distinguishable.

Both components were considered successful in their outcomes. Overall accuracy of Part A was estimated at 81%, and allowed a regional scale assessment of weed extent and distribution (Emeny *et al.* 2005). The user's accuracy was estimated at 71% and producer's accuracy at 82%. The accuracy assessment for Study 2 is still in progress, however a visual assessment of results indicates that *A. longifolia* is readily distinguished from its background and change detection is possible (although issues with misclassifications around some edges and tree shadows are still being addressed).

Whilst Landsat 7 was suitable for Part A and aerial photography for Part B, the reverse was not the case. Landsat 7 was not suitable for Part B, as the Landsat TM series was only launched in the 1980s and therefore did not provide the archival imagery required. The coarser resolution was also unsuitable for detecting small scale changes. Likewise, aerial photographs were not suitable for Part A due to excessive cost, increased data pre-processing, and limited spectral resolution for detecting *A. longifolia* over different vegetation types.

This case study confirms the importance of matching imagery to study conditions, however also identifies that in practice, cost, time and availability of data are necessary considerations.

Implications and future applications

Remote sensing in environmental weed mapping

Provided that spectral discrimination is possible, the primary determinant of successful weed mapping using remote sensing is appropriate matching of method to species and study environment. Two primary considerations are spectral and spatial resolution. Spectral resolution must include areas of the spectrum in which the weed species is distinctive from other species. Generally, higher spectral resolution is better in exploratory studies as it increases this likelihood. Spatial resolution needs to be greater than the minimum weed patch size which is hoped to be mapped; hence, higher spatial resolution is also usually more suitable for single species mapping.

In previous decades, it was not always possible to match imagery characteristics to study aims and conditions due to technological limitations. Imagery was limited to either aerial photography, with fine spatial resolution but low spectral resolution, or satellite imagery such as the Landsat series, which had higher spectral resolution but relatively low spatial resolution. This greatly restricted mapping options to the few species that could be detected using limited spectral bands, or species forming large and distinctive infestations. Most of the existing mapping examples in Australia still fall into these two categories, making use of either high resolution aerial photos or coarser resolution satellite imagery, which explains the relatively small number of species successfully mapped to date.

Imagery has been released in the last five years which combines the benefits of both high spatial and spectral resolution. These include high resolution multispectral satellite imagery (e.g. IKONOS, Quickbird), and hyperspectral airborne and satellite imagery (e.g. Hymap, Hyperion). None of the reviewed Australian studies have made use of the new high resolution multispectral imagery, and only two made use of hyperspectral data (Bulman 2000, Ticehurst *et al*. 2003). Overseas studies using new high resolution multispectral and hyperspectral imagery for weed mapping have achieved extremely high mapping accuracies, many above 90% (e.g. Underwood *et al.* 2003, Everitt and Yang 2004, Glenn *et al.* 2005, Lass *et al.* 2005), and in some cases, at very low weed densities (e.g. Lass *et al*. 2002). There is considerable scope in weed applications for this type of imagery in Australia. At the time of writing, at least two studies such studies are already in progress. A collaborative project between the Department of Agriculture Western Australia, the Tropical Weed Management Branch of CSIRO Entomology in Brisbane, and SpecTerra Pty Ltd of Perth (led by A/Prof Metternicht personal communication), is testing new high resolution satellite and airborne sensors for routine mapping and monitoring of *Echium plantagineum* (Paterson's curse) and mesquite. Another project using high resolution IKONOS imagery is currently being tested for mapping of *Acacia nilotica* infestations on the Mitchell Grasslands in Queensland (Lawes personal communication).

In practice, choice of method in species mapping studies must also consider cost and data availability, as demonstrated in the case study. Feasibility explains the current absence of high resolution, large extent studies shown in Figure 1, as overall cost increase with both resolution and extent. Cost still forces imagery users to compromise on either spatial resolution or extent. Figure 1 suggests that compromising both may lead to failed mapping attempts. Current costs of hyperspectral satellite imagery start at US$20 000 for an area covering just 20 km by 40 km, compared just US$250 for current Landsat ETM data covering 185 km by 185 km (Lass *et al.* 2005), suggesting a likely reason for its limited use in Australia to date. It appears that the current limitation to weed mapping using remote sensing in Australia is no longer technology capabilities, but cost.

The application of remote sensing to weeds in Victorian conditions has been somewhat limited to date. Only six of the reviewed studies were conducted in Victoria, although nine of the species in Table 2 are environmental weeds in this state. Put in context, this represents only nine out of the 584 species listed as environmental weeds by Carr *et al.* 1992. Whilst remote sensing will probably never be suited to all of these species, potential avenues are far from exhausted. Interestingly, a number of Victorian weeds which have not been mapped in Australia using remote sensing have been successfully mapped overseas e.g. gorse (Shepherd and Lee 2002), water hyacinth (Everitt *et al.* 1999). As costs for higher resolution imagery comes down, we are likely to see more of the 584 species successfully mapped using remote sensing. In the mean time, a number of alternative geospatial technologies (GPS, GIS) are being used operationally to map and monitor species currently not suitable for remote sensing e.g. spiny rush (Weaver 2002), bridal creeper (Siderov and Ainsworth 2004), English broom (Allan personal communication).

Remote sensing in environmental weed monitoring

Use of remote sensing in weed monitoring requires all of the same considerations as per mapping, will the added challenges of ensuring methods can be applied repeatedly and consistently with time, additional setup costs, and choice of spatial and temporal scales which adequately detect levels of change of interest to management.

No examples currently exist of operational use of remote sensing for weed monitoring in Australia. This is not surprising, due to the relatively low level of research on methods to date. Many of the reviewed mapping studies had the aim of testing remote sensing methods for future use in monitoring, some with very good success. However, for these methods to be useful in practice, repeatability and consistency over time also needs to be established (Emeny *et al.* 2005). Bulman (2000) was the first to attempt repeat mapping on Paterson's curse, however was unsuccessful. Emeny *et al.* (2005) showed the repeatability of Landsat for mapping *Acacia longifolia* var. *sophorae*, however at a different scale to the previous study by Race and Rollings (1992). Testing of remote sensing methods for monitoring must be done with that purpose in mind. Successful attempts at monitoring historical weed spread indicates that consistent mapping is possible over time; however such retrospective studies have the disadvantage of not being able to quantitatively assess mapping accuracy, making it difficult to assess method consistency. Examples from the US using hyperspectral imagery to monitor weed control strategies (e.g. Glenn *et al.* 2005, Lass *et al.*2005) indicate that this may be the future for remote sensing in weed monitoring.

Conclusion

Remote sensing can be a successful weed mapping tool provided it is done in a way that carefully considers the species, environment, method and available resources. To date, only a small number of species have been mapped in this manner in Australia due to the previous limitation of remote sensing technologies not matching study requirements. Recent developments in technology have removed many of these limitations. However, cost will probably continue to restrict operational use of remote sensing for environmental weed mapping into the immediate future.

The use of remote sensing as an operational tool for weed monitoring in Australia is still some way off; however, method assessments here and operational examples from overseas are promising, particularly using hyperspectral and high resolution imagery. There remain many opportunities for further research in Australia and testing of research results in practice.

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The role of monitoring in weed management: a case study from the Victorian Alps

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Summary Parks Victoria is incorporating robust scientific monitoring into weed and pest management programs through the use of standard monitoring and mapping protocols. These protocols are being trialled in a number of parks to quantify changes in pest and weed abundance (through monitoring) and distribution (through mapping). The weed monitoring protocols are also being used in an adaptive experimental management (AEM) program for English broom (*Cytisus scoparius*) in the Alpine National Park. English broom is managed intensively and ongoing monitoring has been implemented to improve understanding of the efficiency, effectiveness and environmental outcomes of various best-practice herbicide applications. Preliminary results indicate the benefit of controlling English broom in the initial stages with substantial reductions in broom abundance after initial treatment with selective and non-selective herbicides in April 2004. However the removal of English broom using herbicides may not necessarily result in the return of the native flora. Ongoing results from this experiment will guide the future use of selected herbicides to control English broom populations and restore vegetation communities after wildfires. As this program is 'adaptive' in its nature, there is potential to incorporate use of fire, physical or mechanical removal, and establishment of biological control into the experiment.

Introduction

Role of monitoring in weed management

Natural resource monitoring (i.e. determining the status and trends in the condition of selected park resources) is a major component of park stewardship. Without monitoring, how do public land managers know if their management actions are making a difference and if management objectives are being met? Parks Victoria has developed a series of protocols for monitoring weeds and pests using scientifically robust techniques. Monitoring enables Parks Victoria to evaluate performance, identify emerging threats and increase understanding of the ecosystems being managed. Establishing monitoring standards ensures that park management decisions are made with the best available information.

Parks Victoria's weed protocol includes both mapping and monitoring techniques. Mapping weeds provides information on the extent of weed populations, which can be used to direct management programs. While weed mapping is not aimed at detecting changes in the abundance of populations over time, it can help detect changes in distribution over time, if undertaken at an appropriate scale. By monitoring changes in weed abundance at the site level using the techniques recommended in the monitoring protocols, the effectiveness of management programs can be determined. These methods, which are currently being trialled in a number of parks, can also be adapted to record abundance and composition of native species.

Park managers generally have a very good knowledge and understanding of best-practice weed management techniques. However, for many weed control programs there is uncertainty about the effectiveness and cost-efficiency of various control techniques: eg for various best-practice treatments, how do the costs compare, what level of reduction in weed abundance should we expect, and what grows on a site once the weed has been removed? Parks Victoria is establishing adaptive experimental management (AEM) programs to address such questions.

Case Study – English broom control and monitoring in the Alpine National Park, Victoria

Introduction

English broom is a highly invasive woody weed which forms dense thickets and can out-compete native species (Hosking *et al.* 1996, DNRE 1998). The dense canopy and continuous input of litter as a result of the establishment of broom are thought to be largely responsible for the loss of native species richness (Waterhouse 1988, Fogarty and Facelli 1999, Wearne and Morgan 2004). English broom can also fix nitrogen, which may result in substantial changes to the surrounding ecosystem (Fogarty and Facelli 1999). Seed density in the soil beneath mature broom infestations can be in excess of 65 000 seeds m^{-2} and seed can remain viable (if stored dry) for up to 80 years (DNRE 1998). Control programs must aim to deplete the soil seed bank, so prevention of flowering and seed set are of highest priority.

The integrated English broom control program in the Alpine National Park uses chemical control, biological control and physical removal and involves working with other agencies and landholders. Chemical control programs have been in place in the Alpine National Park for approximately fifteen years and are the primary management tool. Physical removal can be used in sensitive sites and where populations are small, while biological control will be important for long-term management. Since 1996, three biological control insects (broom twig-mining moth *Leucoptera spartifoliella*, broom bud psyllid *Arytainilla spartiophila*, broom seed-feeding beetle *Bruchidius villosus*) have been released in the park. However, all sites were destroyed by wildfires in early 2003. New releases are underway and additional biological control agents are being tested for release.

The current management strategy aims to contain English broom within designated areas to prevent further spread, and progressive control programs are in place in sites of high biodiversity value and in catchment headwaters. The only feasible option for immediate management of dense broom infestations is the use of herbicides with high volume spraying. When used in combination with fire, which promotes mass germination of English Broom seeds, this can result in effective control, but few studies have assessed what grows back after such intensive weed control. Herbicide application usually occurs during late spring/early summer when broom is actively growing and flowering. Parks Victoria commonly uses two herbicides in the Alpine National Park to control broom: a woody-weed specific herbicide (300 g L^{-1} triclopyr with 100 g L^{-1} picloram), and a non-selective herbicide (360 g L^{-1} glyphosate) considered safer to use near waterways. However, the environmental effects of both these herbicides are poorly understood. This has prompted the establishment of an adaptive experimental management (AEM) approach to managing English broom with herbicides after wildfires (Allan *et al.* 2004). The project aims to quantify the cost-efficiency of different herbicide treatments, the effectiveness of control under different scenarios and the environmental outcomes of these treatments. This paper outlines some preliminary findings of the project.

Materials and methods

AEM experimental design

Three replicates of seven one-hectare plots were established and permanently marked in the Omeo Valley, Alpine National Park, in April 2004 (Table 1). Sites with waterways were allocated to non-treatment plots or spraying with the non-selective but waterway-friendly herbicide (360 g L-1 glyphosate). Remaining sites were randomly allocated to treatments, which also included the selective herbicide triclopyr applied at the rate of either 300 g L^{-1} with 100 g L^{-1} picloram or at 600 g L^{-1}. Herbicides were applied with no marker dyes or surfactants and treatments were initiated in either autumn or spring / summer, when post-fire regrowth was approximately 15 and 24 months old, respectively.

Plots were monitored prior to spraying of autumn treatment plots in late April 2004. All plots were then remeasured in October 2004 and the spring / summer treatment plots were sprayed in January 2005. Thus before and after measurements have only been undertaken on autumn treatment plots. Autumn annual plots have since been treated again in April 2005. The next plot measurements will occur in October 2005, after which comparisons will be made between initial autumn versus spring / summer treatments.

Evaluating efficiency
Daily record sheets were completed by weed spraying contractors. These included details of start and finish time, quantity of herbicide used, herbicide rate, and weather conditions. From these, summaries of time spent spraying and quantity of herbicide were used to assess costs per one-hectare plot. Mean costs were then calculated for each treatment.

Evaluating effectiveness
Parks Victoria's pest plant monitoring protocols recommend cover by line intercept as a standard method for assessing abundance of shrubs such as English broom. This technique was used to assess the cover of broom before and after spraying. Within each plot, seven permanent 20 m transects were established and the percent cover of English broom plants along each transect is measured each sampling time. The level of dieback due to the effects of herbicide for each patch of broom along the transects was assessed in October 2004, after the autumn treatment, using the following scorch categories: 0 = no dieback, 1 = <25% dieback, 2 = 25–75% dieback, 3 >75% dieback, and 4 = dead. Further details of methods used are provided in Allan *et al.* (2004).

Evaluating environmental outcomes
To set meaningful management objectives, and understand the environmental impacts of herbicides, it is important to evaluate the response of other species after removal of English broom using herbicides. Species composition and cover, and seedling counts in height classes for English broom and *Eucalyptus* species, were measured on fifteen permanently marked 0.75 cm^2 seedling plots before and after chemical control treatments on each one-hectare plot.

Table 1. The current experimental design incorporates three herbicide treatments, implemented at two different times and applied at two different frequencies (N = 3)

Herbicide	Timing of initial treatment	Frequency of treatment
Non-selective herbicide (360gL-1 glyphosate)	Autumn	Annual
	Spring / summer	Annual
Selective herbicide 1 (300 gL-1 triclopyr with 100 gL-1 picloram)	Autumn	Irregular
		Annual
	Spring / summer	Annual
Selective herbicide 2 (600 gL-1 triclopyr)	Spring / summer	Annual
Control (no herbicide)	–	–

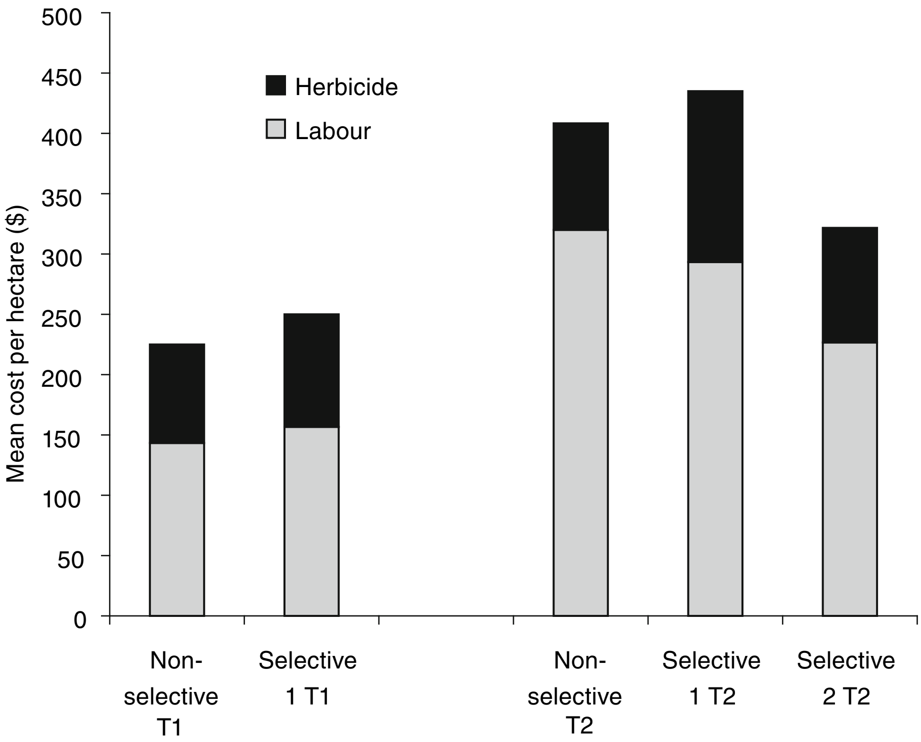

Figure 1. Mean costs per hectare of herbicide and labour for treating English broom at two stages of regrowth after January 2003 wildfires: T1 April 2004, T2 October 2004. Selective herbicide 1: 300 gL-1 triclopyr with 100 gL-1 picloram, selective herbicide 2: 600 gL-1 triclopyr (no April 2004 treatment), non-selective herbicide: 360gL-1 glyphosate

Species richness was compared in October 2004 between sites treated with selective and non-selective herbicides in April 2004 and untreated (control) sites.

Associated research – English broom in the soil seed bank
A pilot study investigating the abundance of English broom seed in the soil was undertaken on a subset of four plots in October 2004. A 12 cm long soil corer was constructed using 5.1 cm internal diameter pipe, with slits at 3 cm intervals so that samples could be separated into subsamples at 0–3 cm, 3–6 cm, 6–9 cm and 9–12 cm below the soil surface. On each of the four plots, 45 samples were collected and sieved to assess abundance of English broom seeds.

Interim results and discussion

Evaluating efficiency
Spraying initially in April 2004 was, on average, almost half the cost of spraying initially in January 2005 (Figure 1). By leaving the English broom stands to grow through the 2004 spring season, the height and density of broom increased such that spraying was much more costly in both time and the amount of herbicide required. This highlights the importance of initiating control programs early after a bushfire

event. Quantifying these costs allows us to improve the accuracy of activity monitoring and predict the potential area that can be treated given limited resources.

Evaluating effectiveness
For plots sprayed in late April 2004, a substantial reduction in cover of live English broom occurred between April and October 2004 (Figure 2). Broom cover increased almost two-fold on untreated plots, whereas on treated plots total cover remained the same and the majority of patches of broom were killed or scorched to some degree after herbicide treatment. However, fewer than 50% of plants were killed in both herbicide treatments. Weed spraying contractors are expected to achieve an 80–90% kill rate on target species, which is usually assessed visually. The results obtained to date suggest that this unlikely to be achieved from spraying in the off-peak time of year (April) and management targets should therefore be revised.

Evaluating environmental outcomes
Native species richness was highest on untreated plots, indicating that in early stages of English broom invasion it is most beneficial to native species to not treat English broom with herbicide (Figure 3). Further, exotic species richness was higher on sites treated with non-selective herbicide than on plots treated with selective herbicide and untreated plots. It is anticipated that on untreated plots, English broom will out compete other species, so a decline in species richness will occur over time due to English broom's capacity to outcompete other species by forming dense stands at least 2m tall. This implies that active site restoration may be required if improvements in native species richness are expected after weed removal. Ongoing monitoring data collected on these sites will determine whether more intensive management measures are required (e.g. reseeding, replanting or burning).

Associated research – English broom in the soil seed bank
Out of 720 samples collected, only 15 had any English broom seed present (Table 2), and most of these had very low seed density. Further sampling is required to ascertain whether this result was due to small sample sizes or whether post-fire germination has depleted soil seed reserves.

Adapting the experimental management program
Although only preliminary, the results obtained from the AEM program thus far can be applied to the management of English broom. One of the most important lessons learnt so far is get in quickly after fire to save on herbicide and labour costs. Management objectives need to be reviewed so that managers set realistic and achievable targets. Results to date show that managers should not expect a 90% kill from spraying in the off-peak time of year (April), nor can they necessarily expect to increase native species diversity in short-term. From ongoing results it may be possible to determine an 'acceptable' cover and top height of broom where a manageable balance can be reached between weed abundance and growth stage and composition and structure of the surrounding vegetation community.

Logistical and practical constraints have already meant alterations have been made to the original design in this AEM program. The original design (outlined in Allan *et al.* 2004) has been reduced from thirty to twenty one plots for two reasons:

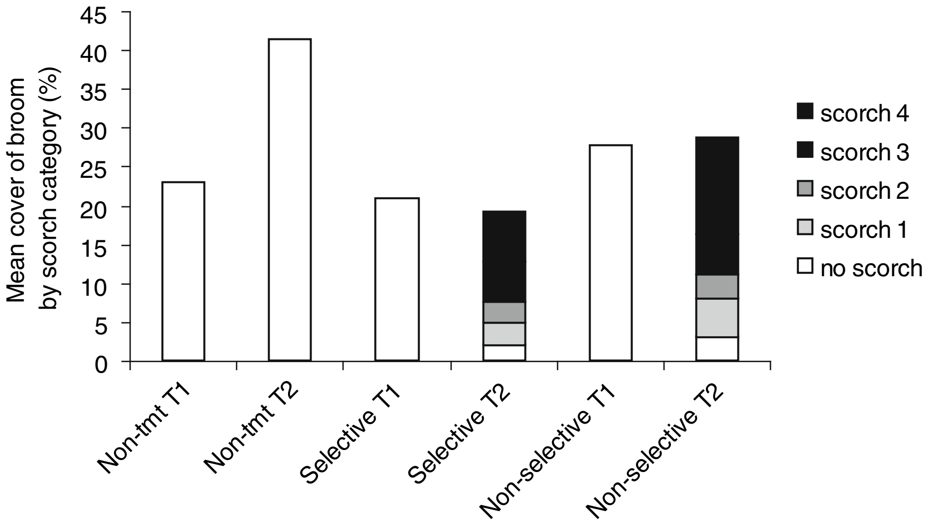

Figure 2. Abundance of English broom before (T1 April 2004) and after (T2 October 2004) initial treatment with selective and non-selective herbicides applied in late April 2004. Level of scorch assessed at T2 as 0: no dieback, 1: <25% dieback, 2: 25–75% dieback, 3: >75% dieback, 4: dead

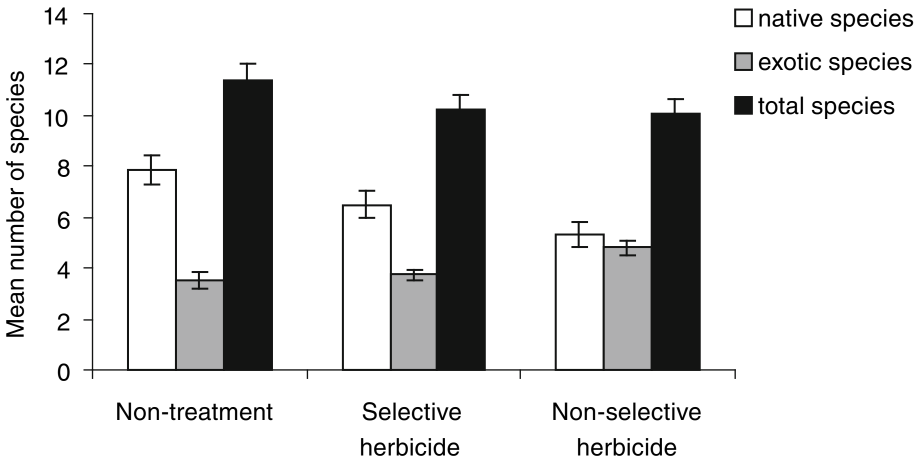

Figure 3. Mean species richness (±SE) in October 2004 for sites that were not treated, treated with selective herbicide 1 in April 2004, or treated with non-selective herbicide in April 2004

Table 2. Mean seed numbers in soil samples collected in October 2004 (N = 180 subsamples at each depth)

Depth of subsample	Number of samples with broom seeds	Mean number of broom seeds
0–3 cm	3	3.25
3–6 cm	6	9.33
6–9 cm	4	3.50
9–12 cm	2	1.50

we underestimated the resources required to establish and carefully monitor all variables; and preliminary observations indicated that annual follow-up would be required on all plots due to the extremely high density of broom.

A number of new questions are arising in relation to best-practice English broom control after bushfires. In areas where herbicides have been effective, we are now faced with dense stands of dead matter which could potentially be a fire hazard. In sites where herbicide control has not yet occurred, English broom is so tall that spraying with herbicide is not practical or affordable, and other options such as slashing and burning need to be considered. A workshop is proposed to be held in early autumn 2006 to discuss future options to test control techniques such as burning, slashing, re-seeding, and interactions between chemical control and establishing biological control agents.

Further research will be carried out to investigate the levels of depletion in the soil seed bank on treated sites versus untreated sites, where prolific seeding is expected to occur in summer 2005–06. Presence and abundance of other species' seeds may also be assessed through glasshouse trials. Opportunities exist to investigate soil nitrogen levels and soil moisture, both of which would have local effects on regeneration of other species after removal of English broom.

This study also highlights the importance of an integrated approach to management. It is widely known that a combination of herbicide and fire treatment results in effective removal of English broom, and that physical removal results in less disturbance on vegetation communities than use of herbicide. This experimental program will allow various combinations of integrated management approaches to be tested which will add to managers' understanding of the likely outcomes of removal of this highly invasive woody weed.

Acknowledgements

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SESSION 6
Getting technical

Molecular genetic breeding to produce non-GM crops

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If the phrase 'molecular genetic breeding' is taken literally it could well be argued that the technology it describes has been used to produce non-GM crops ever since Gregor Mendel, in 1866, published his results on inheritance of traits in garden peas. The reason, in simple terms, is that plant breeding is the application of genetics to develop new plant genotypes. This involves the manipulation of both molecules and genes through crossing and selection.

Conventional plant breeding focused initially on sexual hybridisation between highly related species, but methods were subsequently developed to enable distantly related species to be mated. For example, bread wheat (*Triticum aestivum*) can now be crossed directly with goat grass (*Aegilops tauschii*) to generate *T. aestivum* genotypes with resistance to cereal cyst nematode (*Heterodera avenae*). Work is also in progress to transfer sprouting resistance from *Ae. tauschii* to *T. aestivum*.

The fundamental resource for the development of improved crop varieties is genetic variation and thus access to genes not present in the plant of interest is vital. Therein lies one of the key attractions of the 'transgenic' approach to crop improvement. Targeted genes can be transferred from one plant to another without sexual hybridisation.

Non-GM crops produced by molecular genetic breeding, which produce genotypes with targeted desirable traits, are of particular interest given the controversies around GM crops. Perhaps, however, we should pose the question of where 'acceptable' conventional breeding technology passes over into the grey area of 'unacceptable' genetic modification. This is important given that many crop cultivars have been produced either by applying mutagens to DNA to produce variation or through the selection of beneficial somaclonal variants or variants derived from *in vitro* culture and selection. Presently, plants produced by any of these three methods are not referred to as GMOs but they have certainly been subjected to genetic manipulation.

The molecular revolution in plant breeding has provided several tools to enable the more efficient and faster development of superior plant genotypes by traditional plant breeding methods.

These methods involve the use of:

- Marker Assisted Selection (MAS) whereby markers specific to a trait of interest are used to select for the presence of that trait without the need to use field screening or wait to maturity to assess for the phenotypic expression. The advantages of MAS are:
  * Phenotypic screening for the trait is not required.
  * Markers are not affected by environmental factors.
  * The trait can be detected at the seedling stage.
  * The sampling procedure is non destructive.
  * More than a single trait can be screened for at the same time so there can be the pyramiding of genes and thus the release of varieties with multiple gene traits.
  * DNA fingerprinting to determine the most appropriate plant breeding methods to be used in the development of a new variety and to verify true hybridity prior to germination.
  * The use of markers as diagnostic probes to specifically detect the presence of a pathogen and thus assist breeders in acquiring new germplasm from overseas.
- Targeting Induced Local Lesions IN Genomes (TILLING) a reverse genetic strategy that uses chemical mutagenesis or selection for naturally occurring mutations (ECOTILLING) followed by screening for single-base changes to identify single base changes that alter protein function (Till *et al.* 2004).

It should also be noted that other 'non-traditional' technologies are being applied to the development of crop cultivars through conventional plant breeding. These include:

- The development of doubled haploids to produce clonal lines for more accurate trait screening and hence a reduction in the time required to develop and validate a new variety.
- Somaclonal variation to enhance genotypic variability, to enable choice of a genotype that carries a desirable trait not formerly present in the available germplasm.
- *In vitro* techniques to select germplasm with specific attributes before it is grown in the field.

The methods and techniques described above can also be applied to GM varieties and will therefore facilitate their development and release.

In conclusion, we now have molecular and other advanced tools that have the potential to enhance the breeding of both non-GM and GM crops. The technologies have great potential to dramatically improve crop productivity and quality while the concerns around GM crops are addressed and resolved. An unfortunate situation has developed in most countries however, in that the funding of research into the development of GMs has been at the expense of investment in research on other aspects of plant breeding and the development of agronomic packages to optimise the performance of new varieties.

Verification of the factors affecting clodinafop efficacy

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Background

Medd *et al.* (2001) used Syngenta registration data collected prior to 1995 to identify correlations between clodinafop (Topik®) efficacy and environmental variables at the time of spraying. They showed that clodinafop efficacy on wild oat was correlated with clodinafop dose, adjuvant use, sum of minimum temperatures from seven previous days (TMINPRE7), soil moisture deficit 10 days prior to spraying (SMPRE10), maximum temperature on day of spraying (TMAX), spray water volume (VOL) and a TMAX × VOL interaction.

Interestingly, the temperature by spray volume interaction inferred that increasing spray water volume increased herbicide efficacy under adverse conditions. Those analyses also indicated that geographic location in Australia, and wild oat density and growth stage did not affect efficacy. An aim of ongoing work is to validate these findings with analyses of independent data collated from industry and data generated in field trials.

Industry data

Additional data were collated from 64 experiments, conducted between 1995 and 2003 by either Novartis, Bayer CropScience or Dow AgroSciences. The resulting data set contained 174 discrete entries of mean clodinafop efficacy. Experiments were conducted on commercial wheat crops naturally infested with wild oats on farms located throughout Australia's cropping region.

Site specific weather data around the time of spraying were generally unavailable in the reports and so were derived for the nearest locality using the Climate Impacts and Natural Resource Systems website (www.nrm.qld.gov.au/silo/). These interpolated data are based on hourly information supplied by the Australian Bureau of Meteorology and map coordinates of the experimental sites.

Soil moisture levels were estimated with a model that utilised soil physical parameters (such as wilting point and field capacity), environmental data (daily radiation, wind speed, rainfall, temperature readings) and agronomic information (planting date, ground cover, crop height, rooting depth). Some data that was missing from individual reports, such as crop planting date, were estimated using the methods described in Medd *et al.* (2001). Other information, such as the density of wild oats and other grass weeds, was included where possible.

Field trial data

Trial sites were established in NSW at Breeza, Cowra, Condobolin and Temora in 2003, and Cowra, Condobolin, Orange and Wagga Wagga in 2004. Clodinafop was applied to wild oat infestations from four to nine times at each of the sites, to give a total of 46 separate applications over the two years. On each occasion, the herbicide was applied at four dose rates and in three water volumes, plus non treated controls. Efficacy was quantitatively assessed, in terms of plant mortality, approximately 30 days after application and wild oat panicle density around anthesis. Fully automated stations collected a comprehensive set of soil and weather data at each site except Orange in 2004. Other measurements such as growth stage and leaf extension rates at the time of spraying, were also included in the analyses.

Table 1. A comparison of the factors correlated with clodinafop efficacy in Medd *et al.* (2001) and in subsequent analyses of additional data sets (refer to text for full names of abbreviated variables)

Factors correlated with clodinafop efficacy: industry trial data prior to 1995	Factors correlated in industry data (1995–2003)	Factors correlated in field trial data (2003–4)
Topik dose	✓	✓
Adjuvant use	✓	
TMAX	✓	✓
SMPRE10 / SM	✓	✓
TMINPRE7	✓	×
VOL	×	✓
TMAX × VOL	×	✓

Results and discussion

The correlation of numerous plant, spray and environmental variables with clodinafop efficacy on wild oat was quantified. Generally, the factors found to be correlated with clodinafop efficacy were consistent in both the industry and field generated data sets (Table 1). For example, of the factors identified by Medd *et al.* (2001), only VOL and therefore TMAX × VOL, were not correlated with clodinafop efficacy in the data set collated from industry trials conducted from 1995 to 2003.

Analyses of data generated in field trials showed that TMAX was correlated with clodinafop as a quadratic effect, where maximum efficacy was achieved with a temperature of around 19°C Minimum temperatures were not correlated with clodinafop efficacy. This was clearly demonstrated at one site where excellent wild oat control was achieved despite successive heavy frosts. Interestingly, maximum daytime temperatures at that site were optimal.

Adjuvant rate was not varied in the field trials and so was not included in the analyses of those results. Soil moisture on the day of spraying (SM), rather than SMPRE10, was correlated with clodinafop efficacy in the field data. That may have been influenced by results from the dry Condobolin site, where wild oat control was improved by rainfall immediately prior to spraying.

Medd *et al.* (2001) adopted the novel approach of analysing industry generated data and nominated a number of environmental and spray factors that were correlated with clodinafop efficacy in their analyses. Analyses of an additional industry data set and field trial results support the findings of that study. This suggests that the data could be combined and used to develop an applied, predictive model of clodinafop efficacy on wild oat.

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Ways to improve pesticide application in Australia through new sprayer technology and adoption of sprayer manufacturing and testing standards

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Abstract Even though pesticide application equipment has improved and spraying efficiency increased, operator safety and reduced environmental contamination remain a significant public concern when pesticides are used. This has been reflected in direct government intervention by the imposition of stricter drift and storage regulations in some states as well as necessitating certification for users and resellers in many states. It is also recognised that further Government restrictions are under active consideration relating to better advice on product labels. An alternative approach to Government involvement is the imposition of self regulation, based on standards for sprayer manufacture and testing of sprayers in use as well as the development of sprayers able to vary liquid volume and spray quality without the intervention of the operator. It is suggested that basic to such a strategy is the recognition, by both growers and buyers of produce, that pesticides must be applied as efficiently and effectively as currently possible. It is also argued that for an acceptable strategy pesticide users need to accept the need to ensure that their equipment is properly maintained. It is predicted that even if all of these changes were implemented the publics' concerns are unlikely to be totally alleviated. It is therefore argued that to achieve even greater public acceptance the industry needs to simultaneously adopt the aforesaid strategy as well as adopt a more pro-active transparent stance on educating the public about the advantages and disadvantages of pesticide use.

Introduction

The public continue to maintain that pesticide use is a threat to human health, through residues in food and water and via direct contamination of users and bystanders, as well as contributing to environmental degradation though their effects on biota within and outside the treated areas (Bruhn 1999). This perception has been particularly the case in the EU where pesticides are often used in fields above water aquifers or close to water courses and therefore where leaching of pesticides into underground (Anon 1995) or surface water (Anon 1997) is very important as it can reach the water consumed by the public. Such concerns have led to government restrictions on pesticide use, for example in the UK Local Environmental Risk Assessment for Pesticides (LERAP) (Anon 2001 and 2002) and the development of standards relating to their use (e.g. EN 907; 12761-1; EN 12761-2 and EN 12761-3).

It has been suggested that the development and adoption of these standards will improve pesticide application as well as operator, bystander and environmental safety (Herbst and Ganzelmeier 2002). This is entirely possible when application equipment is frequently not accurately calibrated and inappropriate droplet sizes are used. Rider and Dickey (1980) for example reported that only 40% of the users were applying within 10% of the desired dose; even more alarming are the studies of Cupery (1987) who found only 19% within the same limits. These reports only reflect poor calibration and mixing. These are exacerbated during application by for example boom instability which is reported to account for variations in the dose applied of up to 100% across and 30% along the swathe (Maybank *et al*. 1974). They concluded that if the distribution was improved the dose could be halved. These data are supported by those of Van De Zande *et al.* (2004) who found that spray deposits along the sprayed track in potatoes varied from -20 to +90% of that sprayed and their results also showed the efficacy was related to deposit. In other studies spray mixtures have been shown to vary in lateral distribution by two to three fold (Richardson and Combellack 1996). A similar situation exists in fruit crops where a two fold variation is typical (Manktelow *et al*. 2004). Therefore reported data support the notion that pesticides are applied inefficiently and that this is reflected as higher than necessary dose rates and or off target losses.

This paper will consider recent changes in sprayers to apply pesticides in Australia the Standards used and their likely impact on application efficiency and operator and environmental safety.

I. Recent changes in application technology

There have been a number of structural changes to sprayers which have led to improved work rates, a key need, and safety. In particular: booms made entirely or in part from aluminium to reduce weight and enable widths of up to 48 m; booms that have recirculating lines with air actuated diaphragm check valves so that the spray lines can be primed before spraying and also enable line cleaning; twin liquid lines to accommodate a wider range of travel speed, booms that when folded are not over 4 m in height to prevent contact with over head electric wires; devices to aid in the automatic control of boom height; larger pumps with deliveries up to 320 L min^{-1}; larger, up to 8000 L, and better designed tanks that have better access, drain better, have less rough surfaces and which are fitted with cleaning nozzles; typically two fresh water tanks one specifically for operators and the other to rinse the tank; levers to control fluid flow direction that are simpler to use due to better labelling; induction hoppers that are easier to clean and which typically include a drum washing facility that is effective; more durable pipes that are less prone to product infiltration and/or degradation; improved rate controllers which provide more accurate speed and liquid flow measurement as well as indicating remaining product and area treated; the use of GPS to aid in spraying accuracy using a light bar or through autosteer; faster acting and improved electric shut-off and flow direction valves to control liquid flow; developments in nozzle technology for example increased use of air induction nozzles to reduce drift while maintaining similar efficacy in most cases (Wolf 2002).

Some recent developments that have yet to be widely used but are worthy of consideration in Australia include: patch treatment of weeds using either historical records or image analysis to delineate spatial location and then applying the herbicide using for example pulse width modulation nozzles (Giles, Anderson and Nilars 2002, Giles *et al*. 2004) or direct injection (Christensen, Walter and Heisel 1999); an ultrasonic detection system for detecting height and presence of tree crops to limit spray wastage (Giles, Slaughter and Upadhyaya 2002); use of double spray nozzles i.e. two nozzles the same, or different, type and size in the same holder (Wolf and Caldwell 2002) or the 'double nozzle' designed to exploit the air entrainment characteristics of a downwardly pointing coarse spraying nozzle to entrain droplets from a fine spraying nozzle pointed at the spray sheet of the coarse nozzle (Hall *et al.* 1996); an improved twin fluid nozzle able to generate fine to extra coarse droplets over a wide range of flow rates(Combellack *et al*. 2004); a novel variable flow fan nozzle also able to accommodate a wider range in flow rate than conventional flat fan nozzles (Womac and Bui 2002) the development of a wetter that is much less drift prone (Combellack, Illingworth and Miller 2004).

It can be rationalised from this that there have been, and continue to be, continued improvements in sprayer design to apply pesticides in Australia. However the adoption of new technologies and the standards used by manufacturers varies enormously (Nugent 2001). For example even though AS/ANZ 2153.6:1996. Equipment for Crop Protection has been published as a standard for manufacture of sprayers it appears not to have been widely adopted.

II. Standards for pesticide application that could be used

There are three levels of standards; international which are identified by an ISO number and which have the highest degree of consensus; regional or country the second level of consensus (the most obvious regional standards are those for the EU which are identified by an EN number and which are recognised by all EU members) or National which are recognised within that country and the lowest level of are those defined by a manufacturer. Herbst and Ganzelmeier (2002) argued that harmonisation of standards within the EU, and with global institutions, will benefit all by overcoming trade barriers. They further argued that standards influence economic development more than patents. It is therefore regrettable that Australia is not active on most of the International committees that relate to pesticide application. For example ISO standards have been established for: Test methods for nozzles (ISO 5682-1); Test methods for sprayers (ISO 5682-2); Test method for flow control devices (ISO 5682-3); Antidrip devices (ISO 6686); Nominal tank volume and filling hole diameter (ISO 9357); Data sheet for field crop sprayer – Typical layout (ISO 10627-2); Test method for air-assisted sprayers (ISO 10625); Determination of residues (ISO 13440); Data sheets for air-assisted sprayers – Typical layout (ISO 13441-1) without significant Australian involvement. Even though Australia was not officially represented in the deliberations on these standards the manufacturers of sprayers, as well as those who provide components and or tests sprayers, should be aware of the standards and where possible embrace the outcomes.

There are also a number of EU standards for example:

- EN907:1997 Agricultural and forestry machinery – Sprayers and liquid fertiliser distributors – Safety;
- EN 12761-1:2001 Agricultural and forestry machinery – Sprayers and liquid fertiliser distributors – Environmental protection–Part 1: General;
- EN 12761-2:2001 Agricultural and forestry machinery – Sprayers and liquid fertiliser distributors – Environmental protection – Part 2: Field crop sprayers;
- EN 12761-3:2001 Agricultural and forestry machinery – Sprayers and liquid fertiliser distributors – Environmental protection – Part 3: Air assist sprayers for bushes and tree crops;
- EN 13790-1:2003 Agricultural machinery – Sprayers – Inspection of sprayers in use – Part 1: Field crop sprayers;
- EN 13790-2:2003 Agricultural machinery – Sprayers – Inspection of sprayers in use – Part 2: Air-assisted sprayers for bush and tree crops.

Both ISO and EU standards should be considered, and where appropriate embraced, by Australian sprayer manufacturers so as to ensure that producers are using sprayers made to the same standards as their EU counterparts thus averting the possibility of this being used as a restriction to trade. The relevant standards will thus be reviewed.

A. Suggested mandatory safety standards for Australian made sprayers

These suggestions are based on: EN 907 Standard for 'Agricultural and forestry machinery. Sprayers and liquid fertilisers – Safety'. The key requirements should be:

1. Ensuring sprayer can be operated on 8.5° slopes,
2. Have a cab if the boom is in the front of the sprayer,
3. If a front mounted boom is fitted to a self propelled sprayer the drivers seat must be at least 1000 mm above the maximum working height of the boom,
4. Ensure maximum height of folded boom is less than 4.0 meters,
5. Details how location of handles on manually folding booms must be 300 mm from nearest articulation point,
6. Boom to have a locking device when folded in transport position,
7. Have a device to lock the boom in vertical position,
8. The manual force necessary to raise the boom must not exceed 230 N,
9. If manual boom raised by a winch it shall be self arresting and able to withstand a load at least 1.3 times the weight of the boom,
10. If the boom is raised by hydraulics the downward speed must not exceed 10 mm sec^{-1} and must ensure a minimum height of 500 mm between boom and ground,
11. Provide a device for chemical transfer which is no more than 1500 mm above the ground or platform,
12. Filling hole of the tank must be no more than 1500 mm from the ground and/or 300 mm from the edge of the tank,
13. The tank must be at least 5% oversize of claimed volume,
14. The tank must have a tight lid that allows for pressure compensation,
15. There must be an accessible safe draining outlet that can be opened without a tool,
16. The pressure indicator must be readable from the drivers position,
17. The pressure indicator must have a diameter of 63 mm if within hand reach or 100 mm if beyond,
18. There must be no operator contamination if the pressure indicator leaks,
19. A safety valve must be fitted and operate at no greater than 120% of allowed value,
20. If a fan is fitted it must be protected from drawing in or discharging foreign matter and from access,
21. The fan drive must be able to be disengaged,
22. If a cab is fitted no hoses allowed in the cab,
23. If no cab the hoses have to be covered,
24. Hoses have to be marked with maximum pressure,
25. If there is a manual sprayer control it has to be within reach of the operator,
26. After switching boom off the maximum dripping volume must not exceed 2 mL timed over a 5 min period. The measuring to start 8 s after boom closed,
27. A clean water tank of at least 15 L has to be fitted that is isolated and fitted with a tap that does not need to be continuously pressed,
28. A rinsing water tank shall be provided. It shall not be combined with the clean water tank. It shall have a volume at least 10% of the main tank volume or at least 10 times the volume of the residual which is to be diluted as specified in the Instruction Handbook and,
29. An instruction manual has to be supplied.

B. Suggested basis for an Australian standard for Australian made sprayers

It is suggested that the Standard should be on those of EN 12761 parts 1, 2 and 3:2002 and aim to meet three objectives viz.:

1. Even distribution and effective deposition of spray on the target,
2. Avoidance of unintentional loss of pesticide into off target areas, and
3. Improvements in the handling of spraying equipment.

B 1. Suggested guidelines on sprayer design to achieve the three objectives:

1. Sprayers and their components shall be reliable and designed so that they can be used properly,
2. Sprayers shall be designed so that they can be safely operated and switched off immediately from the operators position,
3. Easy and safe filling and emptying shall be possible,

4. Unintentional dispersal of liquid shall be avoided,
5. Adjustment of application volume rate shall be easy, accurate and reproducible,
6. Adjusting and controlling the intended rate required,
7. Means of calibration of the equipment,
8. Means of adjustment and control of the volume rate,
9. Adequate and accurate measuring systems,
10. Readability of instruments,
11. Instructions for adjusting the volume rate.

(Comment: standard tests for most of these are detailed below.)

B 2. Suggested sprayer design to evenly distribute and deposit pesticides to ensure:

1. Evenness of distribution along the boom in the case of field crop sprayers,
2. Evenness in distribution in the driving direction in the case of field crop sprayers,
   (Comment: it is suggested that 1 and 2 should be possible using flow rate data by testing nozzles within their approved pressure range when new and then carrying out subsequent flow rate comparisons. If there is not >10% increase in flow there should be no change. A more stringent test would be for the sprayer manufacturer to carry out and detail CV tests, it should not be above10% when nozzles are new, and when retested if flow has not increased by >10% then CV should be acceptable.)
3. Evenness of mixing of the mixture,
   (Comment: while a standard of 15% has been set using ISO 5682-2, this is difficult to measure and needs careful consideration before making mandatory.)
4. Adequate deposition and distribution of the spray mixture on the target area,
5. Minimising losses to non target areas.

B 3. Suggested standard to ensure sprayers are easy and safe to clean by ensuring:

1. Complete emptying is possible and changing of worn parts shall be easy and safe. Fundamental to this is a tank which has a smooth inner and outer surface. For example an Rz ≤100 μm, see ISO 4287 (measured using ISO 4288 on surface texture assessment) and which drains completely.

(Comment: cleaning is an activity that is known to be major contributor to point source environmental pollution (e.g. Balsari *et al*. 2002, Basford, Rose and Carter 2004) and procedures are poorly described in sprayer manuals and difficult to carry out both internally and externally (Balsari *et al*. 2002, Ramwell and Johnson 2004, Holst, Neilsen and Anderson 2004) this is an area which requires serious consideration by sprayer manufacturers in Australia because of the legal liability implications.)

B 4. Mandatory markings affixed on the sprayer to include:

1. Name and address of the manufacturer,
2. Year of construction,
3. Designation of series or type.
4. Serial number if any,
5. Allowable circuit pressure,
6. Allowable maximum travel speed,
7. Allowable maximum spraying speed,
8. Mass when empty,
9. Allowable total weight,
10. Nominal rpm. and direction of pto,
11. Nominal power in kW (for self propelled machines),
12. Tank warning not to enter,
13. Warning if boom height when folded is over 4 m,
14. Warning on clean water tank to be filled only with clean water,
15. Tap alignment when filling, recirculating, rinsing and spraying.
    (Comment: there is no mention of durability and or size, colour or type face of lettering, all need to be considered and included.)

B 5. Mandatory markings on the pump to include:

1. Name and address of manufacturer,
2. Serial number,
3. Maximum pump output,
4. Maximum pump pressure,
5. Maximum pump output at maximum pump pressure,
6. Nominal and maximum rpm.

(Comment: there is no mention of durability and or size of lettering, both need to be considered.)

B 6. Mandatory markings on the hoses should show:

1. The maximum allowable pressure,
2. Minimum bend.

(Comment: there is no mention of durability and or size of lettering, both need to be considered; should chemical resistance be advised?)

B 7. Mandatory markings on, and colour of, nozzle tips, so that they can be:

1. Identified directly for type and size and or from information given in the instruction handbook. (Comment: or nozzle manufacturers handbook.)

B 8. Mandatory markings on filters to show:

1. The manufacturers name or sign, model and the mesh size.

B 9. Suggested contents for the mandatory sprayer instruction handbook:

Comprehensive instructions and information on all aspects of maintenance and safe use of the sprayer shall be provided. In particular the following shall be emphasised:

1. Issue warning that additional equipment or attachments for the sprayer must be used in accordance with the intended use,
2. Outline ways of filling to avoid contamination of the environment,
3. Delineate conditions of use, e.g. maximum driving speed when travelling and spraying and any corresponding adjustment to the sprayer.
   (Comment: sprayer speed has important implications in Australia for both operator and environmental safety as they are driven faster than in most countries. An agreed maximum speed should be agreed to by sprayer manufacturers for three point linkage, trailed and self propelled sprayers which could be different for different sized tanks and or booms and tractor size. Therefore they should be agreed to in consultation with tractor manufacturers.)
4. Outline ways of avoiding drift taking into account different parameters such as nozzles, pressure, boom height, wind speed, driving speed etc.
   (Comment: this has serious litigation implications and wording needs to be carefully considered by sprayer manufacturers. It is suggested that the sprayer manufacturer should advise the user to refer the pesticide manufacturers label for advice on spray quality to be used and then consult with the nozzle manufacturer's handbook for guidance on what nozzles to use. It would be advisable to stress to the user that drift is more important than efficacy. A copy of the nozzle manufacturers handbook should therefore be included in the Instruction Handbook.)
5. Provide an indication of total residual, which should be less than 0.5% of nominal capacity of the tank plus 2 litre m^{-1} of boom
6. Detail instructions on emptying and cleaning,
   (Comment: This also needs careful consideration because of possible litigation when sprayers are used for a range of products on a range of crops. It is suggested that the sprayer manufacturer direct the user to the pesticide label for advice on what chemical cleaners are appropriate. The user should then be asked to refer to the cleaner label for advice on how to use the product. The Instruction handbook should detail how to operate the sprayer to ensure both lines and tank are cleaned.)

7. Outline methods to check the application volume rate,
8. Detail mesh size of the strainers,
9. Nominate intervals for checking the sprayer,
   (Comment: this should be done on number of hours of use or annually?)
10. Identify restrictions on use of special crop protection products,
    (Comment: refer the user to the pesticide product label for advice.)
11. Outline necessary preparations for different conditions of use,
12. Identify possibilities of connecting other equipment and the necessary precautions,
13. Outline procedure for checking the sprayer on a daily, monthly, as well as yearly basis,
14. Detail the restarting procedures after winter,
15. Outline methods for adjusting pressure,
16. Detail adjustments to be made to the sprayer when various nozzles are used,
17. Detail the folding/unfolding procedure for the boom. Warn about dangers of overhead wires,
18. Give warning that before maintenance, particularly welding, is to be carried out the spray lines have to be emptied and rinsed,
19. Outline the procedures to deal with blocked nozzles in the field,
20. Detail precautions to be taken by operators against contamination for example use of protective clothing in, the safe use of transfer systems at each of the following stages of use:
    - filling the tank and adding chemicals
    - spraying
    - adjustments
    - draining and cleaning
    - changing chemicals
    - servicing

    (Comment: should the sprayer manufacturers be responsible for this or should they merely advise the user to read and adhere to the label?)
21. Issue warning that booms mounted on the front of the tractor shall not be used where there is no cab,
22. Warn against entering the tank as it is prohibited,
23. Emphasise the need to ensure that no other person is standing near the machine, particularly near a fan,
24. Detail the procedures to be used when parking the machine.

B 10. Suggested specific design requirements for ***Field crop sprayers****. These have been based on: EN 12761-2 Part 2.*

1. When filling
   I. A design that avoids any return from the main tank to the filling supply,
   II. Filling hole of the tank must be no more than 1500 mm from the ground and or 300 mm from the edge of the tank edge (ref. ISO 9357),
   III. Tank volume to be at least 5% more than nominated,
   IV. Strainers to have a minimum depth of 60 to 250 mm depending on tank size (ref EN 12761-2:2002) and a mesh size less than 2 mm,
   V. Filling should be at a rate of at least 100 L min^{-1} for tanks >100 L.

2. When fitting emptying device ensure:
   I. The volume of residual shall not exceed 0.5% of the nominal tank volume plus 2 litre m^{-1} of boom (ref. 2.1 ISO 13440:1996),
   (Comment: many sprayers in Australia would not meet this standard.)
   II. The emptying device shall allow complete emptying, i.e. no visible puddles after 5 min, when in a horizontal position (ref.4.5.3 EN 907:1997),
   III. It shall be possible to collect the liquid from the drain exit without contaminating the operator or other parts of the sprayer.

3. When fitting the tank contents indicator ensure that:
   I. It is visible from the drivers seat and when filling,
   II. Has acceptable tolerances e.g.
   - ± 7.5% for each graduation for up to 20% of the volume,
   - ± 5% for each graduation for volumes >20%.

   The accepted tolerances shall be measured with a maximum error of ± 1% with the sprayer horizontal and that other ways shall be allowable if same accuracy.

4. When fitting an agitating device/system to the sprayer ensure that:
   I. They are capable of producing a mixture that is within ± 15% throughout the tank.
   (Comment: this would be difficult to measure for a sprayer manufacturer and it should conform to ISO 5682-2.)

5. When fitting hoses and lines ensure:
   I. That they have a bending radius that will be within the limits specified by hose manufacturer,
   II. That they have no bends which could affect liquid flow,

6. When fitting a spray boom ensure:
   I. That it shall have maximum section widths of 4.5 m for booms ≤24 m and 6 m if >24 m (ref.4.1.3.1 EN 12761-2:2001),
   II. That it shall be possible to use any one section when required (ref.4.1.3.1 EN 12761-2:2001).

7. When fitting a spray boom ensure that its height adjustment:
   I. Shall have a minimum boom height range of 1.0 m (ref.4.1.3.1 EN 12761-2:2001),
   II. Shall be able to be adjusted to suit the crops to be sprayed thus if crop is 1.0 m boom must be able to be raised to 1.5 m (ref.4.1.3.2 EN 12761-2:2001),
   III. Shall be able to adjust boom height continuously or in a maximum of 100 mm increments (ref.4.1.3.2 EN 12761-2:2001),
   IV. Shall ensure spray is not intercepted by the structure of the sprayer,
   V. Shall have a boom structure that aligns parallel to the ground (ref.4.1.3.2 EN 12761-2:2001).

8. When the spray boom hits obstacles:
   I. Shall if up to 10 m be able to automatically move backwards to their original position (ref.4.1.3.3 EN 12761-2:2001) and be undamaged if hitting an object >0.9 from the mid point to the end of the boom when moving forward at 4 ± 0.2 km h^{-1} (ref.4.1.3.3 EN 12761-2:2001),
   II. Shall if >10 m be able to move automatically backwards and be undamaged if hitting an object >0.9 from the mid point to the end of the boom when moving forward at 4 ± 0.2 km h^{-1} or move forwards when moving backwards at 2 ± 0.2 km h^{-1} (ref.4.1.3.3 EN 12761-2:2001).

9. When fitting filters to the sprayer:
   I. Which has positive displacement pump it shall have a filter on the suction side,
   II. They shall have on the delivery lines one or more fitted central or in the lines of boom sections,
   III. They shall have a mesh size appropriate to the nozzle size to be fitted,
   IV. They must be easily accessible and their inserts easily removed,
   V. It shall be possible to remove the filters when the tank is full with only the liquid in the filter and or in the suction and delivery lines leaking out (ref.4.1.4 EN 12761-2:2001).

10. When fitting nozzles:
    I. It shall be possible to fix nozzles in set positions to ensure the spray is correctly directed.
    II. Dripping from nozzles post an 8 s elapse shall not exceed 2 mL per nozzle after 5 min when the spray is turned off, to achieve this diaphragm check valves shall be fitted (ref.4.1.5 EN 12761-2:2001),
    III. On booms over 10 m the end nozzles shall be protected from contacting the ground (ref.4.1.5 EN 12761-2:2001),

IV. The flow rate from an individual nozzle shall not deviate by more than 5% from the data in the flow rate tables (ref. ISO 5682-1).

11. When fitting measuring systems:
   I. The relevant dials shall be clearly visible from the vehicle seat,
   II. Each measuring system shall be accurate to within a maximum of ± 5% of the true value.
   III. The pressure gauges shall be within ± 20 kPa for 100 to 800 kPa working pressure gauges; ± 50 kPa for 800 to 2000 kPa gauges and ± 100 kPa for working pressure gauges over 2000 kPa (ref.4.6 EN 907:1997).
   IV. The pressure gauge shall be clearly readable and the needle stable.
   V. The scale on the pressure gauge shall be every 20 kPa for working pressures <500 kPa; 100 kPa for working pressures between 500 and 2000 kPa and every 200 kPa for pressures over 2000 kPa. (ref. EN 4.6 907:1997).

12. If supplying a test adapter it shall:
   I. Enable the pressure gauge to be tested using a ¼″ female thread connector,
   II. Be possible to connect a flowmeter between the pump and pressure regulator without damaging any hoses or removing the couplers from the hoses. Suitable ¾″, 1″ or 2″ adapters shall be provided by the manufacturer.

13. That adjustment of application volume rate shall:
   I. Have a maximum tolerance for all measurements of ± 2.5%,
   II. Have pressure adjustment devices that maintain a constant working pressure at constant pump rpm. After switching the boom or its sections on and off the working pressure shall return to its original value ± 7.5% even if the pressure has been changed (ref. 4.2.1 En 12761-2:2002),
   III. Have volume per hectare adjustment systems able to adapt to changes such as switching off nozzles, boom sections or to reflect travel speed to within ± 10% within 7 s (ref. 5.3 ISO 5682-3:1996),
   IV. During repeated adjustments of the same volume rate have coefficient of variation from seven readings not exceeding 3% (ref. 5.3 ISO 5682-3:1996),
   V. If spraying at a constant ground and pto speed have a maximum deviation from the mean rate that does not exceed 5% (ref. 5.3 ISO 5682-3:1996),
   VI. Have a maximum acceptable variation in measured flow rate or application volume rate of ± 6% of the mean or a 3% coefficient of variation (ref. 5.3 ISO 5682-3:1996),
   VII. Have a maximum pressure drop between where the gauge is located and when taken at the nozzle (including the check valve) not exceeding 10%,
   VIII. Provide a measuring jug with a capacity of at least one litre and an accuracy of ± 2.5% with the sprayer.

14. That spray distribution shall:
   I. Have a transverse coefficient of variation volume distribution, measured using a 100 mm wide patternator, not exceeding 8% at one boom height specified by the manufacturer of the nozzles (ref. ISO 5682-2:1996),
   II. Have for other boom heights specified by the nozzle manufacturer a coefficient of variation not exceeding 10% (ref. ISO 5682-2:1996; 5682-3:1996),
   III. For nozzles with overlapping patterns determine the CV only on those parts of the boom where there is total overlap,

15. That the flow rate for each nozzle shall:
   I. Not vary by more than 10% from that stated by the nozzle manufacturer,
   II. If of the same type across the boom not vary by more than 5% from the mean flow rate for all nozzles when tested at 250 kPa (ref.7.1 ISO 5682-1:1996),
   III. Be measured with an accuracy of ± 2.5% of the true value at 250 kPa (ref.7.1 ISO 5682-1:1996).

16. That to reduce spray drift the nozzles fitted shall have:
   I. A 10% volumetric droplet diameter not smaller than that for a 11002 flat fan nozzle delivering 720 mL min^{-1} at a pressure of 250 kPa (ref.7.5 ISO 5682-1:1996;5682-1:1996).

17. A rinsing water tank will be fitted that:
   I. Shall not be combined with the clean water tank for the operators use (ref.4.11 EN:907),
   II. Shall have a volume of at least 10% of the nominal tank volume or at least 10 times the volume of residual after draining (ref. 2.2 ISO 13440:1996),
   III. Shall be designed so that they can be connected to clean the pipes even when the tank is filled,
   IV. Shall also be connected so as to enable dilution of the residual.

18. Drum cleaning device when fitted shall:
   I. Be designed so that the volume of residue after cleaning is less than 0.01% of the drums volume (ref. Annex. A EN 12761-2:2002 also consider Balsari 2004).

*B 11. Suggested requirements for the manufacture of **Air- assisted sprayers for bush and tree crops** based on: EN 12761 2003 Part 3.*

These proposed requirement standards should be encouraged:

1. When filling:
   I. There shall be a design that avoids any return from the main tank to the filling supply,
   II. There shall be a filling hole on the tank that is no more than 1500 mm from the ground or more than 300 mm from the edge of the tank edge (ref. ISO 9357),
   III. The tank volume shall be at least 5% more than nominated,
   IV. There shall be strainers that have a minimum depth of 60 to 250 mm depending on tank size (ref EN 12761-2:2002) and a mesh size less than 2 mm,
   V. Filling should be at a rate of at least 100 L min^{-1} if tank >100 L,
   VI. If chemical induction bowl is fitted it shall have a filter with a maximum mesh size of 20 mm.

2. When emptying:
   I. The volume of residual shall not exceed 4% of the nominal tank volume for a tank volume of <400 litres; 3% if tank volume between 400 and 1000 litres and 2% if the tank volume is more than 1000 litres (ref. 2.1 ISO 13440:1996),
   II. The emptying device shall allow complete emptying, i.e. no visible puddles after 5 min, when in a horizontal position (ref.4.5.3 ISO 907:1997),
   III. It shall be possible to collect the liquid from the drain exit without contaminating the operator or other parts of the sprayer,
   IV. The tank outlet shall be guarded against accidental opening

3. When fitting tank contents indicator ensure that:
   I. It is visible from the drivers seat and when filling (ref ISO 9357),
   II. It conforms to accepted tolerances which are:
      - ± 7.5% for each graduation for up to 20% of the volume,
      - ± 5% for each graduation for volumes >20%.

      (N.B. The accepted tolerances shall be measured with a maximum error of ± 1% with the sprayer horizontal.)
   III. If other ways are used they have the same accuracy,

4. When fitting agitators or other devices to the tank for mixing ensure that they:
   I. Produce a mixture that is within ± 15% (ref. ISO 5682-2).

5. When fitting hoses and lines ensure:
   I. Bending radius will be within the limits specified by hose manufacturer
   II. There will be no bends which could affect liquid flow
   III. Pressure lines will be equipped with quick acting shut off valves

6. When fitting filters ensure that:
   I. Sprayers with positive displacement pumps shall have a filter on the suction side,
   II. On the delivery lines there shall be central filter(s) or filters in the lines of boom sections,
   III. The mesh size of the filter shall be appropriate to the nozzle size fitted,
   IV. Blockages will be indicated to the operator by for example positioning of the central pressure filters and pressure gauge,
   V. Filters shall be easily accessible and their inserts easily removed,
   VI. It shall be possible to remove the filter when the tank is full with only the liquid in the filter and or in the suction and delivery lines leaking out.

7. When fitting nozzles ensure that:
   I. It shall be possible to fix nozzles in set positions to ensure the spray is correctly directed,
   II. When the spray is turned off dripping from nozzles post an 8 s elapse shall not exceed 2 mL per nozzle after 5 min., to achieve this diaphragm check valves shall be fitted,
   III. The flow rate from an individual nozzle shall not deviate by more than 5% from the data in the flow rate tables (ref. ISO 5682-1),
   IV. Swivel nuts shall conform to ISO 14710.

8. When fitting measuring systems ensure that:
   I. The relevant dials shall be clearly visible from the vehicle seat,
   II. Each measuring system shall be accurate to within a maximum of ± 5% of the true value,
   III. Pressure gauges shall be within ± 20 kPa for 100 to 800 kPa working pressure gauges; ± 50 kPa for 800 to 2000 kPa gauges and ± 100 kPa for working pressure gauges over 2000 kPa (ref 4.6 EN 907:1996),
   IV. The pressure gauge shall be clearly readable and the needle stable,
   V. The scale on the pressure gauge shall be every 20 kPa for working pressures <500 kPa, 100 kPa for working pressures between 500 and 2000 kPa and every 200 kPa for pressures over 2000 kPa.

9. When fitting nozzles ensure that:
   I. It shall be possible to measure the flow rate for each individual nozzle,
   II. If multi-head nozzles are used this applies to each multi-head nozzle.

10. When fitting adjustment of liquid and air-flow devices:
   I. It shall be possible to switch off the blower(s) independently from other driven parts,
   II. It shall be possible to independently turn off the spray from each side,
   III. It shall be possible for one person to adjust the liquid and air-jets to spray different crops and crop heights in a reproducible way by means of markings, locking systems or the like,
   IV. It shall be possible to switch each nozzle off and to adjust the direction of their spray independently,
   V. In the case of multi-head nozzles this requirement applies to each multi-head nozzle.

11. When fitting an adjustment of application volume rate device:
   I. The maximum tolerance for all measurements shall be ± 2.5%,
   II. Pressure adjustment devices shall maintain a constant working pressure at constant pump rpm. After switching the boom or its sections on and off the working pressure shall return to its original value ± 7.5% even if the pressure has been changed,
   III. Volume per hectare adjustment systems shall be able to adapt to changes such as switching off nozzles, boom sections or to reflect travel speed to within ± 10% within 7 s (ref.5.1 & 5.2 ISO 5682-3),
   IV. During repeated adjustments of the same volume rate the coefficient of variation from seven readings shall not exceed 3% (ref. 5.3 ISO 5682-3:1996),
   V. If spraying at a constant ground and pto speed the maximum deviation from the mean rate shall not exceed 5% (ref. 5.3 ISO 5682-3:1996),
   VI. The maximum acceptable variation in measured flow rate or application volume rate shall be ± 6% of the mean or a 3% coefficient of variation (ref. 5.3 ISO 5682-3:1996),
   VII. The maximum pressure drop between where the gauge is located and when taken at the nozzle (including the check valve) shall not exceed 10%,
   VIII. A measuring jug with a capacity of at least one litre and an accuracy of ± 2.5% shall be supplied with the sprayer.

13. When measuring liquid output from nozzles they shall not vary by:
   I. More than 10% from that stated by the nozzle manufacturer for each nozzle,
   II. More than 10% from the mean flow rate for all nozzles,
   III. More than 50 ± 5% for left and right hand sides,
   IV. More than ± 2.5% of the true value for the testing device.

14. When measuring distribution of air
   I. The real output of the fan shall not deviate more than 10% from the nominal output,
   II. It shall be possible to adjust the sprayer so that the maximum air velocity is the same for both right and left hand sides (ref. ISO 9898:1999).

15. When fitting a rinsing water tank it shall:
   I. Not be combined with the clean water tank for the operator (ref. 4.11 EN 907:1997),
   II. Have a volume of at least 10% of the nominal tank volume or at least 10 times the volume of residual after draining (ref. 2.2 ISO 13440:1996),
   III. Be designed so that it can be connected to clean the pipes even when the tank is filled,
   IV. Be connected so as to enable dilution of the residual.

16. If a drum cleaning device is fitted it shall:
   I. Be designed so that the volume of residue after cleaning is less than 0.01% of the drums volume (ref. Annex. A EN 12761-2:2002 also consider Balsari 2004).

The above standards relate to the manufacture of new sprayers. Of equal importance are standards that can be used to assess the efficiency of sprayers in use. The EU has developed two such standards one for: 'Field crop sprayers (EN 13790-1:2003)' and one for 'Air-assisted sprayers for bush and tree crops (EN 13790-2:2003)'. These have been used as the basis for a voluntary 'National Sprayer Testing Scheme' in the UK and a mandatory scheme in Belgium (Braekman and Sonck 2004).

EN 13790 lists three arguments for inspection:

i. Operator safety,
ii. Less potential risk of environmental contamination,
iii. Good control of pests with the minimum input of product.

Inspection can be done on a mandatory or, as is suggested for Australia, on a voluntary basis. For this to be acceptable there would have to be an organisation that would be acceptable to the clients (e.g. sprayer and component manufacturers; users; produce purchasers; pesticide manufacturers; government and public) willing to be responsible for implementing and managing the scheme. The said organisation would also have to indicate who is authorised to carry out the inspections, write standards, train inspectors and suggest time intervals between inspections etc. The basis for a standard for such a scheme is outlined below separately for crop sprayers and bush and tree crop sprayers.

C 1. Suggested inspection procedure for:
Field crop sprayers in use

It is suggested that and Australian Inspection of Sprayers in use Standard should be based on the EU standard EN 13790-1:2003:

1. Preparation of the sprayer: The owner to carefully clean the sprayer inside and out including filters and filter inserts. Visible faults to be rectified by the owner before the inspection. An initial overview assessment should be made to decide whether to proceed.

2. Power transmission parts:

- Shaft, universal joints and locking systems no excessive wear and operate correctly,
- Guard for soundness and functionality,
- Restraining device to prevent shaft rotating shall work reliably.

Verify above by: Inspection and function test

3. Pump

- Either the pump must be suitable for purpose and deliver at least 90% its original flow. Verify by: Inspection and function test (Ref. 5.2.1 EN 1390-1:2003).
- or the pump shall deliver sufficient flow to attain maximum pressure with largest nozzles whilst maintaining adequate agitation (ref. 4.3 EN 1390-1:2003). Verify by: measurement (Ref. 5.2.1 EN 1390-1:2003).
- There shall be no visible pulsations caused by the pump. Verify by: Inspection and function test
- Pump safety valve if fitted shall work reliably, verify by: Inspection and function test
- There shall be no Leaks from pump. Verify by: Inspection

4 Agitation

- Visible recirculation shall be achieved when operating normally with the tank half filled. Verify by: Inspection

5. Spray liquid tank

- There shall be no leaks from the tank or its cover when closed. Verify by: Inspection
- There shall be a strainer in good condition in the filling hole which meets length in relation to tank size (ref 4.1.1.2 EN 12761-2:2002). Verify by: Inspection
- There shall be a grating in the induction hopper if fitted. Verify by: Inspection
- Pressure compensation for the tank shall be ensured. Verify by: Inspection
- There shall be a clearly readable liquid level indicator for the tank which is visible from the drivers seat. Verify by: Inspection
- It shall be possible to collect the emptied spray liquid simply, reliably, without tools and without spillage. Verify by: Function test.
- If there is a non-return valve on the water filling device it shall work reliably. Verify by: Inspection and function test,
- If an induction hopper is fitted it shall function reliably. Verify by: Function test
- If a drum cleaner is fitted it shall work reliably. Verify by: Function test

6. Measuring systems and controls

- All devices for measuring, switching on and off and to adjust pressure and or flow rate shall work accurately and reliably and there shall be no leakages. Verify by: Inspection and function test
- Switching on and off of nozzles shall be possible simultaneously. Verify by: Inspection and function test
- The scale of the pressure gauge shall be clear and suitable for the pressure range used. Verify by: Inspection,
- The scale on the pressure gauges shall be marked at least every 20 kPa for working pressures <500 kPa; 100 kPa for working pressures 500 to 2000 kPa and 200 kPa for working pressures over 2000 kPa (refs 4.6 EN 907:1997; 5.2.2.1 EN 13790-1:2003). Verify by: Inspection,
- The minimum diameter of the pressure gauge case shall be 63 mm if within arms reach otherwise 100 mm. Verify by: Inspection.
- The accuracy of the pressure gauge shall be ± 20 kPa for working pressures between 100 to 200 kPa; for pressures >200 kPa it shall measure with an accuracy of ± 10% of the real value. The pointer shall remain stable. Verify by: Inspection and function test (Ref. 5.2.3 EN 1390-1:2003)

7. Pipes and hoses

- There shall be no leakages from pipes or hoses when tested up to the maximum working pressure. Verify by: Inspection and function test.
- Hoses shall be fitted so that there will be no sharp bends and have no visible abrasion. Verify by: Inspection

8. Filtering

- There shall be at least one filter on the pressure side of the pump and if a positive displacement pump one also on the suction side. Verify by: Inspection
- The filters shall be in sound condition and the mesh size appropriate to the nozzles used. Verify by: Inspection and function test
- If an isolation device is fitted it shall be possible, with the tank filled, to clean the filters without any spray liquid leaking out except that which may be present in the filter casing and suction lines. Verify by: Inspection
- Filters shall be replaceable. Verify by: Inspection

9. Spray Boom

- The boom shall be stable in all directions and not worn in the joints or bent. Verify by: Inspection
- Both sides will be of the same length, verify by: Inspection,
- If fitted with beak away device it shall return to its original position when simulated to come into contact with an obstacle. Verify by: Inspection and function test (ref 4.1.3.3 EN 12761-2:2002),
- The boom shall be securely locked when in the transport position. Verify by: Inspection and function test,
- The nozzle spacing and orientation shall be uniform along the boom, except for special end boom nozzles. Verify by: Inspection and measurement,
- When stationary on a level surface the distance from the bottom of the nozzle to the ground shall not vary by more than 100 mm or 1% of the half working width. Verify by: Inspection and measurement,
- Regardless of the operating height of the boom the liquid will not be sprayed onto any part of the sprayer, verify by: Inspection and function test,
- On booms >10 m a device shall be fitted to prevent nozzle damage if the boom hits the ground. Verify by: Inspection,
- It shall be possible to shut on and off individual boom sections. Verify by: Inspection and function test,
- Boom height adjustment shall work reliably and conform to safety standards. Verify by: Inspection and function test (ref 4.4.4 EN 907:1997),
- Devices for damping boom movement and slope compensation shall work reliably. Verify by: Inspection and function test,
- When measured at the inlet of the boom sections the pressure shall not vary by more than 10% when the sections are closed one by one. Verify by: Function test (ref 5.2.7 EN 13790-1:2003).

10. Nozzles

- All nozzles shall be identical (type, size, material and origin) all along the boom except for special end nozzles. Verify by: Inspection.
- Anti drip devices and nozzle filters shall also be identical. Verify by: Inspection,
- After turning off the nozzles they shall not drip more than 2 mL in 5 s after the spray jet has collapsed. Verify by: Inspection and function test (ref 4.1.5 EN 12761-2:2002).

11. Transverse distribution

- The transverse distribution within the total overlapped area shall be uniform thus not exceed a coefficient of variation of more than 10% when an approved 100 mm patternator (ref ISO 5682.2) is used (ref 5.2.4 EN 13790-1:2003). Verify by: Inspection and function test. (Comment: this function test should be optional in Australia?)
- The volume of liquid collected in each groove on the patternator will not deviate more than ± 20% (ref 5.2.4 EN 13790-1:2003). Verify by: Inspection and function test (Comment: a function test should be optional in Australia?)
- The flow rate of each nozzle of the same type used on the boom shall not deviate by more than 5% from the mean flow rate of all the nozzles on the boom and shall not show an increase >10% compared to the mean of the nozzles when new when tested at 250 kPa. Verify by: Inspection and function test (ref. 7.1 ISO 5682-1:1996) (Comment: this test should indicate whether distribution is sound and could be used rather than patternation tests? However as nozzle wear increases CV, nozzles should be changed if flow increases by more than 10% compared to when new)
- The pressure drop between the measuring point for pressure on the sprayer and the end of each boom section shall not exceed 10% of the pressure shown on the pressure gauge. Verify by: Inspection and function test (ref 5.2.6 EN 13790-1:2003)

*C 2. Testing procedure for "**Air-assisted sprayers for bush and tree crops**" based on EN 13790-2:2003.*
The following shall be checked by inspection:

1. Preparation of the sprayer
The owner to carefully clean the sprayer inside and out including filters and filter inserts. Visible faults to be rectified by the owner before the inspection. An initial overview assessment should be made to decide whether to proceed.

2. Power transmission parts and blower:

- Shaft, universal joints and locking systems. Verify by: Inspection,
- Guard for soundness and functionality. Verify by: Inspection,
- Restraining device shall work reliably. Verify by: Inspection and function test.

3. Blower

- The blower (fan, blades and air deflectors) shall be in good condition and mounted in a functional manner. Verify by: Inspection and function,
- All parts shall be free of mechanical deformation, wear, tear, corrosion and vibrations. Verify by: Inspection and function,
- The guard shall be present and have no faults in its mesh. Verify by: Inspection.

4. Pump

- Either the pump must be suitable for purpose and deliver at least 90% its original flow. Verify by: Inspection and function test (Ref. 5.2.1 EN 1390-1:2003),
- Or the pump shall deliver sufficient flow to attain maximum pressure with largest nozzles whilst maintaining adequate agitation (ref. 4.3 EN 1390-2:2003). Verify by: inspection and measurement (Ref. 5.2.1 EN 1390-2:2003),
- There shall be no visible pulsations caused by the pump. Verify by: Inspection and function test,
- Pump safety valve if fitted shall work reliably. Verify by: Inspection and function test,
- There shall be no leaks from pump. Verify by: Inspection.

5. Agitation

- Visible recirculation shall be achieved when operating normally with the tank half filled. Verify by: Inspection.

6. Spray liquid tank

- The tank shall have smooth inner surfaces and shall have no leaks from the tank or its cover when closed. Verify by: Inspection,
- There shall be a strainer in good condition in the filling hole that conforms to length for the tank size. Verify by: Inspection (ref. 4.1.1.2 EN 12761-3:2001),
- There shall be a grating in the induction hopper if fitted. Verify by: Inspection,
- Pressure compensation for the tank shall be ensured. Verify by: Inspection,
- There shall be a clearly readable liquid level indicator for the tank which is visible from the drivers seat. Verify by: Inspection,
- It shall be possible to collect the emptied spray liquid simply, reliably, without tools and without spillage. Verify by: Function test,
- If there is a non-return valve on the water filling device it shall work reliably. Verify by: Inspection and function test,
- If an induction hopper is fitted it shall function reliably. Verify by: Function test,
- If a drum cleaner is fitted it shall work reliably. Verify by: Function test.

7. Measuring systems and controls

- All devices for measuring, switching on and off and to adjust pressure and or flow rate shall work accurately and reliably and there shall be no leakages. Switching on and off of nozzles shall be possible simultaneously. Verify by: Inspection and function test (ref. 5.3 ISO 5682-3:1996),
- All devices for adjusting pressure shall maintain a constant working pressure with a tolerance of ± 10% at a constant rotational speed and reach the same working pressure after the equipment has been switched on and off again. Verify by: Inspection and function test,
- Switching on and off of all nozzles simultaneously shall be possible. Verify by: Inspection and function test (ref. 5.3 ISO 5682-3:1996),
- The scale of the pressure gauge shall be clear and suitable for the pressure range used. Verify by: Inspection,
- The scale on the pressure gauge shall be marked at least every 20 kPa for working pressures <500 kPa; 100 kPa for working pressures 500 to 2000 kPa and 200 kPa for working pressures over 2000 kPa (refs 4.6 EN 907:1997; 5.2.2.1 EN 13790-1:2003).Verify by: Inspection,
- The minimum diameter of the pressure gauge case shall be 63 mm. Verify by: Inspection,
- The accuracy of the pressure gauge shall be ± 20 kPa for working pressures between 100 to 200 kPa; for pressures >200 kPa it shall measure with an accuracy of ± 10% of the real value. The pointer shall remain stable when operating. Verify by: Inspection and function test (Ref. 4.6 EN 907:1996; 5.2.2.1 EN 1390-2:2003),
- All other measuring devices, especially flow meters (used for controlling rate/hectare) shall measure within a maximum error of 5% of the real value. Verify by: Function test (ref. 5.3 ISO 5682-3:1996; 5.2.3 EN 13790-2:2003).

8. Pipes and hoses

- There shall be no leakages from pipes or hoses when tested up to the maximum working pressure. Verify by: Inspection and function test,
- Hoses shall be fitted so that there will be no sharp bends and have no visible abrasion. Verify by: Inspection,
- Hoses shall not be located in the spray plume. Verify by: Inspection.

9. Filtering

- There shall be at least one filter on the pressure side of the pump and if a positive displacement pump is fitted one also on the suction side. Verify by: Inspection,
- The filters shall be in sound condition, and the mesh size appropriate to the nozzles used. Verify by: Inspection,
- If an isolation device is fitted it shall be possible, with the tank filled, to clean the filters without any spray liquid leaking out except that which may be present in the filter casing and suction lines. Verify by: Inspection,
- Filters shall be replaceable. Verify by: Inspection.

10. Nozzles

- The nozzles shall be suitable to apply the products to be used on the crops to be sprayed. Verify by: Inspection,
- The nozzles they shall not drip more than 2 mL in 5 s after the spray jet has collapsed. Verify by: Inspection and function test (ref 4.1.5 EN 12761-2:2002),
- The nozzle type and size shall be the same on the left and right hand sides, except when only one side is used or where different nozzles are used to compensate for asymmetrical blower capacity. Verify by: Inspection,
- It shall be possible to switch off each nozzle separately. This would apply also to multi head nozzles. Verify by: Inspection and function test,
- It shall be possible to adjust the position of the nozzles in a reproducible manner. Verify by: Inspection and function test.

11. Distribution and nozzle output

- Each nozzle shall generate a uniform shape and a spray of similar droplet size range. Verify by: Inspection and function,
- test using blower off for hydraulic nozzles and blower on for air shear nozzles. Verify by: Inspection and function,
- The flow rate of each nozzle of the same type used shall not deviate by more than 15% from the nominal output nor show an increase >10% compared to the mean from all of the nozzles and the difference between the left and right hand sides shall be a maximum of 10%. Verify by: Inspection and function test (ref. 7.1 ISO 5682-1:1996; 5.2.5 EN 13790-2:2003),
- The pressure drop between the measuring point for pressure on the sprayer and the end of each boom section shall not exceed 15% of the pressure shown on the pressure gauge. Verify by: Inspection and function test (ref 5.2.5 EN 13790-2:2003).

11. Blower/fan output

- The fan shall rotate at the speed specified by the manufacturer. Verify by: Function test,
- If the fan can be switched off separately from the pump the clutch shall work. Verify by: Function test,
- Adjustable air deflectors on the blades and outlets shall function properly. Verify by: Inspection and function test,
- The spray shall not impinge on other parts of the sprayer so as to cause dripping. Verify by: Inspection and function test,
- Air velocity shall be measured with the fan operating at maximum recommended rpm at three points, top middle and bottom, on each side of the air outlet to compare output with that claimed. Verify by: Inspection and function test.

12. Test Facilities and measurements

- Pump capacity measurement should comply with 5.2.1 EN 13790-1:2003; 5.2.1 EN 13790-:2003,
- Verification of pressure gauges should comply with 5.2.2.2 and 5.2.2.1 EN 13790-1:2003,
- Flow meters for controlling volume per hectare rate should shall not give an error over 1.5% (ref 5.2.3 EN 13790-1:2003),
- Transverse uniformity if to be measured should use a patternator that conforms to 5.2.4 EN 13790-1:2003,
- Patternators should conform to 4.10.1 EN 13790:2003,
- The measuring error for nozzle flow rate shall not exceed 2.5% (ref 5.2.5 EN 13790-1:2003),
- Measurement of flow rate of nozzles fitted on the boom shall be made in accordance with clause 8 ISO 5682-2:1997,
- Measurement of nozzle flow can also be made removed from the boom on attests bench,
- Measurement of pressure drop shall be made using a standard test gauge,
- Measurement of pressure variation when sections are closed should be done in accordance with the procedure in 5.2.7 EN 13790-1:2003 or 5.2.5 EN 13790-2:2003.

13. Other test facilities required: Tachometer (P.T.O.), measuring tape, stop watch, measuring cylinder 2 litre with 20 mL divisions or a flow meter, air pressure gauge for pulsation damper on pump.

Conclusions

In most developed nations senior administrators continue to accept the assumption that pesticides are a threat to human health. These concerns are reflected as direct government intervention, imposition of stricter registration and application requirements. Adoption of 'new' sprayer designs and application technologies have led to improvements in efficiency but also complexity. Even so there are some 'new' technologies which have yet to be used, and which may well be of benefit, but will add to the complication. It is rationalised that because spraying typically takes up less than 10% of the year's activity for an operator the majority of applicators are not in a position to understand all of the interacting complexities involved. Therefore a change in accountability from the operator to the sprayer or pesticide manufacturer or ways to reduce the complication must to be found. It is suggested that the design of a sprayer that is able to vary flow and spray quality in real time, to reflect changes in adjacent hazard or weather, without the intervention of the operator to be best option. The technology exists for this to be done.

Another area of identified concern is the lack of standards governing the manufacture of sprayers as well as its functionality when in use. Standards are important in minimising operator and environmental hazard. This is an area of considerable interest in Europe, admittedly driven by the purchasers of food and consumers of water. It is therefore surmised that if food is grown in Australia with sprayers that do not conform to standards similar to those in Europe this may well be used as a reason to limit their importation. Further if the standards for sprayers were implemented it could be argued that food purchasers in Australia should not be satisfied with product from other countries unless sprayed with sprayers governed by similar standards. It is recognised that some sprayer manufacturers comply with ISO 9002 which guarantees quality control of components during the manufacture, delivery and aftercare of a sprayer but it does not address the issue of operator or environmental safety. The Europeans have developed and implemented standards that address their concerns about environmental and user risk. AS/ANZ 2153.6:1996. Equipment for crop protection. has been published as a standard for manufacture of sprayers but appears not to have been implemented. The suggested standards herein aim to update the latter as well as promote a testing procedure for sprayers in use that should be suitable for Australia and yet comply with EU requirements.

The main beneficiaries of the suggested pro-active strategy will be the produce buyers, consumers and public.

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SESSION 7
Successful monitoring (concurrent)

Weed biological control impact assessment in Victoria: notes on current activities

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Summary Notes are presented on weed biological control impact assessment activities currently in progress in Victoria.

Introduction

Biological control impact assessment is a necessary component of weed biological control programs (Delfosse 2004, Roush 2003). Such activities help to determine weed biological control success or failure, value of investments to end users, funding agencies and other stakeholders, can be used to persuade funding agencies to make further investments and help to improve the science of weed biological control.

The impact of biological control on weed populations can be evaluated in a variety of ways. These include comparing weed infestations before and after biological control, contemporaneous comparisons of weed infestations at sites with and sites without biological control agents, assessments of correlations between agent numbers and parameters indicative of weed population dynamics (e.g. Swirepik and Smyth 2003, Smyth *et al*. 2004), experiments to manipulate biological control agent attack levels by physical exclusion or containment or pesticidal exclusion methods (e.g. Adair and Holtkamp 1999) and combinations of these (e.g. Smyth and Sheppard 2002).

Each methodology has certain advantages and disadvantages. For example during the interval between before and after biological control, effects of other factors may accrue. These effects may be overlooked or difficult or impossible to resolve from the biological control effects. On the other hand, pesticidal exclusion methods enable studies in which it is possible and practical to compare indicators of fitness of weed populations with and without biological control agents while adequately controlling extraneous variables that in other methodologies may occur uncontrollably in association with temporal or spatial separation of treatment and control observations.

There are several weeds in Victoria for which studies to investigate the impacts of biological control are in progress. These notes briefly outline some of these studies and give preliminary assessments of biological control impacts based on observations and interpretations of researchers involved.

Bridal creeper *Asparagus asparagoides* L.

Site/s:	One site at **Warrandyte State Park** and one within the **Point Nepean National Park at Rye**. The trial is part of a national project, with sites also set up in SA, WA and NSW.
Situation:	Bushland.
Agent/s:	Bridal creeper rust *Puccinia myrsiphylli.*
Basis of assessment method:	Comparisons before and after colonisation by rust.
Indicators of impacts:	Bridal creeper biomass, fruiting, height of growth and ground cover, vegetation composition, photo point.
DPI[1] project staff:	Greg Lefoe and Raelene Kwong, Sarah Holland Clift[2].
Collaborators:	CSIRO Entomology.
Biological control impacts:	• The rust is causing significant reductions in the bridal creeper above ground biomass and fruit production. • At Warrandyte, the biomass was reduced by an average of 76% and seed production by 94% over a three year period (Kwong and Holland Clift 2004).

Site/s:	**Basic monitoring at many sites across Victoria.**
Situation:	Bushland, roadsides, citrus orchards, shelterbelts.
Agent/s:	Bridal creeper rust *P. myrsiphylli* and/or bridal creeper leaf hopper *Zygina* sp.
Basis of assessment method:	Comparisons before and after colonisation by rust and or leaf hopper.
Indicators of impacts:	Photo point, estimation of damage and defoliation.
DPI Project Staff:	Greg Lefoe and Sarah Holland Clift.
Collaborators:	Community stakeholders.
Biological control impacts:	• At high population levels, the leaf hoppers can cause severe defoliation and reduce fruit and seed production (Batchelor and Woodburn 2002, Holland Clift and Kwong 2004).

Spear thistle, *Cirsium vulgare* (Savi) Ten.

Site/s:	**Marysville, North East Victoria; Wilkin,** and **Strathdownie, South West Victoria.**
Agent/s:	Spear thistle gall fly, *Urophora stylata* (Fabricius).
Basis of assessment method:	Comparison of attacked and unattacked plants.
Indicators of impacts:	Numbers of capitula attacked, reduction in seed production.
DPI Project Staff:[3]	Jean Louis Sagliocco and Tom Morley.
Collaborators:	CSIRO Entomology.
Biological control impacts:	• Gall flies reduced seed production by up to 46% at Marysville in 2002, but this level is not sufficient to affect thistle populations (Sagliocco and Hinksman 2002). • Attack rates of capitula by the fly fluctuate widely from year to year.

English broom, *Cytisus scoparius*

Site/s:	**Basic monitoring at many sites.**
Agent/s:	Twig miner, *Leucoptera spartifoliella* (Hubner).
Basis of assessment method:	'Before and after' agent colonisation comparisons.
Indicators of impacts:	Photo points, plant biomass.
DPI Project Staff:	Jean Louis Sagliocco.
Collaborators:	CSIRO Entomology, Landcare research New Zealand.
Biological control impacts:	• Impact trials to commence in 2005.

Paterson's curse *Echium plantagineum* L.

Site/s:	**Balmattum Hills, North East Victoria.**
Situation:	Pasture grazed by sheep for wool and fat lamb production.
Agent/s:	Paterson's curse crown weevil *Mogulones larvatus* (Schultz). Paterson's curse flea beetle *Longitarsus echii* (Koch).
Basis of assessment method:	Insecticidal exclusion.
Indicators of impacts:	Pasture composition, Paterson's curse plant density, biomass and seed bank.
DPI project staff:	Tom Morley and Julio Bonilla.
Biological control impacts:	• Both agents improve pasture composition by suppressing Paterson's curse growth such that Paterson's curse plant density and biomass are reduced and clover (*Trifolium* spp.) and grass proportions of the pasture are increased. • Paterson's curse soil seed bank has declined since 1997 in associated with colonisation and population increases of biological control agents. • The crown weevil's ability to cause these changes diminishes as grazing intensity increases.

Site/s:	**Six sites in North East Victoria, one in South West Victoria.**
Agent/s:	Paterson's curse crown weevil *Mogulones larvatus* (Schultz) and or Paterson's curse flea beetle *Longitarsus echii* (Koch).
Basis of assessment method:	i) Correlation of Paterson's curse plant density and agent prevalence. ii) 'Before and after' agent colonisation comparisons.
Indicators of impacts:	i) Paterson's curse plant density and agent prevalence. ii) Soil seed bank.
DPI Project Staff:	Kerry Roberts.
Collaborators:	CSIRO Entomology, Department of Primary Industries NSW, South Australian Research and Development Institute and the Department of Agriculture Western Australia.
Biological control impacts:	• Based on assessments of sites across South Eastern Australia increases in the prevalence of the crown weevil over the last decade are positively correlated with an increase in Paterson's curse plant mortality (Swirepik and Smyth 2003). • Flea beetle appears to be responsible for substantial decreases in Paterson's curse plant density.

Horehound *Marrubium vulgare* L.

Site/s:	Wyperfeld National Park, North West Victoria.
Agent/s:	Horehound clearwing moth *Chamaesphecia mysiniformis* Boisduval.
Basis of assessment method:	Detailed studies on plant and insect densities.
Indicators of impacts:	Weed density, insect dispersal.

DPI Project Staff: Jean Louis Sagliocco and John Weiss.

Biological control impacts:
- Steady increase of insect frequency, documented insect dispersal, documented reduction in weed density and weed population age structure (Sagliocco and Weiss 2004).

Blackberry, weedy *Rubus* L. spp.

Site/s: **Central Gippsland; Murrindindi; Tallangatta.**

Situation: Large infestations of *R. anglocandicans* A. Newton and *R. leucostachys* in pasture.

Agent/s: Blackberry rust *Phragmidium violaceum* (C.F. Shcultz)Wint.

Basis of assessment method: Fungicidal exclusion.

Indicators of impacts: Foliage cover, cane cover, luxuriance (using point quadrats), cane length, cane mass, crown mass, cover and luxuriance of associated vegetation.

DPI Project Staff: Robin Adair, Franz Mahr, Aline Bruzzese, Julio Bonilla.

Biological control impacts:
- Significant differences in blackberry growth detected after one season.
- Foliage cover, stem cover, cane mass and luxuriance are reduced when blackberry rust is present at high levels on host plants, although not all indicators were significant at all sites.
- Impact effects are apparent across a climatic gradient in Victoria.
- Rust intensity can vary from season to season.
- The project will monitor rust impact over at least 3 seasons.

Ragwort, *Senecio jacobaea* L.

Site/s: **Foster North, South Gippsland.**

Situation: Verges, vehicular track, *Pinus radiata* D.Don plantation, altitude 265 m.

Agent/s: Ragwort plume moth *Platyptilia isodactyla* (Zeller).

Basis of assessment method: Insecticidal exclusion.

Indicators of impacts: Seed production inference, plant size, plant survival, plant density.

DPI project staff: Tom Morley and Julio Bonilla.

Biological control impacts:
- Ragwort seed production, plant size and survival appear to be being suppressed by *P. isodactyla* in this study.
- No difference in ragwort plant density between *P. isodactyla*-infested and insecticidally treated plots has been observed.

Site/s: **Mt Tassie, South Gippsland.**

Situation: Undisturbed open space between silviculture plots, altitude 700 m.

Agent/s: Ragwort crown boring moth *Cochylis atricapitana* (Stephens).
Ragwort flea beetle *Longitarsus flavicornis* (Stephens).

Basis of assessment method: Insecticidal exclusion.

Indicators of impacts: Seed production inference, plant size, plant survival.

DPI project staff: Tom Morley and Julio Bonilla.

Biological control impacts:
- Ragwort seed production, plant size and survival appear to be being suppressed by the combined impact of the crown boring moth and flea beetle in this study.

Site/s: **Callignee South, South Gippsland.**

Situation: Pasture grazed by cattle for beef production, altitude 500 m.

Agent/s: Ragwort crown boring moth *Cochylis atricapitana* (Stephens).

Basis of assessment method: Insecticidal exclusion.

Indicators of impacts: Pasture composition, seed production inference.

DPI project staff: Tom Morley and Julio Bonilla.

Biological control impacts:
- It has not yet been possible to detect any effect of the crown boring moth on ragwort plant density in this study.
- It is not certain whether this is due to absence of significant impact by the moth in this situation or the fact that the insecticidal exclusion method is only partially effective.

Gorse, *Ulex europaeus* L.

Site/s: **Basic monitoring at many sites across Victoria.**

Agent/s:	Gorse spider mite *Tetranychus lintearius* Dufour, Gorse thrips *Sericothrips staphylinus* Haliday.
Basis of assessment method:	'Before and after' agent colonisation comparisons.
Indicators of impacts:	Gorse biomass seed production.
DPI Project Staff:	Kylie MacGregor, Raelene Kwong.
Collaborators:	Tasmanian Institute for Agricultural Research.
Biological control impacts:	• Tasmanian studies have found that gorse spider mite can reduce foliage dry weight of infested branches by 37% over a 2.5 year period (Jamie Davies unpublished). • An integrated control experiment in Tasmania indicated that a combination of gorse thrips, rye-grass competition and simulated grazing resulted in a gorse seedling mortality of 93% (Ireson *et al.* in press). • No comparable data are available for Victoria.

Docks (*Rumex* L. spp.), spear thistle and gorse are all weeds in Victoria on which biological control agents are established but about which knowledge of biological control impacts is insufficient to reliably judge if any benefits are accruing (e.g. Morley *et al.* 2004). Stakeholders in the management of weeds such as these and the Victorian community at large could benefit from further investment in study and publication of the biological control impacts on them.

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Footnotes

[1] Department of Primary Industries, Victoria.

[2] Not currently involved in bridal creeper research.

[3] No Victorian researcher are currently involved in this project.

Taking the wind out of willows: a national focus to willow management in Australia

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Summary Willows are among Australia's most serious riparian and wetland weeds and are listed as one of twenty Weeds of National Significance (WoNS). Victoria has the country's largest number of naturalised taxa and the most extensive invasions. The National Willows Program is working to coordinate willow management across Australia by facilitating progress against the National Willows Strategic Plan. The major goals of this Plan are to halt the spread of willows, effectively manage current infestations and increase community support for management. This paper outlines some of the major challenges facing willow managers in Australia and how a national program can contribute to meeting these challenges. It also provides some case studies highlighting the significance of the problem and the benefits of successful management.

Keywords Willows, *Salix*, impacts, integrated weed management, Weeds of National Significance (WoNS)

Introduction

Originally from Europe, Asia and North and South America, willows were introduced to Australia for a range of purposes, including basket making, cricket bat production, stream stabilisation, ornaments and shelter. Planting began soon after European settlement and was most extensive from the 1950s to 1970s to help control stream and gully erosion and for use as windbreaks. During this time, willows became a familiar icon of the Australian landscape.

Willows (*Salix* spp.) are now among the most serious riparian and wetland weeds in temperate Australia. In 1999, willows (except *S. babylonica*, *S.* × *calodendron* and *S.* × *reichardtii*) were listed as one of Australia's 20 Weeds of National Significance (WoNS), due to their highly invasive nature and impacts on stream and wetland hydrology and biodiversity. The WoNS program provides a focus on weeds for which a nationally coordinated action program would bring greatest benefits. To help guide national coordination, the National Willows Strategic Plan (2001) (pdf version available on www.weeds.org) was published in 2001, with the vision to 'stop willows destroying our waterways and wetlands'. The Plan aims to deliver three primary outcomes:

- stop further spread of willows
- manage the existing areas of willows
- gain community support in managing the willow problem

Some of the major challenges to achieving these three goals include preventing further trade and planting; identifying and preventing the spread of key taxa; effective on-ground management including mapping, control, follow up and replacement with indigenous vegetation; the development and integration of biological control methods; and regulation of industries and people utilising willow taxa (e.g. the nursery and cricket bat industries).

This paper explores these challenges and how a national program can contribute to meeting such challenges. It also provides some case studies highlighting the national significance of the problem and the benefits of successful management.

Stopping the spread of willows

Although willows already infest thousands of kilometres of watercourses throughout south-eastern Australia, only a fraction of their potential habitat has been invaded (Figure 1) (ARMCANZ *et al*. 2001). Willows may therefore spread far more widely, posing a serious threat to the riparian interface throughout southern Australia. Willows can either spread sexually (via seed) or vegetatively (via twigs or branches) or by both of these means. The seeds germinate on bare, wet sediments, while branches, attached or detached, root mainly on wet ground or in shallow water.

To help prevent the further spread of willows, the Australian Quarantine and Inspection Service (AQIS) has restricted additional importation into Australia. Willows (except *Salix babylonica*, *S.* × *reichardtii* and *S.* × *calodendron*) are also not legally allowed to be sold, propagated or knowingly distributed in any State or Territory except Victoria and the Northern Territory. In Victoria, the legislative status of willows is currently being assessed.

Although willows are listed collectively as 'one' of the 20 WoNS, there are at least 32 known naturalised willow taxa and 45 taxa have been sold through the nursery trade in Australia. At least 22 of these taxa are present within Victoria and 33 available through Victorian nurseries (ARMCANZ *et al*. 2001).

The continued sale and planting of willows poses a major challenge to our ability to halt their spread and thus protect our waterways from further impacts. Even within states where the sale of most willows is illegal, prohibited taxa continue to be sold, sometimes under the label of a permitted taxon (e.g. *Salix matsudana* 'tortuosa' sold as *Salix babylonica* in Tasmania,

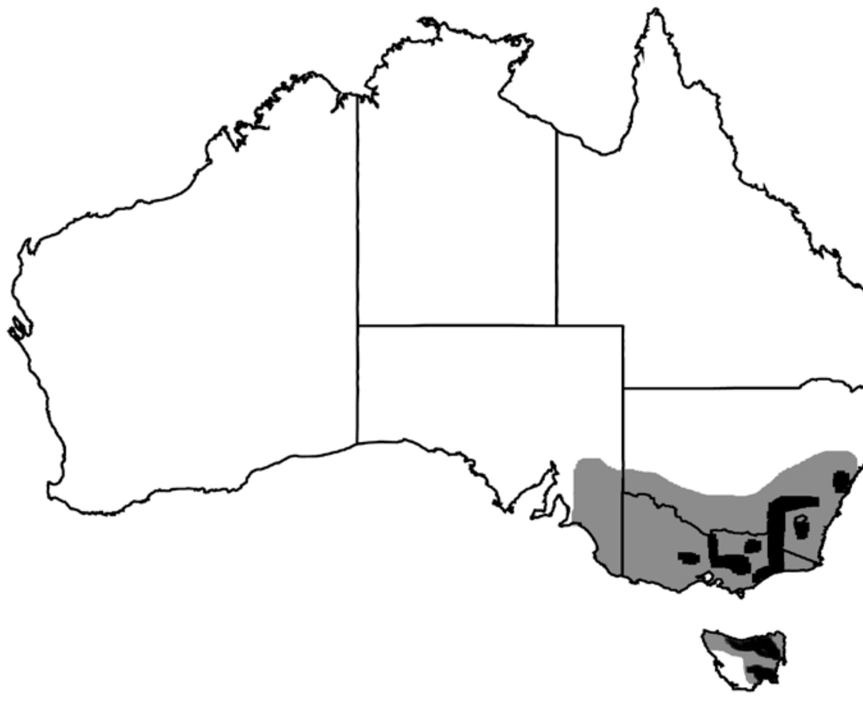

Figure 1. Present (dark areas) and potential distribution (grey areas) of willows in Australia (ARMCANZ *et al.* 2001)

Andrew Crane personal communication). In addition, willows have a remarkable ability to form hybrids, making accurate identification difficult (Cremer 1995). Almost all willow taxa are capable of hybridising with one or more other taxa (mostly within the same subgenus) if they flower simultaneously and fertile male and female plants grow near enough for pollination to occur (Cremer 2001). While some resulting hybrids may not flourish, some have proved to be more invasive and there is potential for strains to develop that are even better adapted to local conditions within Australia (Cremer 2001). Even the iconic weeping willow (*Salix babylonica*), one of three taxa excluded from the WoNS listing, has the potential to hybridise with other willow taxa (e.g. *S. matsudana* ×× *alba* and *S. fragilis*), with some of the resulting hybrids apparently more invasive than their parents (Cremer 2001).

An interesting example of willow hybridisation is the Kilmarnock Willow, which comprises a weeping pussy willow scion grafted onto an upright pussy willow rootstock. One such plant recently discovered in Tasmania comprised a female weeping scion grafted onto an upright male plant (Baker and Conod 2003). The upright male section had begun to sucker and catkin formation occurred simultaneously on both sections of the plant. Seed collected from this plant was sown and successfully germinated (Baker and Conod 2003). Seed from this plant may be the source of the recently discovered northern infestation of wild pussy willows in Tasmania, found just 20 km to the west, but further research is needed to confirm this (Baker and Conod 2003). A similar or identical product is for sale at some nurseries in Victoria, traded as Celtic Cascade®, *Salix caprea* 'Pendula', or Kilmarnock Willow. At one nursery it is advertised as 'the plant you just can't kill'.

The buying and planting of all willows, including the three taxa not listed as WoNS, should always be approached with caution, given the ease with which they can hybridise and the potential for otherwise less invasive taxa to become more aggressive and unpredictable once hybridisation has occurred. It is therefore critical to ensure that compatible male and female plants are kept well away from each other to prevent the formation of viable seed.

The ability of willows to spread by seed highlights the national significance of the willow problem. Whereas vegetatively reproducing willows are generally confined to streams and are dispersed downstream, the great mobility of some seeding willows requires that effective control be coordinated across regions and states. For example, Cremer (2003) observed that the seed of *S. nigra* (black willow) had spread up to 50–100 km in every direction from a site near Tumut in New South Wales since it had been originally planted there 30 years earlier. In addition, Cremer (2003) observed that *S. cinerea* (grey sallow or wild pussy willow) seed can travel by air or water for tens of kilometres.

Such mobility provides these two seeding willows with the ability to move into streams and wetlands and other unexpected environments. *S. cinerea* has proven to be extremely adaptable, invading just about any boggy and intermittently moist sites, anywhere from sea level to above the alpine tree line (Cremer 2003). For example, the first known population of *S. cinerea* seedlings to occur in Tasmania was recently discovered along a road cutting near Hobart (Matthew Baker personal communication). Areas where vegetative willows are being removed could also easily be colonised by seeding willows if not adequately managed and rehabilitated. Infestations of seeding willows therefore urgently need to be identified and incorporated into a national control strategy.

The spread of *S. cinerea* can be slow, as specific conditions are required for successful seed germination. However, while spread may appear restricted for many years, a catastrophic explosion may occur at any time given the right conditions. Sites most likely to be invaded by *S. cinerea* are areas where bare, wet ground exists for a month following seed shed (around October/November) (Cremer 2001). Such conditions conducive to a population explosion of *S. cinerea* occurred at Wingecarribee Swamp in southern New South Wales in August 1998 (Cremer 2001). Heavy rains resulted in canyons of exposed bare wet peat which were invaded by 100 000 *S. cinerea* seedlings in November 1998 and a further 1 000 000 seedlings in November 1999.

Another more recent example has occurred in Victoria's Alpine National Park. Major bushfires in early 2003 resulted in significant stands of native vegetation being burnt. Subsequently, *S. cinerea* seedlings readily established in newly exposed moss beds. These beds form the initial collection and filtering point of a substantial part of Victoria's water catchment. Invasion of *S. cinerea* therefore not only threatens the value of the National Park but threatens water quality throughout the catchment. It has been suggested that this may necessitate increased government spending on water quality infrastructure improvement to compensate for the loss of these alpine moss beds (Parke 2005). A rapid response program was established to control new seedlings and their parent plants through partnership between Parks Victoria, North East Catchment Management Authority, Mt Hotham and Falls Creek Alpine Resort Management Boards, Southern Hydro Pty Ltd. and 4WD Victoria. In one year of control effort so far, it is estimated that more than 50 000 seedlings have been removed and 50 km of mature willows controlled (Mandar Services Pty Ltd. 2005). Continued follow up over a number of years is now required to ensure that all plants are removed.

Such case studies demonstrate the clear need for accurate identification and control of the most invasive taxa, including early detection of and response to the establishment of seedlings and new stems.

Manage the existing areas

Effective and strategic management of willows is not a simple issue and needs to occur over many years as part of a broader program of riparian management and rehabilitation (ARMCANZ *et al*. 2001). Total eradication of willows is clearly not feasible, due to the extent and number of infestations (Groves and Panetta 2002). There is therefore a need to establish clearly defined priorities for control of populations that focus on geographic areas and willow taxa. However, further information is still required on the extent, rate and pattern of spread and impacts of certain willows (e.g. seeding willows), in order to best prioritise which areas and taxa to target. Gaining such information is hindered by difficulty in identifying different species, varieties and hybrids and by the inaccessibility of some areas due to difficult terrain or ownership consideration. Willow management also needs to be approached with the recognition of limited resources and within the constraints of funding bodies and funding periods. Identification and strategic planning, mapping and control of the most invasive willows are therefore the highest priorities in the national plan (ARMCANZ *et al*. 2001).

Numerous willow projects have been undertaken at local and regional scales across Victoria and Australia. While local management efforts are important, broadening the area of control to encompass adjoining areas and catchments that are contributing propagation material would be of most benefit. In this case, partnerships between affected land managers, such as that described for the Alpine National Park project, is the only way to achieve the desired outcome. Otherwise, there is a high chance of reinvasion by willows, and control efforts and funding may therefore be wasted. In addition, a staged control effort over many years is required, to allow the river to gradually adjust to the removal of willows. Willow control funds need to be managed to ensure monitoring and follow-up control occurs in treated areas in subsequent years, even if this means removing fewer willows in the short term.

Mechanical and chemical control methods for willows have been developed over many years. There are now a number of methods to choose from, with the best option dependent on the location, taxa and extent of the willow infestation. Given the complex nature of rivers and the need to understand geomorphological, hydrological and ecological concepts when removing willows, willow control along rivers generally requires expert advice from a number of specialists. Removal of mature willows generally also requires the help of an experienced contractor, due to the operational hazards associated with their removal.

A national best management and case studies guide for willows is currently being compiled to assist managers in adopting best practices in different environments and situations. It will contain detailed information on biology, impacts and identification, options for management in various situations, relevant case studies, management protocols, national data sheets, mapping guidelines and advice for funding applications. The guide is expected to be available free of charge in July 2006.

The recent arrival of the willow sawfly (*Nematus oligospilus*), and other potential organisms associated with willows, may shape future best management practice for willows. The willow sawfly was first found in Australia in Canberra in March 2004, and was already present in such high densities that, even if desired, eradication was not feasible. The sawfly is now well established in the ACT and surrounding areas and there have also been reports of its presence along the south coast of New South Wales, the Adelaide Hills of South Australia and in Keilor in Victoria (Eligio Bruzzese personal communication).

The arrival of the sawfly has already created some controversy, with speculation that it was deliberately introduced. It is not known, however, how this insect arrived in Australia – it has not been deliberately introduced as part of any official biological control program. The sawfly has been present in New Zealand since 1997 and is now common across the country, having dispersed at a rate of approximately 300 km per year. In New Zealand, the sawfly appears to be specific to certain willow taxa (Charles *et al.* 1999).

The potential severity and the dynamics of sawfly outbreaks in Australia are as yet largely unknown. However, it has already been observed on several willow taxa, including *S. fragilis*, *S. matsudana* and *S. babylonica*. By as early as January this year, the sawfly had almost completely defoliated *S. alba vitellina* and *S. fragilis* trees at a site near Canberra Airport, while having minimal affect on nearby *S. babylonica* weeping willow (Lynton Bond personal communication). Work is currently being undertaken nationally to assess the distribution and status of the sawfly and other organisms associated with willows in Australia, with a view to understanding their impacts and facilitating the development of a broader range of willow management options than is currently available.

Gain community support

Engendering support for the willow problem poses a major challenge to willow management in Australia due to the utilitarian and cultural values of willows. However, in order to prevent further spread and effectively manage current infestations of problem willows, community support is desperately needed.

It is only over the last 20 years or so that the problems with willows have been broadly recognised, and now the same trusts and boards that originally advocated their use often conduct extensive willow removal operations (ARMCANZ *et al.* 2001). Given this relatively dramatic shift in waterway management, it is not surprising that people still advocate the planting of willows and/or resist their removal. After all, why should such a useful and beautiful tree so suddenly become a target for those wishing to rehabilitate the environment?

The reason for such a profound shift in perspective has been the mounting evidence of the impacts that willows cause to both aquatic and riparian environments and their ability to so readily and aggressively colonise new areas. Despite having been previously planted along waterways to combat bank instability, willows actually form multitudes of stems that obstruct and divert floods and subsequently erode riverbanks, particularly along small, narrow rivers (Cremer 1999). Being deciduous, willows produce dense shade cover during summer, drop all of their leaves in autumn and remain bare for the winter, compared with native evergreens that provide a constant, less dense shade cover and drop their leaves gradually year round. The dense summer shade cover of willows combined with their impenetrable root system greatly inhibits both terrestrial and aquatic plant growth. In contrast to native trees, willows drop all of their leaves at once in autumn and the leaves break down more rapidly (Hladyz 2001). Such extreme variation in leaf cover and the pulse of nutrients entering the water can alter the temperature and oxygen content and subsequently cause changes to the primary production of algae (Lester *et al.* 1994) and to aquatic food webs (Glova and Sagar 1994, Read and Barmuta 1999).

A common misconception has been that willows provide good faunal habitat. Research has demonstrated that willows cause significant reductions in terrestrial and in-stream insects (Read and Barmuta 1999, Yeates and Barmuta 1999, Greenwood *et al.* 2004), platypus (Graeme Rooney personal communication) and birds (Holland 2002) when compared with native trees and shrubs. In addition, Holland (2002) found that willow-lined reaches did not provide much better habitat for terrestrial birds than did cleared reaches.

Several angling groups have become involved with removal programs in order to create more favourable habitats for fish. For example, $165 000 in funds collected from angling licences in Victoria is being dedicated to willow removal along the banks of the Goulburn River near Thornton in order to improve trout fisheries. The New South Wales Council of Freshwater Anglers has developed a 'Willow Eradication Policy' for use in lobbying landholders, local councils and State government. Numerous other groups are also working towards managing the problem in Australia. In Victoria, this includes numerous Landcare groups, Catchment Management Authorities, local governments, State Government departments and local landholders.

Gaining such community support can lead to early identification of potentially threatening adult or seedling willows. This is critical to our ability to most effectively manage willows with the limited resources available. For example, *S. cinerea* and other seeding willows may be growing in dams, wetlands, drainage lines and any other place that happens to remain moist for the month following seed shed. Without the support and active participation of landowners, it is extremely difficult to detect such plants out of sight of nearby roads.

A network of people who are able to identify, look out for and report on new outbreaks would be of great benefit to our ability to stop the spread of, and most effectively manage, current infestations. General community awareness of willow taxa has so far focussed on the most widespread willows in the context of large-scale removal programs. For example, crack willow (*Salix fragilis*) is widespread throughout Tasmania and Victoria and is widely recognised as an invasive plant, while other taxa are still highly valued. In southern New South Wales, there is greater awareness of the black willow (*Salix nigra*), because a targeted eradication and awareness campaign has taken place. By working together and addressing willows from a national perspective we can learn from the lessons of different states and regions and act on them before they become a problem.

Conclusion

Willows pose a significant challenge to the conservation and rehabilitation of many of Australia's temperate rivers and wetlands. The number of different taxa and their ability to rapidly disperse and to hybridise complicates our ability to manage them, as does their utilitarian and cultural value. To most effectively manage willows across Australia, a national management focus is clearly required. For example, the great mobility of some seeding willows requires that effective control is coordinated across regions and States, as local control will otherwise only be temporary. A national approach will help facilitate information sharing amongst regions and States to more effectively manage infestations and prevent spread into new areas. For a nationally coordinated effort to be a success, all landholders, Landcare groups, Catchment Management Authorities and public land managers need to work together to reduce the impacts of willows and improve and protect the health of our waterways for the future.

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Dedication

Australian willow expert Kurt Cremer recently passed away. Kurt was the original champion of the willow cause, pushing willows into the national spotlight and leading the way in willow research in Australia. Anyone who has ever been involved with willows will know Kurt's name and many knew him personally. His dedication to willow research and assisting people in the management of willows across Australia was impressive. Kurt has left a great legacy, and will be greatly missed.

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Using community-based networks for the distribution of biological control agents for Paterson's curse in Victoria

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Summary The biological control of Paterson's curse program in Australia has pioneered ways to fast track the release and spread of biocontrol agents throughout temperate Australia. By setting up extensive networks involving Landcare and farmer groups, Local Government, Pest Plant officers and hundreds of individual landowners, biocontrol agents have been released over a much wider area and in a shorter amount of time than would have been possible without such involvement. This paper uses the Victorian program to highlight the important role that community-based distribution networks can play in speeding up the success of biological control.

Keywords Biological control, Paterson's curse, *Echium plantagineum*, community groups.

Introduction

Paterson's curse has been the subject of a biological control program since the 1970s, during which time a total of six insect species have been imported from Europe and released across temperate Australia (Swirepik *et al.* 2003). With a suite of biocontrol agents available, coupled with the enthusiastic demand for biocontrol by the community, an excellent opportunity existed to develop a network of community groups to assist in distributing these agents as efficiently as possible.

In 1995, a national collaborative program was initiated involving research agencies from New South Wales, the Australian Capital Territory, Victoria, South Australia and Western Australia.

Over the past 10 years, this program has proven to be a highly successful model in demonstrating effective collaboration between research agencies in the development of a national, community-based network for the distribution of biological control agents (Swirepik and Smyth 2002).

This paper focuses on the Victorian experience, with particular emphasis on the development of the community network and its achievements in the release, monitoring and redistribution of biocontrol agents for Paterson's curse.

Materials and methods

Production of agents

Most of the insects used for the initial releases in Victoria were reared at the insectary facilities at Department of Primary Industries (DPI) – Frankston using methods similar to those described by Swirepik *et al.* (2003). Occasionally, top-up colonies were received from other cooperators if insufficient numbers were reared, and similarly, DPI provided colonies to other states when necessary.

Between 1995 to 1997 the focus of the Victorian program was on the mass rearing and release of the crown weevil, *Mogulones larvatus* which proved relatively easy to rear and were released in numbers of 100 adults per site.

In 1996 two further agents, the taproot flea beetle, *Longitarsus echii* and the root weevil, *M. geographicus* were added to the release program. The root weevil proved difficult rear in large numbers resulting in only a few releases being conducted each year. Releases of the pollen beetle, *Meligethes planiusculus* commenced in 1998. Another agent, the stem boring beetle, *Phytoecia coerulescens* was also approved for release in Australia, but proved to be a less damaging agent. This insect was only released at one site and was not incorporated into the mass-release program.

Community distribution network

The formation of the community distribution network followed the three tiered model as described by Kwong (2003). Tier 1 represented the state coordination role, which was provided by the Paterson's curse Project Officer. Tier 2, referred to as Nursery Site Coordinators, consisted of extension staff such as DPI Catchment Management Officers and community group facilitators. Their role was to plan and coordinate the implementation of biocontrol at a regional scale. The Nursery Site Managers (Tier 3) represented the end-users, such as individual landholders and community groups. Their role in the program was to release biological control at a local level and to feed back information on the progress of agent releases up through the network.

The network participants required training and resources, such as information leaflets, kits and equipment, to undertake their respective roles. Nursery Site Coordinators (Tier 2) were trained through one-on-one contact with the Project Officer on how to select suitable nursery sites based on regional weed management priorities, and how to educate landholders about the role of biocontrol in integrated weed management.

Nursery Site Managers (Tier 3) attended workshops and field days where hands-on training was provided on how to release the agents, look after the nursery sites and monitor agent survival and spread.

Redistribution

At the heart of the strategy was an annual series of Redistribution Field Days. These were conducted in spring, at sites where the agents were present in such large numbers that thousands could be collected without risk of affecting the viability of the population. Landholders and other interested parties wishing to make a release would participate in a field day by helping to collect the agents using sweep nets or beating trays and mouth-aspiration devises called pooters. The participants would then return to their own properties with the insects they collected for release.

Monitoring

Evaluating the progress of biocontrol agents was conducted at three levels as described by Swirepik *et al.* (2003). Level Three monitoring provided information on the establishment and spread of agents at all release sites. Nursery Site Managers were encouraged to monitor their release sites and feed this information back to the Project Officer. Level Two monitoring was conducted at sites where agents had become established and provided data on the population densities of the biocontrol agent and of Paterson's curse. This information was used to determine when nursery sites were ready for redistribution. Level One monitoring was initiated at a long-term study site near Euroa in north-east Victoria and was designed to determine the impact of the biocontrol agents on Paterson's curse populations (see Morley in this publication). Only Level Three monitoring was conducted as part of the community network program, while Level One and Level Two monitoring was conducted by DPI weed scientists (Morley 2004).

Results

Involving Landcare and other community groups in the redistribution process has led to a dramatic increase in the amount of releases being conducted (Table 1). All crown weevil releases prior to 1998 were conducted using laboratory-reared agents with 100 adults per release in autumn. Crown weevil redistribution resulted in 124 new sites being established in just

Table 1. Number of releases of Paterson's curse agents made in Victoria.

Year	Crown weevil	Crown weevil redistribution	Flea beetle	Flea beetle redistribution	Pollen beetle	Pollen beetle redistribution	Root weevil
1993	2						
1994	8						
1995	40						
1996	58		2				2
1997	42		9				
1998	10		6		2		2
1999	10		1		9		1
2000	10		7		6		5
2001		28	6		4		1
2002		40		23		16	1
2003		56		30		22	4
2004		2		34		21	3
Total	170	126	31	87	21	59	19

three years using 1000 adult weevils per release during spring. The larger number of weevils used in spring releases compared to autumn releases was necessary to compensate for natural attrition of weevils over summer ahead of the weevil egg laying season the following autumn. This amount of releases would be impossible to conduct using laboratory-reared agents because of the enormous resources it would require.

Similarly, by holding flea beetle redistribution field days over a number of years, nearly three times as many releases of this agent were made compared to using laboratory-reared insects.

The pollen beetle was initially released at 21 sites over a four-year period, however the number of releases tripled over the following three years from beetle collections made at a nursery site on the DPI Frankston grounds.

Over the past three years, releases have been strategically made across the range of Paterson's curse in Victoria. We have attempted to ensure that most Landcare areas have at least one or two agents established in the region. In the future it will be up to the groups themselves to coordinate and conduct redistribution to continue the spread of the agents. The current network now involves 56 Landcare groups, 79 Catchment Management Officers and Landcare Facilitators as well as representatives from Parks Victoria, Goulburn Murray Water, Local councils and Parklands Albury Wodonga.

Level Three monitoring of agent establishment was conducted at a total of 262 sites between 1993 and 2005. Of the 200 crown weevil sites, recoveries of the insect were recorded at 51% of sites. The flea beetle was recovered at 40% of the 29 sites monitored and the pollen beetle established at 46% of the 24 monitored sites. The root weevil proved to be the most difficult agent to establish, with the agent being recovered at only two (22%) of the nine sites monitored.

Discussion

Only time will tell if the level of training provided to groups will be enough for redistribution to continue without assistance from DPI in the future. However some groups have already begun conducting redistribution on their own, while many others are in the process of planning.

Continued redistribution from sites that are currently established is expected to continue as the managers and groups that maintain the sites are very knowledgeable and experienced on what, when and how to go about the process.

The real test of the training will be in five to ten year's time when sites become ready for redistribution for the first time. Will the Landcare groups and farmers remember what they have been taught and will the enthusiasm they have today still be there in five years?

Acknowledgements

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Regional priority-setting for weed management on public land in Victoria

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Summary Steps for developing regional weed management plans for public land in Victoria are proposed in relation to a cross-tenure, cross-agency priority-setting framework. These are examined in relation to the setting of priorities for weed management in the Otway region of Victoria. Summaries of assets and risks to assets are presented and their implications for weed management priorities considered. Difficulties arising in the collation and analysis of data are examined and potential solutions proposed. The approach can possibly be extended to develop weed priorities at a statewide level for Victoria and would be applicable to other jurisdictions.

Keywords Weed management, biodiversity assets, environmental weed, public land management, native vegetation

Introduction

All landholders, whether managing a farm, a lifestyle property or public land need to make decisions about how to most effectively allocate their resources, including time and finances. Public land in Victoria occupies around 8.5 million hectares and contains a vast array of assets potentially affected by weeds, including some 3140 native vascular plant species and 770 native vertebrate animal species. Therefore, public land managers are faced with particularly complex planning and resource allocation decisions. In Victoria, over 540 exotic plant taxa have been identified (Carr *et al*. 1992) and are readily apparent on public land. To a casual observer, an exotic deciduous tree beside the road in a national park or extensive stand of weeds on a disturbed site may be alarming. But does a particular weed occurrence in native vegetation matter? How can we judge? Are resources spent on dealing with this issue at the expense of more important issues relating to the threat posed by weeds?

To assist public land managers and others consider how the threat of weeds affects the values they aim to protect, a new decision-support framework is being developed, which includes a monitoring and evaluation component. The framework is documented in 'Interim Guidelines and Procedures for the Management of Environmental Weeds on Public Land in Victoria' (Environmental Weeds Working Group, in prep.) and further explained in McArthur and Platt (in press).

This paper explains how the broad principles in the guidelines are being further developed through a case study approach so that they can inform day-to-day operations on public land.

The Interim Environmental Weed Guidelines propose that two key ideas should guide decision-making. Firstly, land managers should aim to prevent any new and emerging weeds (including sleeper[1] weeds) from establishing. This is given the highest priority. Secondly, they propose that for established weeds (those for which eradication is impractical) the approach should be to protect the most important assets first. Thus, a practical decision-support framework needs to help public land managers with organising their surveillance and response to new and emerging weeds. It also needs to identify where the most important assets are located and what weeds are threatening them. Once this is understood, specific aims can be identified and management responses planned, allowing an evaluation process to determine whether project objectives have been achieved.

The Angahook-Otway region of Victoria was selected for a case study to evaluate the principles advocated in the Environmental Weed Guidelines (Figure 1). This region is the focus of a major on-ground, multiple tenure weed project involving collaboration between public land managers and has recently undergone land-use evaluation by the Victorian Environmental Assessment Council (VEAC 2004). The case study encompasses the VEAC Study Area that includes 159 000 ha of public land. This area presented opportunities to work collaboratively with a number of major stakeholders in developing a cross-tenure approach to a large management unit. State government funding, through the Weeds of Public Land Initiative, has provided the opportunity for the planning process to be fully tested in its field application through on-ground treatments.

Public land in the Otway region is of highly variable terrain. Streams dissect a mountain range running parallel to a rugged coastline. Habitats include cool temperate rainforest, tall open forests of mountain ash *Eucalyptus regnans* on upper slopes, tall open-forests and open-forests dominated by a mixture of eucalypt species on the mid-lower slopes, open forest and woodland with heathy understorey in the foothills, wet and dry heathlands, and coastal scrub (Westbrooke *et al*. 1990, DCE 1991). In total, 39 Ecological Vegetation Classes are recognised in the Angahook-Otway region (VEAC 2003). A wide range of significant biodiversity assets occur in the region including a large number of rare and threatened plants (e.g. tall astelia) and animals (e.g. Otway black snail, Otway stonefly). There are around 1500 plant species in the study area with 120 classified as threatened (VEAC 2003). At least 370 non-indigenous plant species are naturalised in the Angahook-Otway region, with many presenting a serious threat to biodiversity, social and economic assets.

In this study, 16 progressive steps that rationalise weed management operations are outlined. Though the steps build on each other, some can be undertaken simultaneously. As the project has recently commenced, only the early steps have been described in detail. The remainder

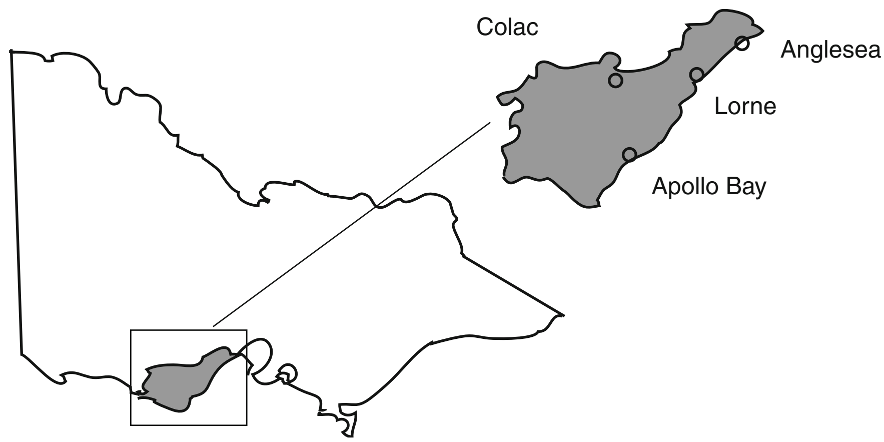

Figure 1. Study area

are untried and will be attempted as the project progresses. The steps are broadly modelled on that used by Tolhurst (2000).

Proposed steps

Step 1

Refer to documents containing broad natural resource management objectives for the region and identify broad ecological objectives. These are included in Victoria's Native Vegetation Management Framework, Victoria's Biodiversity Strategy, Regional Catchment Strategies, Park/Forest Management Plans and Weed Action Plans.

The Otway region falls within the jurisdiction of the Corangamite Catchment Management Authority (CCMA). The CCMA Regional Catchment Strategy (CCMA 2003) aims include: healthy rivers and streams, lakes and wetlands; healthy estuaries, coasts and marine systems; achieving a net gain in quantity and quality of native vegetation across the entire landscape; improved conservation status of all vegetation communities and native flora species; improved conservation status of all native fauna species; cohesive, innovative communities, that value and protect natural resources and participate in planning for the future. These objectives accord with those of Victoria's Biodiversity Strategy (NRE 1997). The Victorian Environment Assessment Council (VEAC 2004) recommends, in regard to its Angahook-Otway Investigation, that the setting of priorities for control of pest species would be further facilitated by regional approaches where land managers act collaboratively. The Victorian Coastal Strategy (VCC 2002) aims to improve the condition of coastal biological diversity, protect coastal habitats and associated native flora and fauna and improve the integration of catchment and coastal management.

Step 2

Identify a landscape management unit based on appropriate criteria that determine an ecologically appropriate scale of management.

In this case, the Otway region of Victoria has been chosen for the reasons outlined above. However, there is a need to further develop planning units based on functionally-connected ecosystems. These then become the Land Management Units of the area under investigation. Ecological Vegetation Class groups are being developed for other applications (e.g. ecological fire management) and may prove a suitable unit.

Step 3

Collate and map biodiversity assets.

Spatial data relevant to biodiversity assets within the Otway region have been collated to create a map reflecting biodiversity values ranked from highest to lowest conservation significance (Figure 2). A range of data 'layers' has been combined in this model of biodiversity assets (Figure 3) and includes:

- primary data from Ecological Vegetation Class (EVC) mapping including the assigned Biological Conservation Status of those units
- a density surface of rare plants records (scaled to landscape at km^2 units)
- habitat models of threatened fauna based on site records and expert input
- spatial data including hydrology and tree density.
- other disturbance data relevant to condition including land use, road density, landscape context (fragmentation), State Forest Resource Inventory growth stage and logging history.

Expert opinion was used to rate EVCs according to their susceptibility to weed invasion (see Step 8). This information is being augmented with additional derived data with a view to mitigating problems associated with spatial precision, incomplete coverage and uneven flora and fauna survey intensities. The various inputs have been converted to 20-metre pixel raster format within the geographic information system (GIS). Expertise has been engaged to weight disparate data. The resultant surface is to be further classified and modified with input from relevant stakeholders and other local experts within a workshop setting.

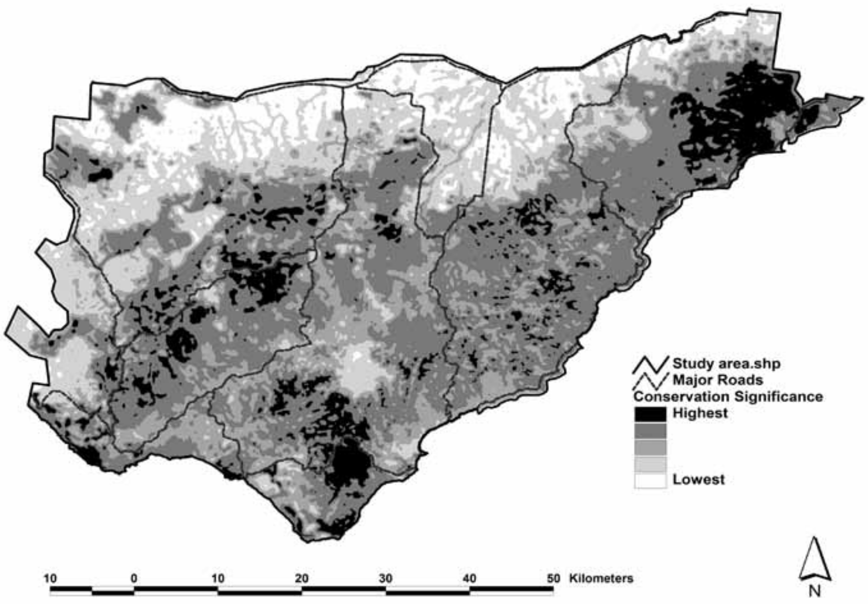

Figure 2. Map of ranked biodiversity values across the Otway study area

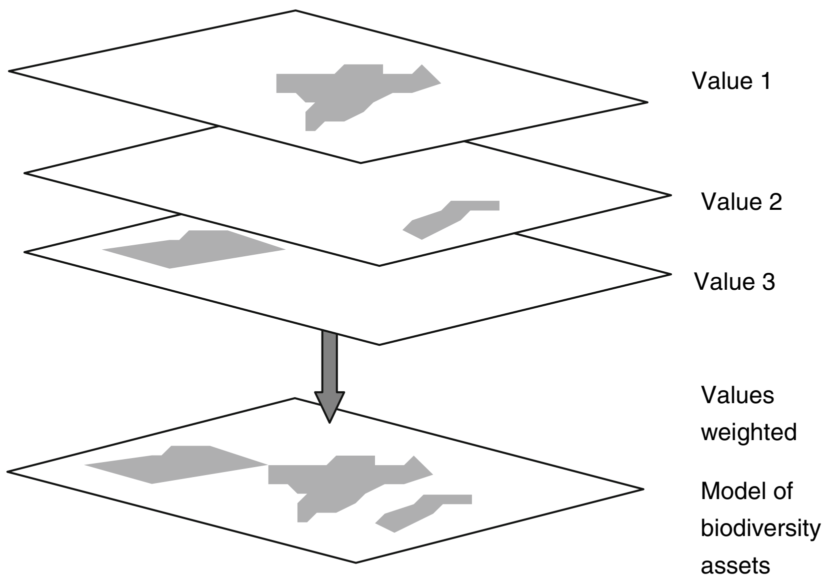

Figure 3. Schematic representation of how geographic information is combined to produce a model of biodiversity assets

Step 4
Collate and map social and economic assets of significant value, likely to be at risk from environmental weeds.

Geospatial datasets for these values on public land in a format useful for identifying those assets at risk from weeds are yet to be developed. Therefore, it is proposed that an expert panel of stakeholders will collate the information for the Otway case study.

Step 5
Identify potential sources of introduction and pathways of weed spread. This step can be undertaken concurrently with Steps 2–4.

At the present time, analysis of data on weed sources and a model of weed spread/invasion within the study area is unavailable and beyond the scope of this project. However, data on the coincidence of potential new and emerging weeds, such as known weed hotspots, towns, roads, rubbish tips, ornamental and trial plantations, can be collated. This information will then contribute to the surveillance component of the management plan. The Weed Alert Rapid Response Plan Victoria (DPI 2005) deals in detail with the issue of new and emerging weeds. Complementary activities in the WARR Plan include establishing and maintaining a network of 'weed spotters' and rapid response teams to manage emergency weed issues.

Step 6
Using available data, collate and map weed distribution records. Classify weeds as new and emerging/sleeper or established.

A census of the exotic plant flora and their distribution is the basis for development of weed management priorities and its application within a framework of protection of biodiversity assets. In Victoria, four main databases are available for examining weed records:

- Flora Information Systems (FIS), the centralised database of the Department of Sustainability and Environment (DSE);
- Environmental Information System (EIS), the management database used by Parks Victoria;
- Integrated Pest Management System (IPMS), used by Department of Primary Industries principally for noxious weed data; and
- State Forests Resource Inventory (SFRI), a natural resource database used by DSE for forest stewardship planning.

In the Otway region, close to 371 species[2] of exotic plants are known from 7991 cases, approximately 17% of Victoria's exotic flora (75% of records used were located in the FIS making it the main source of data). Distribution records covered most of the region, but were concentrated in areas along the coastal fringe and a central band running NE-SW covering a diverse range of land use types.

Government database records are being augmented by spatial weed occurrence knowledge held by community organisations and individuals in the study region, following a targeted request for information. Significant weed species likely to occur in the Otway region, but absent from government databases were the focus of this survey (Appendix 1), together with any weed records from defined areas of biodiversity importance. This process is currently underway and its value is yet to be evaluated.

Datasets could not be used to accurately determine the abundance status of weed species in the study area, as weed case numbers were biased by collection histories. The noxious biennial herb *Senecio jacobaea* had the highest number of records (1285 cases), but is a weed of agriculture or disturbed native vegetation in the region, and has limited ecological impact. In contrast, a widely distributed and abundant weed *Hypocheris radicata* had relatively few records (419 cases). Local knowledge and further survey input are required to accurately ascertain the abundance status of key environmental weeds in the study area, and particularly in areas of high biodiversity importance. Rapid vegetation survey techniques that initially focus on areas with a high probability of weed occurrence are recommended.

Step 7
Supplement and verify weed occurrence and distribution with field surveys, especially at and in the vicinity of priority biodiversity assets.

Weed management decisions should be made using data that accurately reflect actual status of weed occurrence and abundance in landscape management units. Decisions based on poor data-sets are likely to fail in meeting ecological outcomes. In the Otway case study, the adequacy of assessing weed occurrence using the State's principal databases was determined by undertaking weed surveys in five areas of high biodiversity importance. The areas surveyed were Parker River (Otway National Park), Carlisle heathlands (Otway National Park), Tomahawk Creek Nature Reserve, Bald Hills-Angahook forest (Otway National Park), and Carpendeit Nature Reserve. In all cases, new records of weeds with potential moderate to high ecological impact and high ranking scores were located. Nearly all records were in the early invasion stages, and therefore likely to have been missed in previous data collection or survey exercises. While few new weed species to the study area were located in the five survey areas of biodiversity importance, the presence of unrecorded, significant environmental weeds at the landscape management unit scale highlighted the need for more detailed weed distribution data.

While existing databases provide a general overview of weed records in the region, they are insufficiently detailed to provide large-scale mapping data required for effective management decisions. In the Otway case study, additional survey input using rapid vegetation survey techniques will improve the credibility status of existing databases, particularly for new and emerging weeds in areas of high biodiversity importance.

Step 8
To the extent possible, identify the relative risk/threat that each species/group poses to environmental assets.

Weed species were ranked using a series of weighted criteria to produce classes of weeds grouped according to their threat to native vegetation integrity in the region. This system was modified from White and Carr (2001), where weeds of the alpine region at Falls Creek were ranked. Weighting criteria listed according to importance are: invasiveness (establishes in native vegetation or not), ecological impact (high, medium, low); distribution currently occupied (extensive, moderate, limited); range of ecological vegetation classes susceptible to invasion (high, medium, low); and rate of dispersal (rapid, moderate, slow). The ranking system allocated scores between 1 and 81. Weeds with the higher ecological impact received lower scores than those with negligible ecological impacts. Weeds were grouped into classes of (I) high impact weeds (score 1–10), (ii) weeds of importance (scores 11–30) (iii) weeds of concern (scores 31–50) (iv) minor weeds (scores 51–70) (v) weeds of least significance (scores 71–81) (Appendix 2).

The remaining proposed steps are yet to be undertaken in the Otway case study. Thus, there is no indication of their current status.

Step 9
On the basis of the known assets and perceived weed threats, set the more specific ecological management objectives (eg. 'to conserve the grassy woodlands against the threat of (name high impact weeds)') for the management unit.

Step 10
Prioritise sites according to the framework described above and identify areas on the ground that are candidates for management of the threat of weeds. Pay particular attention to sources of new and emerging weeds and opportunities for co-ordinating activities between private and public land (largely covered by the Good Neighbour Program (NRE 2002).

Step 11
Assess the practicality of achieving the required ecological objective. This should also consider issues such as the causes of vegetation decline, the feasibility of weed management, the community interest, capacity and commitment to contribute to the project and the likelihood of re-invasion.

Step 12
Define specific site objectives of environmental weed management (compare with the ecological management objectives) and performance indicators based on Specific, Measurable, Achievable, Relevant and Time-framed (SMART) principles (Platt 2002) and record these in the site plan. For example, an ecological objective at the site level might be 'to maintain natural processes within the grassland ecosystem leading to a minimum of three viable populations of *Diuris fragrantissima* by reducing the threat from **Nassella neesiana* and **Vulpia bromoides* by January 2010'.

Step 13
Document the results of the above steps and incorporate in appropriate plans (eg. Park/Forest Management plans, Weed Action Plans).

Step 14
Design a management process that will deal with the causes of risks at priority sites.

Step 15
Undertake the management actions, recording biodiversity asset condition before, during, and after treatment according to monitoring and evaluation procedures. These procedures should be designed to accommodate the needs of adaptive management of landscape management units and target a range of environmental assets but particularly the key assets identified as important.

Step 16
Evaluate the results against the specific management objectives. Return to Step 3 and if necessary update and repeat.

Discussion

This paper describes a project that aims to develop an operations plan for public land managers that is independent of land tenure and based on a set of accepted management principles for reducing the threat of weeds. In achieving this, large and complex information about the values on public land needs to be considered. Progress to date has shown that there is great potential to use GIS-based models to help plan for both prevention of new and emerging weeds and to identify key areas containing important assets that can be protected against the threat posed by established weeds. The areas derived from the GIS model have been checked against the expectations of local stakeholders and generally correspond with their views. Using geographic information systems to support decision-making has a number of advantages including the ability to deal with spatially complex data, objectivity, a capacity to provide transparency (the process is open to scrutiny), and adjustable weightings.

The model developed for ranking assets (Steps 3 and 4) attempts to represent a range of values humans place on the natural world. These values are not fixed attributes. In developing the model, values have been captured through existing processes, such as the value given to threatened species. Values are also being captured through discussions with stakeholders and the community over the weightings given to the various inputs used in developing the model and in understanding the criteria they use to allocate value. The map produced as a result of the model is highly sensitive to the weightings given to particular components. For example, whether the conservation status of the vegetation type is given equal or higher/lower weight than the threatened species surface. The environment in which the model is built enables an iterative process that can be run again as further information becomes available or as community values change. Thus the process should be seen as dynamic and facilitating exchange of views about values and their expression in the landscape.

Though progress has been made, problems with the adequacy of datasets have arisen. Whilst in Victoria valuable datasets for identifying biodiversity assets are available, similar datasets for assessing social and economic assets at risk from weeds have not yet been identified. Decision-making processes based on data are heavily reliant on the quality and representativeness of the data. Though supported by some of the leading information systems in the country, data limitations have already become obvious. Whilst around 371 species of weeds are recorded on government databases for the Otway case study area, a further 66 species expected to occur in the Otways are not recorded. Targeted surveys indicate many unrecorded weeds occur in areas of high biodiversity importance. Processes for increasing the flow of weed data are under discussion. The issues associated with data availability and adequacy need to be addressed in the future management of the threat of weeds in the Otway region.

Whilst it has been possible to rank biodiversity assets relative to each other, it is less clear what advice can be offered to land managers having to make choices across environmental, social and economic asset classes. There are currently no frameworks available to guide decision-making where assets must be compared across classes. For example, guidance when a land manager must decide whether resources be put toward conservation of an area of native vegetation versus an recreational asset, such as a picnic area. A system that ranks all assets in an unbiased way would be beneficial in making such decisions. The ecosystem services concept, which attempts to allocate economic value to a wide range of services provided by nature (and thus a common currency for comparing assets) may be valuable in resolving this issue in the future. Whilst this issue is beyond the scope of the current project, by providing data-rich mapping products, land managers utilising the results of this case study will be in a position to interrogate the various attributes that confer priority on a place.

During the development of the Interim Guidelines it became apparent that prevention of new and emerging weeds requires a weed-led approach. That is, for new and emerging weeds it is necessary for the land manager to go to where the weed is and apply treatments. Whereas, for established weeds, the focus is on managing weeds at a particular location (a site-led approach). From the perspective of management activity, this is an important distinction. Typically, most weed management tends to focus on the weed, rather than the assets or values at risk from weeds and thereby risks losing the purpose of the activity. Focussing on the prevention aspect of a weed led approach means that not all weed occurrences need to draw attention during surveillance activities, just the subset of new and emerging weeds.

A major benefit of an asset-based approach to the threat posed by established weeds is that the places identified as a priority for management action are also sites of biodiversity importance and likely to correspond with other natural resource management activity. This helps to facilitate an integrated approach to a site whereby a number of threats can be addressed simultaneously in order to maintain functionality of the ecosystem. Focussing on the asset rather than the suite of established weeds provides a clear focus for the land manager when dealing with established weeds.

This process does not presuppose the appropriate management approaches but rather enables management to be focussed on addressing a particular threat. The management tools applied need to be based on addressing the causes of weed invasion. For example, reducing potential sources of weed spread into native vegetation may involve closing a walking track. Reducing soil disturbance (potentially leading to weed invasion) might involve changing procedures for road making. Use of chemical herbicides should be considered in the wider context of the management objectives and tools available.

A Regional Working Group assisting the project, comprising representatives of the major public land stakeholders, has proven invaluable in validating and fine-tuning the methodology, in assigning weightings and assisting in networking with the wider community.

The Interim Guidelines place a strong emphasis on achieving outcomes for the protection or improvement in quality of biodiversity assets. A prerequisite for identifying meaningful outcomes is to set clear objectives. The steps described above aim to provide the information required for an explicit statement of objectives. For example, once the values at a particular site are known and the specific risks identified then the objective is around protecting those particular values.

Protocols for monitoring biodiversity and weed occurrences at sites are reasonably well understood and documented. However, our understanding of what is happening at a landscape scale requires further development. The Otway case study aims to develop a set of indicators applicable at the broad level of understanding. For example, by asking whether the threat from weeds is increasing or decreasing at a land management unit scale. This will be done at a later stage of the project. Greater understanding of the actual, rather than assumed, impact of weeds on biodiversity assets is also urgently required (Adair and Groves 1998).

The processes articulated above are relevant to other bioregions in Victoria. The project aims ultimately to broaden its analysis, based on the experiences gained in the Otway case study, to assist in identifying weed management priorities on public land at the statewide level.

Interstate and internationally, weed invasions are regarded as one of the key threats to natural ecosystems on public lands (Holzner *et al*. 1983, Lake and Lieshman 2004). In line with the approach proposed in the Interim Guidelines, prevention is seen to be the most effective approach. However, in many jurisdictions, the emphasis is on a weed-led approach to all weed occurrences without a complimentary asset-based approach as described in this paper. Public education and coalitions of stakeholders aiming to prevent weeds from public lands affecting private lands are also common. However, there are few cases of a strategic approach to environmental weeds on public land. In Western Australia, an environmental weed strategy has been prepared that recognises weed-led and site-led approaches but stops short of explicitly defining the steps for achieving this in a practical, operational, framework (CALM 1999).

Though yet to be fully tested and assessed, the approach being used in the Otway case study promises to deliver a transparent and thorough new approach to dealing with weed threats that enables resources to be better targeted. It will also provide an opportunity to determine with greater precision whether management actions are achieving desired outcomes.

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Footnotes

1. Sleeper weeds are exotic plants that have naturalised in a region but have not yet rapidly increased in population size.
2. Some species were listed as an aggregate e.g. *Avena* spp., therefore the total number of species in the study area is slightly higher than that quoted.

Appendix 1. Plants 'known to be invasive' with high to moderate ecological impacts, but not recorded in databases for the Angahook-Otway region

Scientific name	Common name
Acacia cyclops	Western coastal wattle
Acacia prominens	Gosford wattle
Acer negundo	Box-elder maple
Acer pseudoplatanus	Sycamore maple
Achnatherum caudatum	Espartillo
Alternanthera philoxeroides	Alligator weed
Anredera cordifolia	Madiera vine
Asparagus asparagoides	Bridal creeper
Berberis darwinii	Darwin's barberry
Buddleja davidii	Butterfly bush
Cabomba caroliniana	Cabomba
Calluna vulgaris	Heather (N.B. no records for Victoria but occurs in Tasmania)
Cestrum elegans	Elegant poison-berry
Cestrum parqui	Green poison-berry
Chrysanthemoides monilifera subsp. *rotundata*	Boneseed
Clematis vitalba	Traveller's joy
Coprosma robusta	Karamu
Cortaderia jubata	Pink pampas-grass
Cotoneaster spp.	Cotoneaster
Cuscuta campestris	Field dodder
Cytisus multiflorus	White Spanish broom
Disa bracteata	South African orchid
Echium vulgare	Viper's bugloss
Eragrostis curvula	African love-grass
Erica arborea	Tree heath
Fallopia japonica	Japanese knotweed
Galenia pubescens var. *pubescens*	Galenia
Gladiolus tristis	Evening-flower gladiolus
Gladiolus undulatus	Wild gladiolus
Glyceria maxima	Reed sweet-grass
Gymnocoronis spilanthoides	Senegal tea
Hypericum tetrapterum	St Peter's wort
Ilex aquifolium	English holly
Iris pseudacorus	Yellow flag iris
Leersia oryzoides	Rice cut-grass
Lotus creticus	Lotus
Myriophyllum aquaticum	Parrot's feather
Nassella charruana	Uruguayan needle-grass
Nassella hyalina	Cane needle-grass
Nassella leucotricha	Texas needle-grass
Oenothera glazioviana	Reddish evening primrose
Olea europaea	Olive
Opuntia spp.	Prickly pears
Orobanche ramosa	Broomrape
Pennisetum alopecuroides	Swamp foxtail-grass
Pennisetum macrourum	African feather-grass
Phalaris minor	Lesser canary-grass
Physalis viscosa	Sticky ground-cherry
Pittosporum bicolor x *undulatum*	Hybrid pittosporum
Prunus laurocerasus	Cherry laurel
Prunus spinosa	Blackthorn
Puccinellia fasciculata	Borrer's saltmarsh-grass
Pyracantha angustifolia	Orange firethorn
Rhamnus alaternus	Italian buckthorn
Sagittaria brevirostrata	Arrowhead
Sagittaria platyphylla	Sagittaria
Salpichroa origanifolia	Pampas lily-of-the-valley
Salvinia molesta	Salvinia
Senecio angulatus	Climbing groundsel
Solanum pseudocapsicum	Madiera winter-cherry
Sorbus aucuparia	Rowan
Sparaxis bulbifera	Harlequin flower
Spartina anglica	Common cord-grass
Spartina × *townsendii*	Townsend's cord-grass
Thinopyrum junceiforme	Sea wheat-grass
Typha latifolia	Lesser reed-mace

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Appendix 2. Ranking of environmental weeds recorded from the Angahook-Otways study area – sorted by score

Species	Ecological impact[2]	Impact attributes[3]	Potential distribution[4]	Habitat range[5]	Rate of dispersal[6]	Ranking score
HIGH IMPACT WEEDS						
Asparagus scandens	H	6,7,8,9	E	H	R	1
Cotoneaster pannosus	H		E	H	R	1
Hedera helix	H	6,7,8,9	E	H	R	1
Lonicera japonica	H		E	H	R	1
Sollya heterophylla	H		E	H	R	1
Acacia longifolia	H	1,2,4,6,7,8,9	E	H	M	2
Chamaecytisus palmensis	H	2,6,7,8,9	E	H	M	2
Fraxinus spp.	H		E	H	M	2
Passiflora tarminiana	H	6,7,8,9	E	H	M	2
Pittosporum undulatum	H	6,7,8,9,10	E	H	M	2
Acacia elata	H	1,2,7	E	H	S	3
Allium triquetrum	H	1,2,6,8	E	H	S	3
Genista linifolia	H		E	H	S	3
Genista monspessulana	H	1,6,7,8,9	E	H	S	3
Vinca major	H	4,6,7,8,9	E	H	S	3
Chrysanthemoides monilifera subsp. *monilifera*	H	1,4,5,6,7,9	E	M	R	4
Coprosma repens	H	1,4,6,7,8,9	E	M	R	4
Cortaderia selloana	H	1,6,7,8,9	E	M	R	4
Leycesteria formosa	H	1,6,7,8,9	E	M	R	4
Agrostis gigantea	H		E	M	M	5
Callistachys lanceolata	H		E	M	M	5
Cytisus scoparius	H	1,2,6,7,8,9	E	M	M	5
Dipogon lignosus	H	2,4,6,7,8,9	E	M	M	5
Leptospermum laevigatum	H	1, 6,7,8,9	E	M	M	5
Calystegia silvatica	H	1,6,7,8,9	E	M	S	6
Crocosmia × crocosmiiflora	H	1,6,8,9	E	M	S	6
Erica lusitanica	H	1,6,7,8,9	E	M	S	6
Leucanthemum maximum	H		E	M	S	6
Leucanthemum vulgare	H	6,7,8,9	E	M	S	6
Pinus radiata	H	6,7,8,9,10	E	M	S	6
Tradescantia fluminensis	H	1,4,6,7,8,9	E	M	S	6
Ulex europaeus	H	1,2,4,6,7,8,9	E	M	S	6
Watsonia meriana var. *bulbillifera*	H	1,4,6,7,8,9	E	M	S	6
Watsonia versfeldii	H		E	M	S	6
Fuchsia magellanica	H	6,7,8,9	E	L	R	7
Nassella tenuissima	H		E	L	R	7
Zantedeschia aethiopica	H	6,7,8,9	E	L	R	7
Delairea odorata	H	1,6,7.8,9	E	H	M	8
Polygala myrtifolia var. *myrtifolia*	H	6,7,8,9	E	L	M	8
Salix spp.	H	1,2,3,6,7,8,9	E	L	M	8
Acacia sophorae	H	1,2,4,6,7,8,9	E	L	S	9
Alstroemeria aurea	H	7,9	E	L	S	9
Cupressus macrocarpa	H	1,6,7,8,9, 10	E	L	S	9
Lamium galeobdolon subsp. *argentatum*	H	6,7,8,9	E	L	S	9
Pennisetum clandestinum	H		E	L	S	9
Pinus nigra	H		E	L	S	9
Pinus pinaster	H	6,7,8,9,10	E	L	S	9
Populus alba	H		E	L	S	9
Spartium junceum	H	3,4,5,6,7,8,9	E	L	S	9
Rubus fruticosus agg.	H	4,6,7,8,9	M	H	R	10
WEEDS OF IMPORTANCE						
Ehrharta erecta	H	8,9	M	H	M	11
Ehrharta longiflora	H	8.9	M	H	M	11
Holcus lanatus	H	1,6,7,8,9	M	M	M	14
Myosotis discolor, M. laxa subsp. *caespitose, M. sylvatica*	H	1,6,7,8,9	M	M	M	14
Lycium ferocissimum	H	1,6,7,8,9	M	L	R	16
Nassella neesiana	H		M	L	R	16
Nassella trichotoma	H	1,8,9	M	L	R	16
Parapholis incurva	H	6,7,8,9	M	L	M	17
Dactylis glomerata	H	1,3,6,7,8,9	M	L	S	18
Stenotaphrum secundatum	H	6,7,8,9	M	L	S	18
Anthoxanthum odoratum	H	1,4,6,7,8,9,10	L	H	M	20
Phalaris aquatica	H		L	M	M	23
Ammophila arenaria	H	4,5,6,7,8,9	L	L	M	26
Prunus cerasifera	M		E	H	R	28
Acacia baileyana	M	2,6,7	E	H	S	30
Acacia decurrens	M	2,6,7	E	M	S	30
WEEDS OF CONCERN						
Sambucus nigra	M		E	M	R	31
Freesia alba × F. leichtlinii	M		E	M	M	32
Ixia polystachya	M		E	M	M	32
Sparaxis tricolor	M		E	M	M	32
Acacia saligna	M	2, 6, 7	E	M	S	33
Agapanthus praecox subsp. *orientalis*	M	1,6,7,	E	M	S	33
Erica baccans	M		E	M	S	33
Erica quadrangularis	M		E	M	S	33
Melaleuca armillaris	M	9	E	M	S	33
Echium plantagineum	M	9	E	L	R	34
Chenopodium murale	M		E	L	M	35
Gladiolus undulatus	M		E	L	M	35
Selaginella kraussiana	M	9	E	L	M	35

Cynodon dactylon var. *dactylon*	M		M	M	M	41
Euryops abrotanifolius	M		E	M	M	41
Oenothera glazioviana	M		M	M	M	41
Oxalis incarnata	M	8,9	M	M	M	41
Oxalis pes-caprae	M	8,9	M	M	M	41
Rosa rubiginosa	M	6,?9	M	M	M	41
Vicia hirsute, V. sativa, V. sativa subsp. *nigra, V. tetrasperma,*	M	2,6,7,8,9	M	M	M	41
Trifolium repens var. *repens*	M	2,9	M	M	S	42
Crataegus monogyna	M	1,2,4,6,7,8,9	M	L	R	43
Juncus acutus subsp. *acutus*	M	3,4,6,7,8,9	M	L	R	43
Asphodelus fistulosus	M	1,4,9	M	L	M	44
Bromus catharticus	M	1,6,7,8,9	M	L	M	44
Bromus diandrus	M	1,6,7,8,9	M	L	M	44
Euphorbia paralias	M	4,5	M	L	M	44
Galenia pubescens var. *pubescens*	M		M	L	M	44
Gazania linearis	M	9	M	L	M	44
Juncus articulatus	M	3,4,6,7,8,9	M	L	M	44
Oxalis purpurea	M	8,9	M	L	M	44
Rorippa palustris	M		M	L	M	44
Carpobrotus aequilaterus	M	9	M	L	S	45
Carpobrotus edulis	M	9	M	L	S	45
Ranunculus repens	M	6,7,8,9	M	L	S	45
Vulpia bromoides, V. ciliata, V. fasciculata, V. myuros, V. myuros	M		L	H	M	47
Plantago australis, P. coronopus, P. lanceolata P. major	M	7,8,9	L	M	R	49
Brassica × juncea, B. rapa, B. tournefortii	M	9	L	L	M	50
Paspalum dilatatum	M		L	M	M	50
MINOR WEEDS						
Briza maxima	M	1,?9	L	M	S	51
Arctotheca calendula	M	4,6.9	L	L	R	52
Lagurus ovatus	M	6,7,8,9	L	L	R	52
Cyperus eragrostis, C. congestus	M	9	L	L	M	53
Hordeum leporinum, H. marinum	M		L	L	M	53
Lolium perenne	M	6,7,8,9	L	L	M	53
Lolium rigidum, L. temulentum	M		L	L	M	53
Paspalum distichum	M	7,8,9	L	L	M	53
Agrostis capillaries, A. castellana	M	6,7,8,9	E	L	S	56
Agrostis stolonifera	M	6,7,8,9	E	L	S	56
Crassula natans var. *minus*	M		E	L	S	56
Egeria densa	M		E	L	S	56
Elodea canadensis	M		E	L	S	56
Hakea sericea	M		E	L	S	56
Melaleuca hypericifolia	M		E	L	S	56
Mentha pulegium, M. spp.	M	7,8,9	E	L	S	56
Nymphaea spp.	M	7	E	L	S	56
Paraserianthes lophantha	M	6,7,8,9	E	L	S	56
Psoralea pinnata	M	6,7,8,9	E	L	S	56
Euphorbia terracina	L		E	M	S	60
Navarretia squarrosa	L		E	M	S	60
Orobanche minor	L		E	M	S	60
Phleum pratense	L		E	M	S	60
Ranunculus parviflorus	L		E	M	S	60
Solanum douglasii	L		E	M	S	60
Carthamus lanatus	L		E	L	R	61
Cichorium intybus	L		E	L	R	61
Cirsium arvense	L		E	L	R	61
Ligustrum vulgare	L	6,7,8,9	E	L	R	61
Asparagus officinalis	L		E	L	M	62
Carex divulsa	L		E	L	M	62
Danthonia decumbens	L		E	L	M	62
Eragrostis cilianensis	L		E	L	M	62
Euphorbia lathyris	L		E	L	M	62
Hirschfeldia incana	L		E	L	M	62
Linum trigynum	L		E	L	M	62
Onopordum acanthium	L		E	L	M	62
Physalis alkekengi	L		E	L	M	62
Physalis peruviana	L	7,8,9	E	L	M	62
Ranunculus trilobus	L		E	L	M	62
Xanthium spinosum	L		E	L	M	62
Acetosa sagittata	L	7,	E	L	S	63
Agonis flexuosa, A. juniperina, A. parviceps	L		E	L	S	63
Aloe spp.	L		E	L	S	63
Amaryllis belladonna	L		E	L	S	63
Aponogeton distachyos	L	7	E	L	S	63
Astartea heteranthera	L		E	L	S	63
Berkheya rigida	L		E	L	S	63
Chamaemelum nobile	L		E	L	S	63
Chamaesyce maculata	L		E	L	S	63
Crassula tetragona subsp. *robusta*	L		E	L	S	63
Elytrigia repens	L		E	L	S	63
Erigeron karvinskianus	L		E	L	S	63
Glyceria declinata	L		E	L	S	63
Hakea laurina	L		E	L	S	63
Hypericum calycinum	L		E	L	S	63
Isolepis sepulcralis	L		E	L	S	63
Madia sativa	L		E	L	S	63
Melissa officinalis	L		E	L	S	63
Moraea flaccida	L		E	L	S	63
Papaver dubium	L		E	L	S	63

Pelargonium quercifolium	L		E	L	S	63
Phalaris arundinacea	L		E	L	S	63
Pittosporum tenuifolium	L		E	L	S	63
Ranunculus ophioglossifolius	L		E	L	S	63
Solanum lycopersicum	L		E	L	S	63
Soleirolia soleirolii	L		E	L	S	63
Viola odorata	L		E	L	S	63
Conium maculatum	L	9	M	H	M	65
Fumaria capreolata	L		M	M	M	68
Lotus uliginosus	L		?M	M	M	68
Malva parviflora	L		M	M	M	68
WEEDS OF LEAST SIGNIFICANCE						
Briza minor	L	?9	M	L	M	71
Diplotaxis muralis	L		M	L	M	71
Ehrharta calycina	M	8,9	M	L	M	71
Eleusine indica, E. tristachya	L		M	L	M	71
Euphorbia peplus	L		L	M	M	71
Holcus annuus	L		M	L	M	71
Juncus microcephalus, J. bulbosus, J. fontanesii subsp. *fontanesii*	L	?9	M	L	M	71
Sherardia arvensis	L		M	L	M	71
Sporobolus africanus	L		M	L	M	71
Veronica arvensis, Veronica persica	L		M	L	M	71
Atriplex prostrata	L		M	L	S	72
Bellis perennis	L	?10	M	L	S	72
Ciclospermum leptophyllum	L	?9	M	L	S	72
Digitalis purpurea, D. sanguinalis	L		M	L	S	72
Malus pumila	L	6	M	L	S	72
Anagallis arvensis	L	?9	L	H	R	73
Aphanes arvensis	L		L	H	R	73
Cirsium vulgare	L	9	L	H	R	73
Conyza spp.	L		L	H	R	73
Cotula bipinnata	L		L	H	R	73
Hypochoeris glabra, H. radicata	L	6,7,8,9	L	H	R	73
Poa annua	L		L	H	R	73
Poa infirma	L		L	H	R	73
Senecio vulgaris	L		L	H	R	73
Solanum americanum	L		L	H	R	73
Solanum nigrum	L		L	H	R	73
Soliva sessilis	L		L	H	R	73
Sonchus asper, S. oleraceus	L		L	H	R	73
Stellaria media	L		L	H	R	73
Romulea rosea	L		L	H	M	74
Trifolium arvense, T. campestre, T. cernuum, T. dubium, T. glomeratum, T. subterraneum T. obliterum	L	2,9	L	H	M	74
Verbena bonariensis	L		L	H	M	74
Cynosurus cristatus , C. echinatus	L		L	M	R	76
Dittrichia graveolens	L		L	M	R	76
Galium murale	L	?9	L	M	R	76
Gamochaeta purpurea	L		L	M	R	76
Helminthotheca echioides	L		L	M	R	76
Lactuca sativa	L		L	M	R	76
Leontodon taraxacoides subsp. *taraxacoides*	L	?9	L	M	R	76
Polycarpon tetraphyllum	L		L	M	R	76
Rumex conglomerates, R. crispus,	L		L	M	R	76
Sagina apetala, S. procumbens	L		L	M	R	76
Taraxacum officinale spp. *agg.*	L		L	M	R	76
Aira spp.	L	?9	L	M	M	77
Bromus hordeaceus subsp. *hordeaceus*	L		L	M	M	77
Centaurium spp.	L	?9	L	M	M	77
Cerastium spp.	L		L	M	M	77
Modiola caroliniana	L		L	M	M	77
Parentucellia latifolia, P. viscosa	L		L	M	M	77
Polygonum aviculare	L		L	M	M	77
Polypogon monspeliensis	L	?9	L	M	M	77
Polypogon viridis	L		L	M	M	77
Raphanus raphanistrum	L		L	M	M	77
Setaria parviflora	L		L	M	M	77
Sisymbrium orientale	L		L	M	M	77
Acetosella vulgaris	L	?9	L	L	R	79
Aster subulatus	L		L	L	R	79
Avena spp.	L	1	L	L	R	79
Cakile edentula, maritima	L		L	L	R	79
Callitriche stagnalis	L		L	L	R	79
Cardamine hirsuta	L		L	L	R	79
Carduus pycnocephalus, C. tenuiflorus	L	9	L	L	R	79
Crepis capillaries, C. vesicaria	L		L	L	R	79
Cyperus tenellus	L		L	L	R	79
Galium aparine	L	?9	L	L	R	79
Juncus capitatus	L		L	L	R	79
Senecio elegans	L		L	L	R	79
Senecio jacobaea	L		L	L	R	79
Silybum marianum	L		L	L	R	79
Alopecurus spp.	L	7,9	L	L	M	80
Amsinckia spp.	L		L	L	M	80

Avellinia michelii	L		L	L	M	80
Catapodium rigidum	L		L	L	M	80
Cicendia filiformis, C. quadrangularis	L		L	L	M	80
Epilobium ciliatum	L		L	L	M	80
Foeniculum vulgare	L		L	L	M	80
Geranium dissectum, G. molle, G. yeoi	L	9	L	L	M	80
Hypericum androsaemum	L	6,7,8,9	L	L	M	80
Hypericum perforatum	L		L	L	M	80
Lepidium didymum	L		L	L	M	80
Lotus corniculatus	L		L	L	M	80
Lotus subbiflorus	L		L	L	M	80
Marrubium vulgare	L	6,7,8,9	L	L	M	80
Medicago spp.	L	9	L	L	M	80
Melilotus indicus	L	9	L	L	M	80
Minuartia mediterranea	L		L	L	M	80
Moenchia erecta	L		L	L	M	80
Petrorhagia dubia	L		L	L	M	80
Ranunculus muricatus	L		L	L	S	80
Silene gallica, S. gallica, S. nocturna	L	?9	L	L	M	80
Sisyrinchium iridifolium	L	?9	L	L	M	80
Spergula arvensis, S. rubra	L		L	L	R	80
Urtica urens	L		L	L	M	80
Vellereophyton dealbatum	L		L	L	M	80
Verbascum thapsus subsp. *thapsus*	L		L	L	M	80
Achillea millefolium	L	9	L	L	S	81
Arrhenatherum elatius var. *bulbosum*	L	1,3,6,7,8,9	L	L	S	81
Convolvulus arvensis	L	6,7,9	L	L	S	81
Dipsacus fullonum	L		L	L	S	81
Erodium cicutarium , E. botrys, E. malacoides	L	6,8,9	L	L	S	81
Festuca arundinacea	L	9	L	L	S	81
Festuca rubra	L		L	L	S	81
Lotus angustissimus	L		L	L	S	81
Mimulus moschatus	L		L	L	S	81
Ornithopus pinnatus	L		L	L	S	81
Reseda luteola	L		L	L	S	81
Tropaeolum majus	L		L	L	S	81

FURTHER ASSESSMENT REQUIRED[6]						
Brachythecium albicans	FAR					
Equisetum sp.	FAR					
Pilea cadierei	DR					
Plectranthus ciliatus	FAR					
Plectranthus graveolens	FAR					
Plectranthus oertendahlii	FAR					
Rostraria cristata	DR					
Solanum marginatum	DR					

1 Within the Angahook-Otway study Area. H= High impact species. Species with the ability to cause acute disruption to ecological processes, dominate vegetation strata, cause severe loss of biodiversity. Rates of biomass accumulation are generally high. Multiple cases of invasion with high impact consequence known or documented.
M= Medium impact species. Species with the ability invade native vegetation with low levels of disturbance, cause loss of biodiversity. Moderate to high rates of biomass accumulation. Cases of invasion known or the potential to cause biodiversity losses considered sufficient to require suppression. L= low impact species. Species naturalised in native vegetation, but causing minimal disruption to ecological processes, losses to biodiversity or their presence is of an transient nature.

2 Impact attributes are listed as: 1. Changed fire regime, 2. Changed nutrient conditions, 3. Changed hydrological patterns, 4. Changed soil erosion patterns, 5. Changed geomorphological processes, 6. Changed biomass distribution, 7. Changed light distribution, 8. Loss of biodiversity, 9. Substantial reduces regeneration opportunities of native plants, 10. alleopathic effects.

3 Area of potential habitat within the study area that could be occupied. E=extensive, M=moderate, L=limited

4 Range of habitat types that can be occupied – an expression of the number of susceptible EVC's within the study area. H=high, M=medium, L=low

5 Rate of dispersal. R=rapid, M=moderate, S=slow.

6 FAR = further assessment required, DR = doubtful record.

Machinery hygiene – what is on our vehicles?

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Summary Recent assessment of material for weed contamination, manually removed from vehicles during training in weed movement, machinery inspection and cleaning workshops has identified over 130 contaminant species. Fourteen species were declared noxious weeds in Victoria and six have regionally prohibited status. One weed of national significance was identified on two separate vehicles. Of the 18 utilities/4wd vehicles assessed an average of 617g of dry material was removed and 44% were carrying noxious weeds or Weeds of National Significance. Two vehicles were carrying multiple noxious species.

Introduction

The Victorian pest management framework identifies that risk of introduction and spread of pests needs to be communicated to the community so attitudes and behaviour are modified (DNRE 2002). It is well known amongst weed professionals that vehicles can disperse an array of weed species. Wace (1977) in his survey of car wash facilities in Canberra identified over 259 species or taxonomic entities that are potentially dispersed by vehicles. Gathering some hard data on the actual contaminants on each vehicle and comparing between vehicle types can be an expensive and time-consuming activity.

Workshops have been developed, that are aimed at increasing participants awareness of their obligations under the Victorian Catchment and Land Protection Act 1994 in particular to the movement and dispersal of noxious weeds and how they can implement practices to help them meet their obligations (Lardner *et al*. 2004). These workshops have been conducted for 12 local or state government organisations both within Victoria and South Australia since July 2004.

These workshops provided a unique opportunity to assess contaminants cleaned from a variety of equipment for weed contamination. Assessment of much of the material is still on-going.

Materials and methods

An opportunity existed for assessing material carried on vehicles and equipment used as part of training courses in weed movement, machinery inspection and cleaning run by DPI over the last 12 months. A manual clean down and collection of samples from vehicles was required to be performed by participants as part of their assessment against national competencies. This generated over 100 individual samples from 35 items of machinery or passenger vehicles. Samples were collected and stored in zip-lock plastic bags.

Visual assessment was made on all samples for seed contamination and where possible seeds were identified to species. All samples were tested for germinants. Many of the samples, due to their volume, required sub sampling for economical germination assessment. Approximately 380 mL (one punnet 12.1 × 6.7 × 4.7 cm) of loose sample was spread thinly over half of a 30 × 27 cm trays containing three litres of commercial sterile, potting mix. Two samples were placed on each tray and were separated by a ridge of potting mix to stop seed/soil movement from one sample to the adjoining sample. Trays were watered overhead and placed in an un-heated glasshouse and watered as required.

Germinated plants were assessed approximately fortnightly and identified as early as possible in their lifecycle. Due to time constraints species emerging were recorded but numbers of individuals of each species were not. Germination assessments continued for at least 12 weeks and for some samples up to 26 weeks. At the time of writing this paper samples collected after March 2005 were still being assessed.

Results have been recorded for the location of the sample on each vehicle, weight of sample taken and sub-sample assessed. Samples were not necessarily taken from all locations on all vehicles and total weights of samples are not necessarily all the material that could be removed off the vehicle. Hence results are likely to be an underestimate of the species present as germination conditions generally favoured winter germinators and not species likely to germinate in the summer. As a result of the sub sampling some species may have been missed in the assessment.

Results

Results presented in this paper are a summary of the samples taken from each vehicle. A total of 35 items of vehicles and machinery have been cleaned and assessed for weed contamination. This consisted of; 18 utilities and 4wd vehicles, five tractors and slasher units, three out-front mowers, three graders, three backhoes and three trucks and trailers. The utilities are mainly from local government and state government organisations with three vehicles belonging to private contractors. All the vehicles are exposed in their daily business to weed propagules, some of them are put into high-risk situations on a frequent basis (i.e. spray units and, slashers for CNG control). Details for of material collected from each vehicle or machine, weights of material collected and assessed and the number of species identified for each vehicle are listed in Table 1. The noxious weeds and weeds of national significance are also listed.

Over 130 species have been identified from the samples assessed. The highest number of species on one vehicle was 38. No vehicles were contaminant and species free. Almost 40 families are represented in the flora observed on the vehicles and Table 2 lists the families represented. The most frequent family observed was Poaceae followed by Asteraceae and Fabaceae.

The top 15 weed species identified on vehicles and machinery are presented in Table 3 along with the noxious weeds detected. 39% of passenger vehicles and 29% of machinery carried noxious weeds, while 11% of all vehicles carried multiple noxious weed species. The sample size is possibly too small to draw any conclusions regarding the type of propagule that is likely to be carried on particular vehicles or plant and machinery. It is more likely that the situation the vehicles are exposed to determines the species they will pick up.

Conclusion

Vehicles play an important role in the potential spread of weeds. Passenger 4wd vehicles used by local government and government business that are exposed to weed propagules pose a significant risk in spreading weed species of concern. The movement of plant and machinery will also spread weeds. Thorough cleaning of vehicles will significantly reduce this weed spread risk.

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Table 1. Weeds species identified from vehicle inspections

Vehicle type	Date collected	Location	Weight (g) or volume (L) of material removed	Weight (g) or volume (L) of material assessed	Number of species detected	Noxious weeds species identified
Passenger vehicles						
4wd wagon*	23/5/05	Koroit	67	53	8	
4wd tray*	11/5/05	Horsham	448	220	10	
4wd ute*	19/4/05	Naracoorte	942	204	13	
4wd ute*	10/5/05	Horsham	160	74	5	*Pennisetum macrourum* African feather grass
4wd ute*	20/4/05	Roseworthy	768	160	5	
4wd ute*	4/5/05	Bendigo	59	59	13	
4wd wagon*	4/5/05	Bendigo	2698	304	13	
4wd tray slip-on*	19/4/05	Naracoorte	556	98	17	
4wd ute*	20/4/05	Roseworthy	206	90	5	*Cenchrus longispinus* spiny burr grass
4wd spray unit*	21/4/05	Pt Augusta	824	236	36	*Xanthium spinosum* Bathurst burr, *Tribulus terrestris* caltrop, *Marrubium vulgare* horehound, *Cirsium vulgare* spear thistle, *Centaurea calcitrapa* star thistle, *Dittrichia graveolens* stink wort
4wd ute spray*	23/5/05	Koroit	902	134	15	*Ulex europaeus* gorse, *C. vulgare* spear thistle, *Silybum marianum* variegated thistle
4wd ute*	21/4/05	Pt Augusta	746	100	4	*D. graveolens* stink wort
2wd ute*	20/4/05	Roseworthy	2	2	3	*T. terrestris* caltrop
4wd ute*	10/5/05	Horsham	382	172	15	
4wd ute	20/7/04	Bacchus Marsh	0.2 L	0.2 L	11	
4wd ute	21/7/04	Bacchus Marsh	0.2 L	0.2 L	10	
4wd ute*	21/4/05	Pt Augusta	42	42	4	
4wd ute*	9/6/05	Hume	810	188	24	*Nassella neesiana* Chilean needle grass
Machinery (plant)						
Backhoe	21/7/04	Bacchus Marsh	57.6 L	1.5 L	38	*Juncus acutus* spiny rush
Backhoe*	3/5/05	Bendigo	129 L	413	17	
Backhoe*	4/5/05	Bendigo	40	40	5	
Wing mower*	8/6/05	Hume	1066	118	7	
Tractor and slasher*	8/6/05	Hume	1116	340	19	*Foeniculum vulgare* fennel, *Oxalis pes-caprae* oxalis
Tractor and slasher*	8/6/05	Hume	178	48	26	*N. neesiana* Chilean needle grass
Tractor and slasher*	4/5/05	Bendigo	182	48	21	*T. terrestris* caltrop
Tractor and slasher*	23/5/05	Koroit	222	86	13	
Out front mower	20/7/04	Bacchus Marsh	12 L	0.4 L	17	
Out front mower	21/7/04	Bacchus Marsh	5.7 L	0.4 L	20	
Out front mower*	8/6/05	Hume	652	80	10	
Grader*	23/5/05	Koroit	494	262	14	
Grader	20/7/04	Bacchus Marsh	11.9 L	3.8 L	32	*O. pes-caprae* oxalis, *Conium maculatum* hemlock
Grader*	9/6/05	Hume	2086	790	0	
Truck semi*	11/5/05	Horsham	2713	296	6	
Truck tipper*	4/5/05	Bendigo	1980	86	6	
Trailer*	4/5/05	Bendigo	52	26	13	

* Samples still under assessment at time of writing this paper

Table 2. Families and number of species identified in samples from vehicles and machinery

Family	Species identified	Family	
Amaranthaceae	2	Aizoaceae	1
Apiaceae	3	Anacardiaceae	1
Asteraceae	14	Boraginaceae	1
Brassicaceae	9	Cucurbitaceae	1
Caryophyllaceae	5	Euphorbiacaea	1
Chenopodiaceae	3	Gentinaceae	1
Crassulaceae	2	Geraniaceae	1
Cyperaceae	3	Liliaceae	1
Fabaceae	11	Lythraceae	1
Juncaceae	3	Meliaceae	1
Lamiaceae	3	Mimosaceae	1
Malvaceae	2	Oleaceae	1
Myrtaceae	3	Onogaraceae	1
Oxalidaceae	2	Pinaceae	1
Plantaginaceae	2	Primulaceae	1
Poaceae	38	Ranunculaceae	1
Polygonaceae	3	Thymelaceae	1
Rosaceae	2	Verbenaceae	1
Rubiaceae	2	Zygophyllaceae	1
Solanaceae	2		

Table 3. Number of vehicles and machines contaminated by species

Species Noxious weed or WoNS*	Number of contaminated vehicles			Species	Number of contaminated vehicles		
Number of units	Total (35)	Passenger (18)	Plant (17)		Total	Passenger (18)	Plant (17)
Tribulus terrestris caltrop	3	2	1	*Vulpia* sp. silver grass	16	7	9
Dittrichia graveolens stink wort	2	2	0	*Phalaris* sp.	15	7	8
Cirsium vulgare spear thistle	2	2	0	*Lolium sp* ryegrass	15	7	8
Oxalis pes-capre soursob	2	0	2	*Juncus bufonius* toad rush	15	7	8
Nassella nessiana Chilean needle grass*	2	1	1	*Plantago coronopus* buckshorn plantain	14	4	10
Pennisetum macrourum African feather grass	1	1		*Polygonum* sp. wire weed	14	4	10
Xanthium spinosum Bathurst burr	1	1		*Rumex* sp. dock	13	4	9
Foeniculum vulgare fennel	1	0	1	*Crassula* sp.	12	6	6
Cenchrus spp. spiny burr grass	1	1		*Medicago* sp.	12	5	7
Centaurea calcitrapa star thistle	1	1		*Poa annua* winter grass	12	4	8
Juncus acutus spiny rush	1	0	1	*Trifolium* sp. clover	11	6	5
Silybum marianum variegated thistle	1	1		*Bromus catharticus* prairie grass	10	4	6
Conium maculatum hemlock	1	0	1	*Plantago lanceolata* ribwort	10	2	8
Ulex europaeus gorse	1	1	0	*Sonchus oleraceous* sow thistle	10	5	5
Marribum vulgare horehound	1	1	0	*Hordeum* spp. barley grass	10	6	3

SESSION 8
Getting technical (concurrent)

The National Serrated Tussock Survey – impacts and implications of its resistance to the herbicide flupropanate in Australia

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Abstract A population of serrated tussock at Diggers Rest just north-west of Melbourne has been identified as being resistant to the herbicide flupropanate. This has prompted a national mail survey of 5000 land managers impacted by serrated tussock across Australia. Survey results have shown that serrated tussock has spread widely throughout Victoria, NSW, ACT and Tasmania with 15 out of 399 respondents reporting resistance and requiring further investigation. The survey has also shown that serrated tussock is costing each land manager between $15 000 and $20 000 annually in control and lost production costs. This emphasises the importance of promoting integrated management of serrated tussock.

Keywords Survey, serrated tussock, *Nassella trichotoma*, economic impact, herbicide resistance, flupropanate

Introduction

Serrated tussock (*Nassella trichotoma* Trin. & Rupr Barkworth) is a perennial, drought resistant tussock grass species that is native to the pampas grasslands of Argentina, Uruguay, Chile and Peru (Parodi 1930, Rosengurtt *et al.* 1970) and Bolivia (Walsh and Entwisle 1994). Serrated tussock is a proclaimed noxious weed in the Australian Capital Territory, New South Wales, Victoria, South Australia and Tasmania. It has been described as causing a greater reduction in pasture carrying capacity than any other weed in Australia with heavily infested paddocks in NSW carrying only 0.5 dry sheep equivalent (dse) per hectare compared to 7 to 15 dse on improved pasture without the weed (Parsons and Cuthbertson 1992). Serrated tussock is a Weed of National Significance (Thorp and Lynch, 2000) that has been estimated to conservatively cost Victoria $5 million per year (Nicholson *et al.* 1997) and the economy of New South Wales $40.3 million per year (Jones and Vere 1998). In 1977 it occupied 680 000 ha (Campbell 1977) and now occupies more than 870 000 ha in New South Wales with an estimated 2 000 000 ha at risk of infestation (Ian McGowan, NSW Department of Primary Industries, personal communication). In Victoria, serrated tussock was first collected at Broadmeadows (15 km NNW of Melbourne) in 1954 where it occupied 4 ha (Parsons 1973). By 1979 it had spread to occupy approximately 30 000 ha (Lane *et al.* 1980) and by 1998 it occupied in excess of 130 000 ha (McLaren *et al.* 1998). Serrated tussock is also found in Tasmania where it is currently spread in scattered populations over an area of approximately 1000 ha (Christian Gonninon, Tasmanian Department of Primary Industries Water and Environment, personal communication). The potential distribution of serrated tussock based on its current infestations in Australia has been estimated at 32 million ha with substantial areas of New South Wales, Victoria and Tasmania at risk of invasion (McLaren *et al.* 1998). Serrated tussock is being increasingly recognised as a serious environmental weed and the associated native vegetation being invaded by serrated tussock is described in McLaren *et al.* 1998.

Despite years of research, there are still limited control options for managing serrated tussock in Australia (Michalk *et al.* 1999). The only registered herbicides for control of serrated tussock in pastures are flupropanate, glyphosate, and 2,2-DPA. Flupropanate is widely regarded as the most selective and effective herbicide for controlling serrated tussock (Campbell and Vere 1995). Species such as phalaris, cocksfoot and kangaroo grass have some tolerance to flupropanate (Campbell 1979, Campbell *et el.* 1979, Campbell and Ridings 1988) while its residual action in the soil can prevent serrated tussock regrowing for three to five years (Campbell and Vere 1995). Flupropanate resistance has been identified in a population of serrated tussock in Victoria (Noble 2002). Serrated tussock plants suspected of being resistant to flupropanate were grown in a pot trial and treated with a range of flupropanate rates. The resistant serrated tussock survived application rates as high as 8L ha^{-1} which is four times the recommended rate used for controlling this species (Noble 2002). Similarly, Petri dish dose response trials undertaken on serrated tussock seeds have shown that the flupropanate dose required to reduce the germination of seeds from resistant plants by 50 % was approximately 10 times higher than for susceptible seeds (Graeme Pritchard, Victorian Department of Primary Industries, personal communication) This has prompted a national survey to try and determine whether serrated tussock resistance to flupropanate is wide spread and to raise resistance awareness and promote integrated management of serrated tussock.

Materials and methods

In November 2004, a tick-box questionnaire was sent out to land managers in Victoria, NSW, ACT and Tasmania. In Victoria and Tasmania, questionnaires were sent out directly to landholders that had been recorded with serrated tussock on the land they managed. This also included a mailing list of 1130 within the Melton Shire in Victoria. The Melton Shire was targeted because the property identified with serrated tussock resistant to flupropanate was located within this Shire. A further 931 questionnaires were mailed directly to land managers recorded with serrated tussock on the Victorian Department of Sustainability and Environment's Integrated Pest Management System (IPMS). Twenty questionnaires were sent out to Victorian park rangers, 10 to VicRoads and 30 directly to Victorian spray contractors. In Tasmania, 275 questionnaires were mailed out directly to land managers recorded with serrated tussock. In New South Wales 338 questionnaires were sent directly to NSW Landcare groups within serrated tussock infested locations while the remaining 2265 questionnaires were sent to NSW and ACT Weeds Inspectors for distribution to land managers in their districts. The questionnaires were targeted to regions thought likely to be infested by serrated tussock. A total of 5000 questionnaires were sent out (2125 to Victoria, 2450 to NSW, 150 to ACT and 275 to Tasmania). A colour CRC for Australian Weed Management Fact sheet entitled 'Understanding the mechanisms behind herbicide resistance' was also sent out with the questionnaires to help land managers understand what herbicide resistance is and how it can be prevented. Each questionnaire included a prepaid return envelope to aid land managers.

Respondents were requested to provide information on the extent of land they manage and the coverage of serrated tussock infestation on their land. The infestations were categorised either as '**Dense** – monoculture or close to monoculture – very few native/other species present', '**Medium** – roughly equal proportions of serrated tussock to other native/pasture/crop species present', '**Scattered** – native/pasture/crop species in much greater abundance than serrated tussock', '**Rare** – single or very few serrated tussock plants present' or '**Absent**'. They were also asked to classify what proportion of these infestations occurred on pasture land, native vegetation or other (roadside, cropping, forestry etc). Respondents were also asked to indicate the costs as 'Material costs', 'Labour costs', 'Time (days/year) cost' and 'Other costs', to control serrated tussock infestations in 'pasture', 'native vegetation' and 'other' land classes. Questions were asked about chemical control including what herbicides they used for serrated tussock, the number of times they used these herbicides and the year they first used these herbicides. They were also asked whether they had noticed serrated tussock on the land they managed that had not died after two or more applications of a serrated tussock herbicide and whether they thought this could have been due to resistance.

Results

Distribution and type of infestation

A response rate of approximately 8% (399) was obtained while approximately 250 questionnaires were returned address unknown. The respondents reported on a total area of approximately 0.42 million ha consisting of pasture, native vegetation and other (roadsides, cropping, etc) across Australia. The respondents reported serrated tussock infestations totalling approximately 102 048 ha comprising 48 747 ha on pasture, 43 019 ha in native vegetation and 10 281 ha on other areas (roadsides, cropping etc). Of this total, some 82 094 ha was in NSW, 8113 ha in Victoria, 11 520 ha in the ACT and 321 ha in Tasmania (Table 1).

Table 1. Serrated tussock infestations categorised by State, land use and density reported from survey

		Serrated tussock infestation density (ha)				
State	Land use types	Dense	Medium	Scattered	Rare	Total
NSW	Pasture	878	1 078	17 909	19 735	39 600
	Native	1 099	4 303	16 798	10 855	33 055
	Other	143	12	3 910	5 375	9 439
	Total	2 120	5 393	38 617	35 965	82 094
VIC	Pasture	37	371	2 353	2 754	5 515
	Native	6	195	939	816	1 956
	Other	99	70	225	247	642
	Total	142	636	3 517	3 817	8 113
TAS	Pasture	30	31	121	39	221
	Native	1	2	64	28	95
	Other	0	0	5	0	5
	Total	31	33	190	67	321
ACT	Pasture	190	25	2 130	1 067	3 412
	Native	370	1 030	5 976	537	7 913
	Other	0	0	45	150	195
	Total	560	1 055	8 151	1 754	11 520
Total Australia		2 853	7 117	50 475	41 603	102 048

The most significant serrated tussock infestations reported occur in NSW where the majority of dense and medium infestations were reported on native vegetation with more scattered and rare infestations reported on pasture land (Table 1). Similarly, in the ACT respondents reported greater areas of dense, medium and scattered serrated tussock infestations in native vegetation than pasture. However, in Victoria and Tasmania more serrated tussock was reported in pasture than in native vegetation. These results may also reflect that all the Victorian and Tasmanian land managers received questionnaires through direct mail. However, in NSW and the ACT, questionnaires were sent via weeds officers, environmental officers and agronomists for distribution to land managers. In some cases these professionals reported on an entire district or region. In Victoria, the 'Other' category recorded the largest area of dense serrated tussock. However, this was reported by a single landowner who did not provide contact details.

Economic impact

Table 2 lists the annual costs of serrated tussock control expressed as materials, labour and other (other costs of serrated tussock not included in materials and labour) listed for land use and State affected. As expected, NSW, the state with the most significant serrated tussock infestations are spending the most money on serrated tussock control ($691 759 per year and $7745 per respondent). However, land managers from the ACT are spending on average $9405 per respondent per year on serrated tussock control which is more than double that reported for Victoria ($3862 per respondent per year) and Tasmania ($2130 per respondent per year). Labour was recorded as the greatest cost component in all land use types except in native vegetation in the ACT where $43 450 was spent on materials compared to $13 640 estimated for labour. The annual total production losses caused by serrated tussock is listed in Table 3. In total, production losses were estimated at $662 820 while the average losses per respondent was approximately $13 000 per year. In total, serrated tussock was estimated to be costing the respondents approximately $1.8 million in management costs and lost production or about $15–20,000 per year per respondent.

Herbicide resistance

Table 4 shows the number of respondents using flupropanate and glyphosate and average years/times used for control of serrated tussock compared by State. Almost twice as many respondents were reported using flupropanate to glyphosate in NSW and vice versa for Victoria.

Table 2. The annual costs of serrated tussock control reported from survey

State	Land use types	Annual total cost to control serrated tussock by State ($ y^{-1})				Average per respondent ($ y^{-1})
		Materials	Labour	Other	Total	
NSW	Pasture	165 714	177 110	23 970	366 794	2 134
	Native	50 180	116 172	87 570	253 922	3 199
	Other	15 347	41 286	14 410	71 043	2 412
	Total	231 241	334 568	125 950	691 759	7 745
VIC	Pasture	53 609	76 478	26 460	156 547	1 010
	Native	16 142	50 898	17 600	84 640	918
	Other	9 275	43 800	8 425	61 500	1 934
	Total	79 026	171 176	52 485	302 687	3 862
TAS	Pasture	2 050	5 390	3 350	10 790	715
	Native	2 325	4 650	2 500	9 475	1 415
	Other	0	0	0	0	–
	Total	4 375	10 040	5 850	20 265	2 130
ACT	Pasture	21 550	30 760	40 300	92 610	5 438
	Native	43 450	13 640	17 800	74 890	3 755
	Other	110	500	100	710	212
	Total	65 110	44 900	58 200	168 210	9 405
Total Australia		379 752	560 684	242 485	1 182 921	

Table 3. Annual total production loss by State ($ y^{-1})

State	No. of replies	Total $	Average per respondent $
NSW	31	478 600	15 439
VIC	15	91 740	6 116
TAS	1	1 000	1 000
ACT	4	91 480	22 870
Australia	51	662 820	12 996

Table 4. Herbicides used to control serrated tussock (number of respondents) and average years/times used

State	Flupropanate No. reporting – Ave years / times used	Glyphosate No. reporting – Ave years / times used	Total No. reporting
NSW	96 – 10.7	68 – 7.6	164
VIC	57 – 5.1	120 – 5.6	177
TAS	7 – 1.4	4 – 6.0	11
ACT	10 – 10.9	11 – 3.8	21
Australia	168 – 8.0	203 – 6.3	373

Flupropanate has been used on average more than ten years / times by respondents from NSW and the ACT. Glyphosate has been used more frequently than flupropanate in Victoria and Tasmania (Table 4). The number of respondents reporting herbicide resistance is shown in Table 5. Serrated tussock resistance to flupropanate was identified by nine land managers and resistance to glyphosate by six land managers (Figure 1). All the Victorian flupropanate resistance reports were from properties in the Diggers Rest, Sydenham, Bulla locality just north of Melbourne.

Discussion

This survey has confirmed the massive impacts this weed is having on Australian agriculture with average annual serrated tussock costs ranging from $15 000 to $20 000 per year per respondent. This survey has also identified nine (2%) properties reporting serrated tussock suspected of being resistant to flupropanate. A process of contacting these land managers and obtaining serrated tussock samples for testing resistance is underway. Similarly, six land managers have also expressed concern that glyphosate is not killing serrated tussock and that this could be due to resistance. The Victorian Department of Primary Industries has been working in collaboration with the Melton Shire Council to ensure that all serrated tussock on and surrounding the property confirmed with resistant serrated tussock is controlled. In addition, RMIT University in collaboration with the Victorian Department of Primary Industries have commenced a PhD project investigating the heritability and mechanisms causing resistance to flupropanate by serrated tussock. It is critical that land managers do not rely solely on one herbicide type to control serrated tussock. Land managers need to consider mechanical control, cropping, pasture rehabilitation, grazing management and a strategic use of herbicides to try and reduce the likelihood of resistance. This

Table 5. Survey respondents reporting resistance

State	Flupropanate resistance?	Glyphosate resistance?
NSW	2	1
VIC	6 [A]	5
TAS	0	0
ACT	1	0
Australia	9	6

[A] Includes one property confirmed with resistance

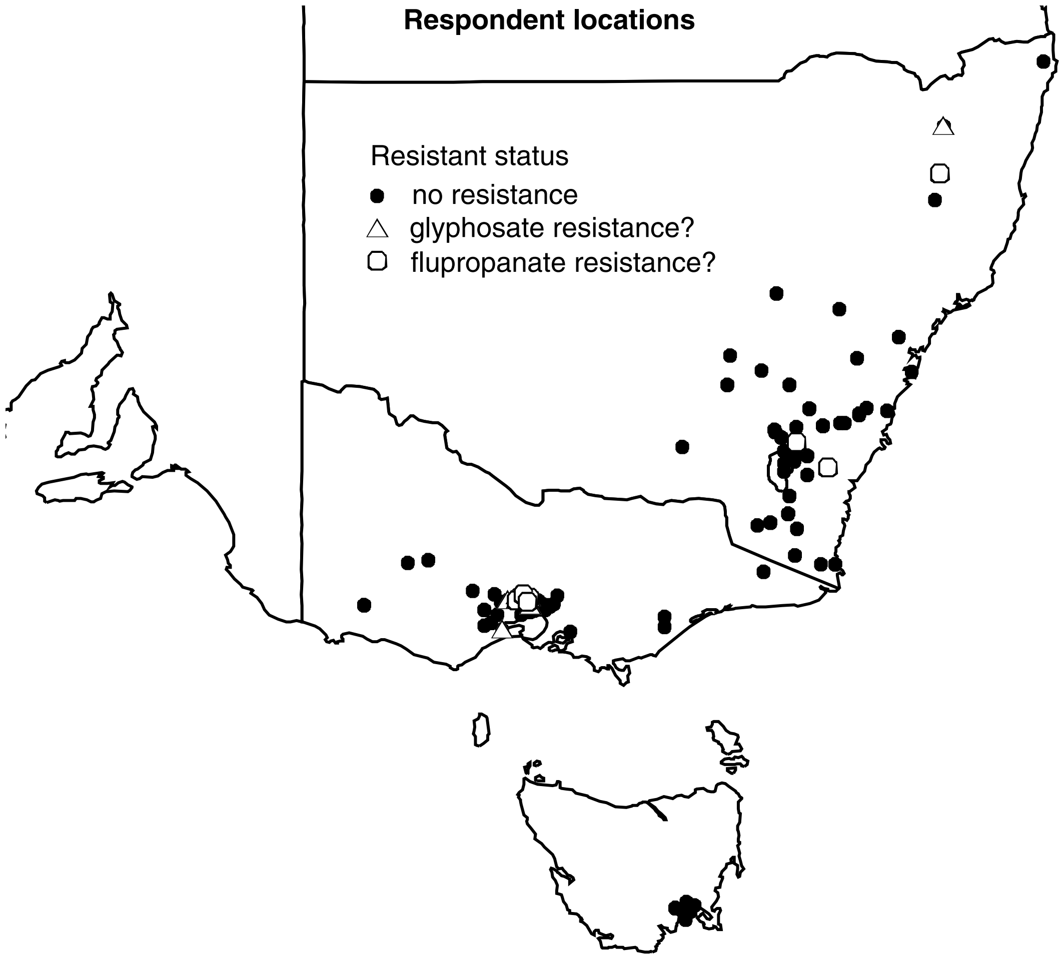

Figure 1. Distribution of survey respondents reporting resistance in serrated tussock in 2005

survey reinforces the need to practice integrated weed management to control serrated tussock.

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Applying field-based information tools to weed management – an examination of field information issues in DPIS Landscape Protection Program

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Introduction

Information is one of the main assets of the Department of Primary Industries Landscape Protection program – the way in which it uses information is a major determinant of how successful the program will be in managing the pest plant problem in Victoria. Business-specific information is one of the main factors that influences how Landscape Protection field staff behave in their day-to-day business context. It impacts on how they meet challenges and solve problems, how they interact with clients, investors and each other, make decisions, take action and respond to the primary needs of the program. In turn, it is the information that field staff collect that informs the program leaders' decision making processes and communicates success to investors. It is this information that determines the future direction of the Landscape Protection program.

In this light, it seems obvious that the Landscape Protection program needs to ensure that it provides its field staff with the best information tools it practically can. In doing this it must ensure that it doesn't simply design more ways to hold its information, but instead focuses on developing a suite of innovative customised tools that meet specific information needs. Rather than tools that simply contribute from outside the process, it must employ tools that become an integral part of the process itself. Any tool developed for use by Landscape Protection field staff must be designed with their needs as the primary focus. And most importantly, these tools must represent value to field staff – they must represent something that contributes to their work and enables them to perform at a level that realises their true potential.

One way in which this can be achieved is through providing information tools filed staff actually do their work rather than limiting them to office bound or low value hard copy field based systems. Field based information tools have the potential to unlock some significant gains for the Landscape Protection program in not only increased efficiency, but also improvements in the quality of the work the program does and the value it represents to investors, the community and other stakeholders in the weeds issue in Victoria.

The primary weed management information tool in Landscape Protection is the Integrated Pest Management System (IPMS). Use and user perception of IPMS is highly variable. While a few staff apply IPMS with a level of success, many feel that IPMS is not a tool that effectively meets their day-to-day needs – a tool designed to meet business management, not operational information needs. Regardless of the validity of these perceptions, the very real fact remains that developers have to date been unsuccessful in effectively meeting field staff information needs.

The most common complaint in relation to IPMS is the limited ability for staff to extract useable information. IPMS contains a variety of standard reports readily available to all registered users. In addition to this, a team of support officers across the state is available to provide customised information products such as queries and reports using InfoMaker. Yet these negative perceptions remain reflected in comments such as 'its like an information black hole', 'I put information in, but I can't get it back out in a form that I can use' and 'IPMS doesn't help me do my job'.

Assuming that the reports in IPMS do provide the type of information field staff require, the Landscape Protection program needs to look at why their information needs still aren't being satisfactorily met. If it is not the reports themselves – the information they contain – is it the format and delivery mechanism that is proving inadequate?

Current information practices

So what are the basic information needs of field staff and how are they currently meeting their own information needs as well as the data capture requirements of program leaders? There are three main types of information currently being utilised in Landscape Protection – spatial, photographic and textual. All of these play a role at various stages in the core Landscape Protection education, extension and compliance processes. Throughout these processes there is a constant two-way exchange of information taking place (Table 1).

Data supports and informs program decisions, is used to measure, and is recorded throughout the entire process. The methods and tools used vary considerably across the program and range from use of local knowledge, to electronically automated processes.

- **Local knowledge** What the team members knows about his or her work and local area. This extends to where infestations are, ownership history, works history and the results of previous contacts. Local knowledge obviously grows over time and in many cases, the longer a person has worked an area, the more likely they are to rely on local knowledge as their primary information tool. There are many obvious issues with the reliability of this type of information tool and it should always be supported by a reliable electronic or hardcopy resource. However, there are some distinct advantages – the human brain is after all a powerful database – though these are limited to the individual holding the knowledge.
- **Land holder file** Hardcopy files that record the contacts and the outcomes of contacts with each land holder in a work area. These are formed and maintained purely by the choice of the individual staff member and are not a standard tool. There are no standard formats, contents or storage protocols. They can be a useful tool recording a level of detail not contained in other standard databases such as IPMS. However they do perpetuate all the issues associated with a purely hardcopy system.
- **Paper based forms** Work Plan Agreements record the actions agreed to and required of the land holder and constitute a request made by DPI to the land holder. Data entry forms are used as a field tool to capture the mandatory information required by IPMS.
- **IPMS** The primary database of the Landscape Protection program which records information on assessments, infestations, properties, land holders, contacts, treatments and the like. IPMS can provide information of previous contacts in the form of a reassessment report.
- **Spatial databases and related tools** Spatial data and associated tools are themselves the subject of great variability in terms of sophistication and functionality and the means in which they are applied. IPMS itself records some spatial information in the form of points describing the location of each infestation. In addition to this, DPI has access to a wide array of corporate spatial data. Some tools include ArcView, MapShare (an intranet based map service based on ESRIs ArcIMS), mobile GIS (primarily ArcPad), and various GPS tools.

Because of the number of contrasting information sources available to field staff, it is obvious that there is no one standard

Table 1. Flow of information supporting the education, extension and compliance processes

Process	Information type	⇦ ⇨ ⇔	Information source or tool
Initial Contact	Project area	⇦	*Spatial database*[A]
	Properties (and numbers)	⇦	*Spatial database*
	Property owner details	⇦	Ratepayer database
	General contact details	⇨	*Land holder file (local hardcopy)*
Initial Assessment	Previous assessment information (if applicable)	⇦	IPMS
			Land holder file
			Local knowledge
	Infestation location, size, dimensions etc	⇦	*Spatial tool (automated or manual)*
		⇨	IPMS
		⇔	*Spatial database*
	Other property, contact and infestation details	⇨	IPMS
	Treatment details	⇨	IPMS and Work Plan Agreement form (WPA. Stored locally on hardcopy file)
		⇔	*Spatial database*
	Extension packages	⇦	Various (Landcare notes, Ag Notes, PIRVic data etc)
	Infestation photograph	⇨	*Stored locally. Digital photos linked to (but not stored in) IPMS*
	General contact details	⇨	*Land holder file*
Follow-up Assessment	Initial assessment details	⇦	IPMS
			Land holder file
			WPA
	Treatment status / inspection details	⇨	IPMS
			Land holder file
			WPA
Compliance	Non-compliant land holder requiring further action	⇨	Land Management Notice (LMN) form and register
	Brief (court action) evidence	⇦	All utilised sources
		⇨	Hard copy file for defence team
	Court result	⇨	Court action register

[A] Text in italics denotes a non-standard source that is applied in addition to standard source where resources are available. In the case of spatial data, where electronic systems are unavailable, manual and variable processes apply

process for capturing and utilising program information. This is due to a number of factors:

- Previous regional structure did not effectively promote statewide data capture and use standards or processes;
- Differing levels of operational staff skill, ability and propensity to adapt new technologies;
- New techniques employed by a few early adopters, but ability to disseminate these beyond immediate working teams was difficult;
- A culture of negativity towards electronic based technology due to previous experience with ineffective information systems;
- Focus of current information systems being on storage of information rather than meeting workflow needs has led to field staff members developing their own processes.

We can however make an estimation of the broad data capture process that many staff use which essentially involves the capture of filed data using a hard copy form and then transposing this information into IPMS at a later stage (Figure 1). Of course there are a multitude of variations within this process including the type of form used, the source of spatial coordinates, the means of measuring the infestation and the means of entering the data onto the system.

Issues and risks associated with current information practices

Data quality

Current information capture and use practices present some significant risk in terms of data quality and reliability. Data quality (as described by the Australian Bureau of Statistics, 2005) refers to:

- Relevance – the degree to which the data meets (or is relevant to) the needs of the user.

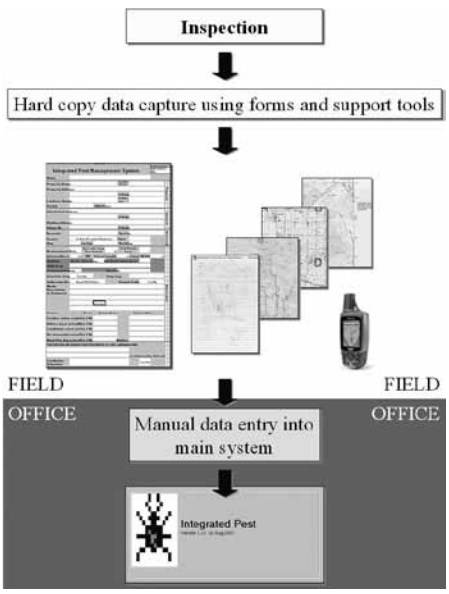


Figure 1. The broad data capture process

- Accuracy – the degree to which the information correctly describes the item it was intended to measure (and is perhaps one of the most immediately apparent and significant concerns relating to Landscape Protection data processes).
- Timeliness – the lapse in time between the data being recorded at its source and it becoming available, in this instance within IPMS.
- Accessibility – how readily available the data is to the user or the degree of difficulty facing the user in accessing the data
- Interpretability – refers to the provision of associated data (metadata) that supports the understanding of the primary dataset
- Coherence – the compatibility of the main dataset with other related datasets.

Relevance The information which is supplied to field staff must be relevant to their needs and applicable in the day-to-day processes they participate in. Without readily available relevant data field staff will either operate under their own assumptions or seek alternate sources of information that are potentially less reliable.

In this area, we have tended to focus on the relevance of information to program decision making and accountability, rather than on supporting operational process with effective information tools.

Accuracy Accuracy is a major concern in relation to Landscape Protection information. Some of the main issues relate to completeness of records and the correctness of the information contained within the records. For example it was discovered during a recent audit that a significant portion of one team members infestation records were listed against the incorrect species. The source of this error was a failing in the data capture process - in this case the person making the observation did not enter the records onto the system, rather the records were entered by a third party.

A major area of concern in terms of accuracy is the correctness of spatial coordinates entered into IPMS. A significant number of IPMS records cannot be included in spatial data analysis because they are too inaccurate. In some cases, records are positioned in other states or even the ocean. While these are alarming, of greater concern are those records that are not positioned correctly but are not obvious to the data analyst.

These errors come about because of a number of factors:

- Incorrect reading of maps coordinates
- Use of inappropriate scale maps (resulting in an error of up to 1 km)
- Use of coordinate systems that are not compatible with IPMS (specifically since the introduction of GDA94 replacing AGD66)
- Incorrect set up of GPS
- Data entry error
- Incomplete coordinates (ie four digit easting instead of six)

Timeliness The delay between data being captured in the field and it being entered onto IPMS can in some cases be quite significant. Data captured using the hard copy IPMS data form are not always entered onto the system immediately. In some cases, especially when the team member relies on a data entry officer to process the form, this delay can be significant. The issue here is not the efficiency of the entry process, rather the 'rainy day' mentality that is applied. Many field officers do not submit forms as they fill them out, instead they wait to accumulate a number of forms before sending them to be entered. In extreme cases, some team members wait for up to a year! This results in significant gaps in the dataset.

Accessibility Accessibility of data in a useable format is perhaps one of the most common complaints of operational staff. This is a significant issue and one that impacts negatively on field staff propensity to participate in the data capture process. The 'what's in it for me' factor plays a significant role here. Collecting data that they feel is of no use to them reduces their propensity to capture the data or to ensure that the data they do capture is of a reasonable quality.

Interpretability While interpretability generally related to an external party being able to understand a dataset, in this case it applies equally to field staff collecting the data. Data capture protocols that have been previously developed did not sufficiently communicate to field staff the definition of mandatory fields and the type of data required in each. This has resulted in some variability in the main dataset that have an impact on the overall quality of the data.

In addition to this, the current data capture process does not apply any control other than identifying fields that must be captured to counter this issue. As long as something is entered into a mandatory field, it will be accepted by the system. This has resulted in some mandatory fields containing meaningless information.

Coherence Compatibility of Landscape Protection with other datasets is probably an issue at the system level more so than the data level. The ability to combine IPMS data with other related data captured by other DPI programs is a significant limitation of the data that impacts on the ability of operational staff to obtain a complete picture of the environment in which they operate.

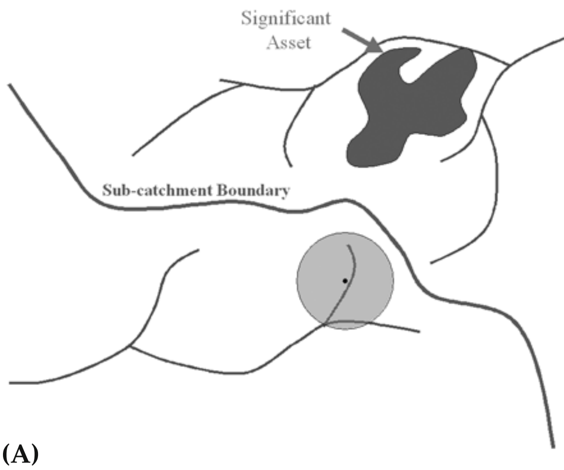
Process inconsistency
Process inconsistency can impact on the quality and reliability of field captured information. This error as a result of inconsistency can have an accumulative effect when then applying analysis processes to this data. Difference in data capture techniques and processes must be considered when combining two data items. Two items, which appear to be the same, may not in fact be equal depending on the process applied. A simple example is that of an area statement – using a variety of methods to measure the size of an infestation may result in a variety of answers. So if one team member is measuring all infestations using one method and another team member is using a different method, those two sets of data cannot be reliably compared.

Points vs polygons
Infestations, which are two dimensional, having a breadth and a width, are currently recorded as points rather than polygons. While recording these as points is easier and faster than polygons, the potential to apply effective spatial analysis process to the data is significantly reduced. We cannot spatially measure changes in infestations over time, or carry out effective spread predictions at a local level. We cannot apply effective spatial analysis to determine the connectivity of infestations in the landscape, how they interact with each other or how they might impact on uninfested areas.

Figure 2 demonstrates the limitations of recording point data and then applying spatial analysis. A 50 hectare infestation close to a sub-catchment boundary is recorded using a point. A data analyst wants to use this point data to determine risks to a significant asset within the catchment. In order to polygonise the point record, the analyst buffers the point so that a circular polygon of 50 hectares is generated. They then apply another analysis technique to determine the risk to assets in the catchment and based on the data, this process determines that the asset is not at risk from this infestation (A).

What the analyst doesn't know is that the coordinates used to generate the point were not taken from the centre of the infestation and the infestation was more oblong in shape rather than circular. It's actual extent placed it over the sub-catchment boundary, meaning it in fact does pose a threat to the asset lower in the adjacent sub-catchment (B).

Loss of workflow efficiency
Current information systems do not effectively support workflow processes where



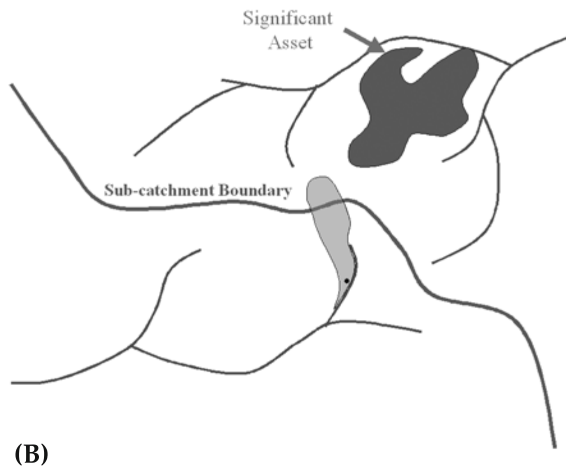


Figure 2. Demonstration of the limitations of point data over polygon data in data analysis. (A) Point data that has been buffered in order to generate polygon data for analysis purposes does not effectively estimate (B) the true risk the infestation poses on the asset in the adjacent sub-catchment

in the field where staff do their work. As outlined earlier, field staff compile information in the office, collect new data in the field and then return to the office to enter it into a database. In addition to this, there is no automated process for entering the data into the system. This is a costly process results in double handling of data, increasing opportunity for error in the data.

Field staff also collect IPMS data, complete a WPA form with land holders and in some instances, record these interactions in land holder files. These three tasks overlap in terms of their purpose and the data captured and applied.

Third party data entry
Data entry officers provide support to operational staff by entering the contents of data capture forms onto IPMS. Apart from lost efficiency issues, this process increases error in the data as it is open to interpretation error, such as that in the earlier example of the infestations recorded against the wrong species. In this case, the field staff member did not write the species name on the form. The data entry officer assumed that the records related to the same species that all other field staff members were working on. Had the field staff member entered the data himself, he would have known that this was not the case and (hopefully) entered the correct species.

In addition to this, the data entry officer often returns incomplete, ambiguous or unreadable data forms to the field staff for clarification. This obviously extends the process and increases costs and the time between the data be collected and it being entered onto the system.

Known extent of pest plant problem
Our current data capture methods do not effectively capture the true extent of the pest plant problem – a significant limitation in effectively managing the threat. At best, our IPMS records communicate mitigation effort – our assessments – not the actual pest plant extent as we only record those areas that we have both inspected and that are infested. We do not attempt to record all infestations, nor do we appropriately record those areas that have been inspected and found to be free from infestation.

Age of infestations
We record the date of the inspection rather than the approximate date the infestation first appeared. This has lead to a tendency to assume new infestation records represent new and emerging infestations rather than simply an assessment of an infestation previously unrecorded – an incorrect and dangerous assumption.

Considerations for Field-base Data Module

Data capture applications
ArcPad ArcPad is an ESRI mobile GIS application that was developed in Melbourne by RIA, an ESRI business partner. Of course there are many mobile GIS applications on the market, but given that DPI's ITS group support ESRI applications as standard operating environment (SOE) software and ArcPad is compatible with GIS tools already utilised in our day-to-day operation, it seems logical to prefer this specific application.

ArcPad allows field staff to take GIS data into the field, update existing information and collect new data. Spatial data can be displayed, queried and edited, while customised data forms allow for easy collection and update of textual information. Spatial data is captured either by digitising directly on screen (Figure 3) or through receiving GPS sourced coordinates. Using ArcPad, Landscape Protection field staff could record reassessments, updating existing IPMS data or add new assessments.

Figure 3. Field based staff using ArcPad to digitise directly on screen

ArcPad Application Builder allows systems management staff to develop data capture forms (Figure 4) that both assist in data entry, but also contribute to data integrity. Using the form, you can control the way the data is captured and formatted:

- Mandatory fields ensure all required data is captured.
- Drop down boxes allow the user to select pre-defined values rather than having to manually enter them. In addition to this, these lists can be tailored to individual users needs.
- Radio buttons and tick boxes streamline data entry for binary type data entry.
- Scale-ramp bars for estimating a value along a continuous scale.
- Calendar selection tools ensure easy and accurate date formatting.

ArcPad Application builder is not limited to these standard functions, but also allows for additional functionality to be programmed into both the forms and the application itself to provide specialist operation. For example, we could create a

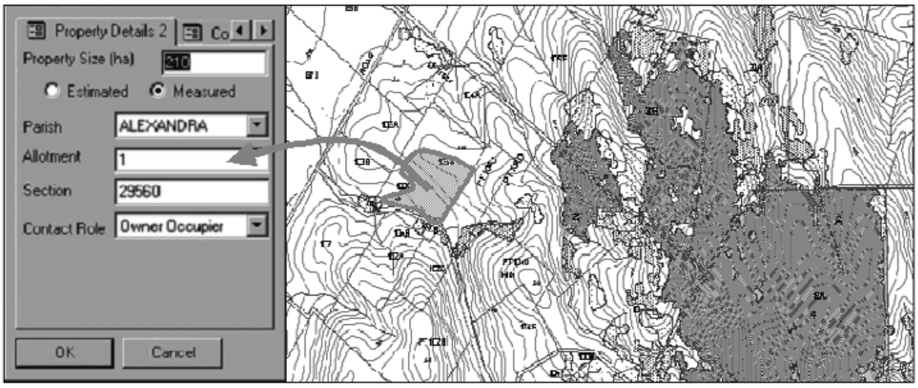


Figure 4. An example of a data entry form connected to a polygon spatial dataset

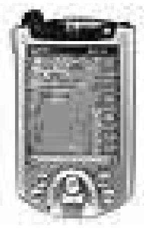


Figure 5. HP iPAQ Pocket PC

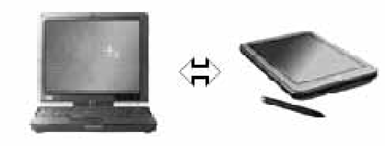


Figure 6. Tablet PCs can move between normal laptop mode to pentop tablet mode

function that automatically populates fields based on other spatial data layers. In the case of the IPMS fields of shire, parish, CMA, LandCare group and the various allotment details, all of this information is already captured and store in spatial datasets. This data could be automatically populated in a record using a basic drill down function that queries these spatial data layers. Other functionality developments might include:

- Automatic population of easting and northing fields using the centroid coordinates
- Automatic population of area field using an area calculation function.
- Ability to copy data from another existing record
- Automatic population of contact and property details based on existing IPMS data.

Not only does ArcPad have the potential to improve data capture processes in the ways outlined above, but it also represents a vehicle that provides digitisation of polygon and line data in addition to the already supported point format in IPMS. When used in conjunction with a GPS, it would essentially eliminate error in spatial data resulting from the recording of inaccurate coordinates. These two features in themselves represent a significant advantage for Landscape Protection by addressing two significant spatial data issues.

Mobile IPMS An alternative to building ArcPad forms is to develop a mobile IPMS application. This mobile application would essentially be a scaled down version of the main IPMS database that included simple data capture functionality and allowed access to current IPMS data. Put simply, it would allow staff to take IPMS into the field with them, eliminating the need for intermediate data capture tools and the data conversion processes that would be required if a different such as ArcPad platform were used.

In using ArcPad forms to capture IPMS data, systems management staff first need to convert IPMS data into a format compatible with ArcPad and conversely convert field captured data to an IPMS compatible format. If IPMS were the tool used to capture data in the field, these processes would not be required.

It would not (assuming Mobile IPMS would essentially mirror the current application) however be able to operate in isolation and capture the valuable spatial data allowed for in ArcPad. Instead, it would need to either be developed with a spatial component built in (an expensive exercise) or alternatively connect to ArcPad for the spatial data capture component of the process. The essential difference here is that the textual data otherwise captured using the data form in ArcPad would instead be captured using IPMS, with a link then created between the IPMS data and the spatial ArcPad data.

This type of development would truly represent a whole of system solution to current Landscape Protection filed-based data issues. It would obviously require major developmental changes in the current IPMS database, but in doing so, would exponentially increase the flexibility of IPMS, creating a system that more accurately supports the workflow processes of our operational team.

Data transfer Applying either of the above solutions requires an effective data transfer process between the field module and the central database. New data and updated records must be incorporated into the main database while applying rigorous data quality assurance processes and avoiding edit conflicts. Data transfer processes should be as automated as possible and require as little input from users as possible.

In its current format, IPMS does not allow for the uploading of new records, only uploading edits to existing records. However, this difficulty can be circumnavigated through the development of an upload module already scoped by IPMS developers. Obviously the form this module would take would depend on the field data capture solution chosen.

Digital Workplan Agreement forms The information captured using the electronic data capture form can also be used to automatically populate an electronic WPA form. This form can then be printed and signed by the land holder during the assessment and does not require operational staff to duplicate information.

Mobile hardware

Pocket PC Pocket PCs are an inexpensive mobile platform that can run a variety of Windows CE compatible applications. A standard pocket PC can be expanded to accommodate greater disk space, increase battery life and can also connect to a variety of accessories such as Compact Flask GPS, mobile printers and scanning devices.

Pocket PCs are light weight and easy to handle. However, the drawback to this technology when applied to field data capture processes is its sensitivity. Pocket PCs are not very rugged and can be subject to damage during daily tasks. The small screen too, while facilitating handheld operations, can be a disadvantage in that only a small segment of a map or data form can be displayed at one time.

Several organisations have attempted to increase the ruggedness of this type of unit. An example of this are the Trimble units which can be dropped on hard surfaces, exposed to harsh environmental conditions and can even be submerged in water without damage (Trimble, nd). Of course, these units are more expensive than the less rugged versions.

Tablet PC Tablet PCs (Figure 6) are laptops with a twist. They can operate as a normal laptop but can also convert to tablet mode allowing the user to utilise pentop functionality. These PCs, unlike Pocket

PCs, operate in the standard Windows environment (Compaq Computers Australia, nd). The advantages here are significant offering normal computer functionality and the ability to operate ArcPad in the same way as a Pocket PC, but without the size limitations. Like Pocket PCs, Tablet PCs can also connect to a variety of add-on hardware components. Their processing power, disk capacity and battery life are also superior.

This additional functionality comes at a greater cost (around four times that of the Pocket PC option) but have the potential to represent some significant savings. There is potential for field staff to use this PC as their main computer, allowing them to carry all of their data with them both in the office (or to multiple offices) and into the field. If built with DPIs SOE, field officers would not need a desktop pc and a mobile pc, simply using the Tablet PC for both.

Add-on hardware

Mobile PCs, as mentioned above, can come with a variety of add-on hardware accessories. These include:

- **Compact Flash GPS** A low grade GPS that connects to the PC via a compact flash slot. This type of GPS produces and accuracy on average of 5–20 m depending on the various factors impacting on signal quality.
- **Correctable GPS** By attaching a higher quality GPS receiver and applying correction processes, you can improve the accuracy of GPS coordinates down to about 1 m (Trimble, nd). This level of accuracy is really only required in a small number of situations and for the most part, the less accurate receiver would suffice.
- **Portable printer** Portable printers can be attached to both Pocket PCs and Tablet PCs for instant hardcopy documents anywhere. This technology is currently being utilised by Melbourne City parking officers who electronically record parking infringements using an iPAQ and then print an instant ticket (personal observation)!
- **Digital camera** Digital photographs can be taken for instant evidence and stored on the mobile device using a compact flash digital camera. These photos can also be automatically linked to IPMS data.
- **Rangefinder** Rangefinders (Figure 7) can be used to accurately measure distances when measurement with GPS in not possible. The data from rangefinders can be utilised by GIS applications including ArcPad to record features in the landscape (Johnny Appleseed GPS, nd).

Applications supporting Field Based Information

The important thing to remember when attempting to address field-based data capture issues is that it is not just the field component of the system that should be considered. Issues such as those outlined above have come about as a result of whole of system shortcomings, rather than the failing of just one component of the process. In addition to this, no component of any system operates in isolation of the other system components – they all impact upon and are impacted upon by each other. In addressing field data capture issues we need to also consider the central database, access to spatial information and a means to effectively and seamlessly connect all these components (Figure 8). We must review current data models to ensure they are robust enough to support field data capture, workflow process and address data quality issues.

Benefits of field-based information systems

There are many advantages to the Landscape Protection program in adopting this technology. Some of these include:

- **Improved IPMS data quality** This system would address many of the data quality issues currently facing IPMS including accuracy and completeness, timeliness and accessibility issues. The system would enforce the capture of mandatory fields at their physical source, apply formatting and textual controls to improve the uniformity of data while automated upload processes significantly reduces the time delay between data collection and entry into IPMS.
- **Increase in spatial data quality** By providing field staff with the appropriate tools to capture spatial data we can eliminate a great majority of our spatial data issues. This would improve significantly our currently highly limited ability to apply spatial analysis techniques to our data, providing us with the ability to glean a greater understanding of the issues, our impact on the pest problem and inform future program decisions.
- **Provides field staff with information where they do their work** This system would increase the amount of information used to support decision making processes our field staff can take with them in the field.
- **Reduced administration time** Less time in the office entering data into a means more time for core high value field work.
- **Reduce the reliance on data entry officers** There are a number of savings to be gained by reducing reliance on data entry officers including more efficient processes and reduced interpretation error, salary costs and triple handling of data.
- **Eliminate double handling of data** By collecting data electronically in the field, staff do not then need to rehandle the data to enter it into the system.

Figure 7. Leica Rangefinder

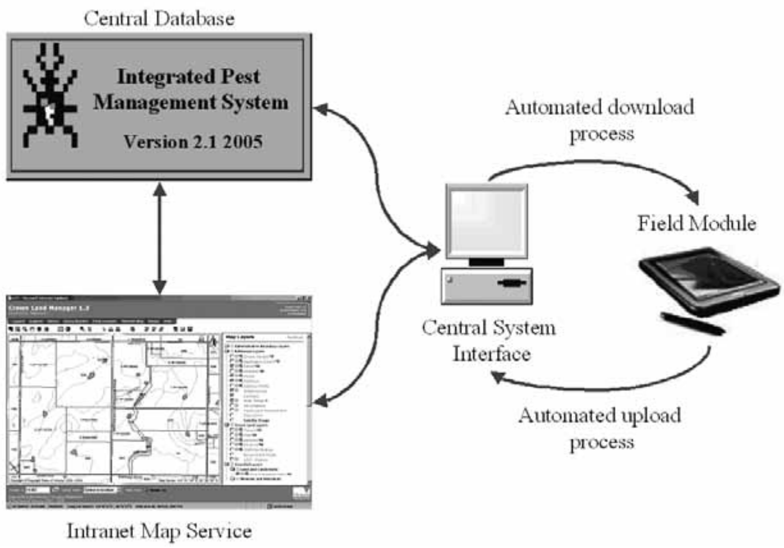


Figure 8. Pest plant management system incorporating a central database connected to an intranet map service and field data capture module

- **Electronic WPAs** Generating these electronically from data already captured in the process reduces data handling and also provides a mechanism to electronically store agreements entered into with land holders.

Where to form here – implementation considerations

Human

Perhaps the primary considerations in the implementation of a system such as this are the ones relating to the people who will operate the system. Even the 'best' system is only as effective as the people that use it and this includes their propensity to adopt the system. We may put massive effort into design a leading field information tool, only to find our adoption rate is so low that the system fails. In furthering the development of field information tools we must:

- **Effectively engage operational staff throughout ALL stages of development** Without an effective engagement process, any system that is developed is almost guaranteed not to effectively meet the needs of its users. Our field team are not a homogeneous group – they have differing needs, abilities and thought processes. The consultative process needs to take this into account engaging staff across the entire spectrum.
- **Understand the work processes currently employed** Ensure that the processes this system follow best represent the processes as they are actually applied in practice.
- **Maximise the impact of early adopters** Initial adoption of this system will be amongst a keen few. These early adaptors are generally those who can see the value in the system and therefore tolerate the initial difficulties of development. Broader adoption of this technology will spread outwards from this group. As fellow team members begin to see and understand the benefits gained from the system, they too will take on the technology. However, if we do not target purely early adopters and instead insist that less interested parties take part, we are increasing the chance that the system will not succeed.
- **Apply a staged process** Adoption of technology is not an over night process. Use of technology within an organisation is an evolutionary, or maturing process, taking small steps.
- **Maintain a balanced focus on operational staff information needs** By meeting these needs we have a better chance of meeting broader program management needs. We cannot make effective program decisions if the information tools used to capture base program data are not designed to meet the needs of those using them.

Technical

As discussed earlier, the adoption of this kind of technology requires changes throughout the entire process. In order for the adoption of this kind of technology to be successful, we must consider the entire system including:

- A comprehensive assessment of IPMS and Landscape Protection data models;
- Development of an effective and robust data transfer module;
- Development of data management processes;
- Linking of IPMS to a MapShare engine to improve spatial data ;
- Mobile PCs as standard SOE hardware by ITS;
- ITS support for development of field based tools.

With careful planning, we can significantly improve weed management in Victoria.

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Robotic weeding in grain crops

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Many old hands will tell you there is nothing new in agriculture. I hope to persuade you otherwise in this paper, despite many elements of 're-discovery' that will unfold.

Sowing of crops in rows was adopted some 300 years ago when Jethro Tull invented his horse drawn seed drill and hoe to enable inter-row tillage. For the next 250 years, weed management in grain crops relied in the main upon cleanly tilled seedbeds and manual guidance of hand pushed or horse pulled inter-row cultivators. Today, the vast majority of Australian winter grain crops are grown in rows, yet inter-row tillage is conspicuously absent. In the relentless quest for economies of scale, equipment and crop size became too large to permit tillage using manual guidance; especially at the high levels of precision required for crop rows spaced less than 50 cm apart.

Prior to the advent of selective herbicides, crop losses due to weed competition were often substantial. Grain growers regularly resorted to strategies to deplete weed seedbanks, including long fallowing, haycutting and delayed seeding which often entailed negative impacts upon soil structure, fertility and crop yield.

During the 40 years after World War 2, remarkable innovations in organic chemistry produced a proliferation of new herbicides with differing modes of action and crop selectivity. Herbicide development has, by and large stalled however, with no new herbicide groups presented to Australian grain farmers in the past twenty years. Research endeavours with herbicides are declining as a result of fewer prospects, patent maturation leading to intense generic competition and widespread company mergers. Consequences in the marketplace are the triumph of image over substance, as advertising agencies attempt to become the drivers of change, rather than the technical attributes of the products. This is often achieved by re-badging of the same active ingredients to create an illusion of innovation.

Pre-sowing tillage for seedbed preparation has been progressively discarded over the past 30 years in southern cropping systems of Australia by the substitution of herbicides for cultivation.

No-tillage agriculture has benefited from major and patient investments by the agricultural chemical industry and machinery manufacturers during this period. Strong financial incentives to advocates (i.e. herbicide and machinery sales) and regular use of 'product champions' to spread the word been a consistent feature of no-tillage agriculture. Growers have also identified many agronomic, biological, logistical and economic benefits with no-till systems and their adoption has been exponential across southern cropping systems. Some critical problems are now emerging however that threaten the practical and financial continuation of no-till systems.

Herbicide resistance is common in a number of crop weeds to almost all chemical groups suited to their management and threatens their viability as on-going tools of crop agronomy. Resistance is evolving in most intense cropping systems with many attempts at prevention or delay failing. In Australia, regular use of herbicides alone for annual ryegrass (*Lolium rigidum*) control has led to thousands of hectares infested with this weed, for which no selective herbicide remains effective.

Glyphosate resistance is expected to increase exponentially in no-till systems. Adoption of disc seeding equipment is likely to exacerbate glyphosate resistance as the opportunity to kill weeds surviving pre-sowing glyphosate is lost when no-till discs are substituted for the full seedbed disturbance offered by tyned implements.

Internationally, glyphosate resistance has been reported in seven species to date; particularly in the USA with fields growing glyphosate-tolerant crops such as cotton and soybean.

A common factor in the development of herbicide resistance is a lack of tillage after application of the herbicide. Tillage enables any surviving (resistant) individuals to be killed prior to them setting seed, preventing the irreversible drift towards dominance of the weed population by herbicide resistant biotypes.

Tillage kills by physically breaking roots and enabling subsequent desiccation and/or burial of the weed. For tillage to be effective in preventing herbicide resistance, it must be timed to act against the same cohort of weeds as were affected by the herbicide. For example, if glyphosate is applied prior to seeding a crop, tillage must occur after the glyphosate is applied or, if a selective in-crop herbicide is applied, tillage must occur in-crop after the herbicide.

Inter-row cultivation relies upon disturbance very close to each side of a drill row. A high proportion of the field ought to be disturbed during the operation, as weeds surviving in the crop row (intra-row) can compete with the crop and set seed. Manual systems tend to be slow and tiring, although skilled operators can commonly till to within 3 cm of a crop row.

Attempts to use GPS navigation for inter-row cultivation in Australia have been disappointing due to a lack of reliability and accuracy. Whilst finding utility in wide-spaced crops (85–100 cm) where high precision is not essential, autosteer options for tractors currently on offer in Australia appear unlikely to meet expectations for inter-row cultivation of narrowly-spaced (<50 cm) winter crops.

Given that GPS technology is unable to recognise any crop, one is left to ask; why communicate with six satellites orbiting the globe when you can obtain a visual fix on your crop immediately in front of the implement ?

Computerised vision guidance for inter-row tillage has been in development for at least 17 years. These devices use video cameras and image analysis software to guide toolbars mounted behind linkage tractors. Commercial systems first appeared in Europe in 2001; with initial adoption in the sugar beet and vegetable industries. Adoption to date by cereal growers has been limited to organic producers.

Silsoe Research Institute and Garford Farm Machinery in Britain have developed the ROBOCROP vision guidance system. To date over 60 units have been sold and successfully used in cereals, canola, sugar beet, cotton, soybeans, field peas, carrots, parsnips, leeks, brassicas, field beans and pumpkins. This device won a silver medal at the Royal Agricultural Society of England Show in 2003.

Robocrop uses a colour video camera to scan ahead of the tillage bar. Images are analysed twenty times per second to determine a fix on the crop rows. Signals are relayed back to electro-hydraulic valves that control a sideshift used to position the tillage bar in relation to the crop rows. No satellite signals are used, just a real-time video image of the crop ahead. Multiple rows and discontinuity of the row are not a problem. Robocrop will follow curves, thus it will correct for GPS errors incurred during sowing or follow contours (in dryland crops). Cultivators up to 12 m wide for any crop row configuration are available.

Parallelograms are fitted across the bar to enable accurate depth control, thus preventing root damage or excessive moisture loss from cultivating too deeply. Even soil flow also occurs when knives are suspended off parallelograms, so clearances can be minimised and intra-row weeds can often be buried. Burial of weeds within the row can occur at an earlier stage with a higher probability of suppression or kill. This is assisted by the high speed of operation, enabling more acres to be covered when the crop, the weeds and the weather demand it.

Robocrop cultivators are designed for very shallow tillage, thus draft requirements are low, tractor horsepower needs are minimised and fuel conserved. Row clearances can be diminished, leading to a higher percentage of the field subjected to a terminal dose of 'cold steel'.

Testing of Robocrop at Silsoe Research Institute in Britain has documented the increased accuracy of vision guidance over manual tractor operators, as demonstrated in Table 1.

Skilled operators manually guiding hoes cannot maintain peak performance consistently as the operation involves intense concentration. By contrast Robocrop guidance will operate day and night with the same consistency. With lower deviation from the crop rows, hoe blade clearances can be reduced.

Table 1

Guidance method	Speed	Standard deviation
Manual guidance	6.5 km h^{-1}	14 mm
Robocrop guidance	6.5 km h^{-1}	9 mm
Robocrop guidance	11 km h^{-1}	10 mm

Source: An experimental study of lateral positional accuracy achieved during inter-row cultivation, Home *et al*. 2002 Proc. 5th EWRC Workshop on Physical Weed Control, Pisa, Italy.

Australian testing

A commercial scale evaluation of a ROBOCROP precision guided hoe was undertaken in south eastern Australia in the 2004 winter cropping season. Collaborators included the inventors (Silsoe Research Institute) the manufacturers (Garford Farm Machinery), an Australian contract R&D company (Agropraisals) and several grower groups with funding support generously provided by the Grains Research and Development Corporation and in-kind support from Case IH.

Potential advantages of the system to Australian grain growers were perceived to include: low capital cost, low input costs (on-going herbicide inputs reduced or eliminated) and alternative 'mode or action' for weed control in a manner complementary to current strategies for managing herbicide resistance.

After airfreighting, assembly and commissioning, the Robocrop precision guided hoe was demonstrated at seven sites; across southern New South Wales and northern Victoria in winter cereals, lupins, faba beans and canola at row spacings of 225–670 mm.

The Robocrop precision tillage hoe proved to be a robust and functional device capable of accurately tilling in level cultivated seedbeds. Tracking of the Robocrop guidance system worked effectively in all circumstances (including under tractor lights at night). All crop stages, spacings and weed densities were tracked without any apparent difficulty.

Tillage accuracy depends upon tractor linkage stability, the skill of the operator in keeping the tractor near the tramlines, matching of the Robocrop tynes to those of the drill and following the same direction of travel as the seed drill (unless the drill is fully symmetrical).

Crop growth stage influenced tillage speed and vigour, as young crops are susceptible to burial.

Narrow row spacings (e.g. <250 mm) substantially reduced the proportion of tilled to untilled ground and limited forward speeds to below 8 km h^{-1} in order to prevent crop burial. Optimum row spacings to facilitate inter-row tillage of winter cereals crop appeared to be in the range of 300–350 mm.

Inter-row tillage is a slow operation compared to contemporary work rates for crop spraying. Forward speeds are likely to be 8–12 km h^{-1} and swath width must match that of the seed drill (i.e. typically 6–18 m wide), thus giving spot work rates of approximately 7–22 ha h^{-1}. Fertilisation and inter-row tillage operations could be combined to assist in justifying the costs of operation.

Guidance of hooded sprayers in wide-spaced crops using the Robocrop guidance system would be feasible, although unlikely to present some of the advantages on offer by introducing precision guided inter-row tillage into winter-cropping systems.

Adaptation of Robocrop technology to suit some major Australian imperatives of low till seedbeds and stubble retention are the current goals in on-going endeavours to capture the value of robotic weeding for local grain producers. The Grains Research and Development Corporation is currently investing in a program to develop tillage bars capable of seeding crops into undisturbed seedbeds with retained stubbles, then subsequently tilling the crop inter-rows with high speed and accuracy. This 'Seed'nWeed' equipment will present opportunities to defer tillage until a crop is established to protect soil from erosion, to restrict traffic across the field to prevent compaction, to place fertilisers more accurately and efficiently than can be currently achieved and to restrict placement of selective herbicides to the crop row only; resulting in major savings in herbicide inputs. Now that the technology has arrived, our challenge is to integrate precision guided tillage and herbicides for a more durable outcome than current weed management practices offer.

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Weed spread prevention wash down trial

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Summary Weed prevention measures are the most effective way of protecting assets from weed invasion. Educating the community and industry on issues associated with high-risk activities such as movement of machinery will save time and money in the long term. The precautionary approach is a concept being widely employed to guide future environmental planning processes and funding decisions.

The Weed Spread Prevention Wash Down Trial aims to raise awareness and increase the capacity of Local Government in improved machinery hygiene to prevent the spread of weeds. The trial was conducted over a period of twelve months and involved three municipalities. The equipment selected for the trial consisted of a portable wash down unit and a containment mat, designed to wash tractor slashers used to cut roadside vegetation while also recycling the water used back into the unit.

In each of the three municipalities, five trial sites were selected and surveyed for weed species. The sites were slashed and vegetative samples taken to determine the viability and amount of weed seeds from each of the fifteen trial sites.

The preliminary findings from both weed seed counts and viability study found large amounts of viable weed seeds are collected by the process of slashing. Surveys of the municipalities involved showed an increase in understanding of both the responsibilities concerning weed hygiene principals as well as the rate of use of machinery hygiene principles and practices.

Introduction

Many of the alien plant species introduced into Australia have become weeds and have invaded a wide range of environments. These invasive plants are reducing yields in crops and pastures and changing the natural environment (Castles 1992). In the recent past, the rate and risk associated with alien species introductions have increased enormously because human population growth and human activities altering the environment have escalated rapidly (Pimental *et al*. 2000).

Prevention of weed spread is a key consideration for cost effective control in resource management. The Federal and Victorian Governments have identified in their policies the protection of our landscapes as one of their most important duties. The Weed Spread Prevention Wash Down Trial is a part of the Victorian Governments' 'Tackling Weeds on Private Land Initiative'. The aim of the initiative is to have key stakeholders accepting and acting on their weed management responsibilities in a collaborative manner in new and innovative ways to reflect the goals of the Victorian Pest Management Framework (VPMF). The Trial involved three major stakeholders the Department of Sustainability and Environment, Department of Primary Industries and the municipalities of Surf Coast, Golden Plains and Moorabool.

Why conduct a wash down Trial? Seeds and other viable plant parts can hitch a ride on machinery and contaminate previously 'weed-free' areas. The trial concentrated on tractor slashers, typical local government equipment. Slashing is done for many reasons; it aims to reduce biomass and fire risk, improves driver safety by improving roadside visibility, and it reduces or prevents the flowering of weed species thus reducing their spread into neighbouring properties. However, a previous study has also shown slashing actively disperses weed seeds scattering them around the slasher deck during the performance of the slashing process and carrying them further afield if the machinery is not kept clean (Erakovic *et al*. 2003). It is therefore essential that machinery operators inspect and thoroughly wash down machinery before it enters a clean area.

This funding opportunity has allowed Local Government to build internal capacity by improving hygiene controls on equipment, which have the potential to spread weeds through their daily activities.

The final aim of the project is to investigate the amount and type of weed seed taken from the slashers at the trial sites. Once this has been achieved the viability of the weed seeds found will be tested to determine the value of the wash down process and the threat that slashing proposes in the spread of weeds.

Materials and methods

Wash down equipment

The selected equipment for the trial is portable, has the ability to contain the water and vegetable matter washed from the tractor and slasher and recycle the water back into the holding tank to be reused. The tray or trailer mounted polyurethane tank has a capacity of 300 L and is driven by a top mounted five horsepower petrol pump. The water pressure rate was lowered to conserve water and enable the operator more time to clean down machinery. The containment matt is constructed from an industrial strength vinyl with bunted walls containing memory foam. The memory foam allows a vehicle to move over the bunted wall and then immediately assume its shape. To recycle the water a twelve-volt marine pump, which has 100 litres per minute flow rate, removed water from the mat back to the unit through a vortex filter. The vortex filter is designed to capture vegetable matter and large suspended solids.

Trial sites

Five sites were selected for their infestations of Chilean needle grass and serrated tussock in each of the participating Local Government municipalities. The sites occurred on roadside verge and were four metres in width and fifty metres long. A Global Positioning System marked the corners of each site and a star picket was placed as a visual marker. To measure the weed density at each of the fifteen locations a flora survey was undertaken using a metre square quadrant.

Logbooks

Machinery wash down logbooks were developed by the Department of Primary Industries and then provided to each of the participating municipalities. The machinery checklist in the log book leads the machinery operator through a systematic search for contamination points on the tractor slasher. The logbook also captures information on the use of the equipment, how the inspection and clean process was undertaken and other factors such as weather.

Field samples

Samples were taken between October and December 2004, during the municipalities' roadside slashing program. Two types of samples were taken – dry and wet. The dry sample was collected prior to the wash down process and sourced from the chaff on top of the slasher. The wet sample came from the contents of the mat after the cleaning process had been undertaken. Each sample was labelled with site information then packed and couriered to the LaTrobe University Department of Botany.

Weed seed counts and chemical testing

To perform the seed counts and identify the weed seeds contained within the sample all other matter was removed including mud and chaff. Due to Chilean needle grass' larger seed size this weed species was used as a representative species to determine the amount of weed seed. A grab sample of Chilean needle grass seed was then taken and treated with tetrazolium chloride to determine seed viability.

Evaluation
The project evaluation consisted of semi-structured interviews and questionnaires. The semi-structured interviews were conducted with Environmental Officers and the questionnaires were targeted at the Field Operators from each of the three municipalities.

Discussion

Although each of the Local Government Municipalities had unlimited use of the equipment for a twelve-month period the use of the equipment outside the trial sites was minimal. The weight of the equipment provided a barrier to its use as the machinery operator predominantly works alone. This presented issues with Occupational Health and Safety policies. The Environmental Officers were targeted to be advocates of the project. All were supportive and cooperative throughout the life of the project. However, as the field staff were part of a different business within local government the amount of influence the Environmental Officers had was limited. A training program was to be implemented for the field staff involved with the project, however, it was discovered that the municipalities had already organised their own weed spread prevention training. Consequently the Weed Spread Prevention wash down trial dovetailed into this process by providing training in the use of the equipment. All participants in the trial commented on the amount of plant material obtained at the trial sites due to the cleaning process. It was a clear example of how effective machinery hygiene procedures can be.

Through the implementation of the VPMF the move toward preventative weed management is being recognised as a sound investment by Government. Consequently the DPI compliance program has purchased two units to enable adequate clean down of equipment used to perform compliance entry in the administration of the Catchment and Land Protection Act 1994.

The benefits of the equipment for managing *Phytophthora* dieback were recognised by Parks Victoria who also purchased a unit. Comments from local government staff regarding improvements to the design of the pump were incorporated by Parks Victoria making the unit effective in the removal of water from the mat. Some of the benefits of using this equipment in the management of *Phytophthora* dieback included low water pressure, ability to recycle chemical and the use of recycled water in remote locations.

Conclusion

Preliminary results of the weed seed counts and chemical testing study showed that the process of slashing roadside vegetation has the potential to spread viable weed seed to other locations.

For clean down equipment to be adopted by Local Government field operators of tractor slashers, it needs to be able to be operated by a single person and the process of cleaning performed quickly. The understanding by the participants of the principles and practices concerning machinery hygiene increased over the course of the Trial.

It is apparent that the provision of appropriate training is a corner stone to increase the capacity of field staff in the practice of effective clean down. Also, the prudent purchasing of the equipment used in the Trial (clean down unit and mat) will benefit other departments with its continued use.

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Himalayan honeysuckle control at Mt Buffalo

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Himalayan honeysuckle (*Leycesteria formosa*) is a native of western China, India, Nepal and Burma, and was imported to Australia as a garden species. It is a deciduous multi-stemmed shrub to 3 (rarely to 4) m high, with erect hollow stems and ovate leaves. Fruit are ovoid and fleshy (Australian Weeds Committee 2005). A fact that makes them highly attractive to parrots and smaller forest birds, foxes and browsing animals such as wallaby and deer, all are believed to be vectors of spread.

It is a highly invasive weed capable of out-competing Australian natives to the point of completely altering the floristics of a forest understorey if left uncontrolled. Established infestations are known in a considerable area of the foothill forest of Mount Buffalo National Park on sections of the eastern boundary. Efforts to control the species have been carried out for many years to varying degrees of effect.

Observations of Rangers stationed at Mt Buffalo in the 1970s were that the plant was seen at certain sites on roadsides on the lower section of the mountain. These plants were hand pulled and not considered a major threat at the time. Its occurrence on roadsides suggests it was transported in the gravel used to surface the roads of the area. Once established on the roadsides however, it is now presumed that infestations rapidly spread deeper into the surrounding forest.

During the mid-1980s concern began to increase regarding the extent and impact Himalayan honeysuckle was having on the foot hills of the Park. As a result an extensive survey was undertaken by Steve Millington (Ranger) in 1988. He walked much of the eastern side of Mt Buffalo to determine the extent and concentration of infestations. Maps were made of these infestations and identified three catchments in which Himalayan honeysuckle was present: the Eurobin, Kangaroo and Buffalo Creeks. These catchments are concentrated in an area to the north and north-west of Eurobin Falls covering approximately 700 hectares. At that stage the extremity of the infestation appeared to be no higher than 900 m in elevation, with infestations being thickest in the base of drainage lines, becoming scattered on gully flanks.

Control programs gained momentum using park and forestry staff, with hand pulling, and high volume spraying being undertaken off roadsides. These efforts although considerable, were unfortunately not tackling the root of the problem.

By the 1990s it was apparent that the plant had established itself in significant infestations that would require a more concentrated effort. A formal control strategy was developed that formed the basis for planning and consolidated a more strategic approach, from this control lines and priority areas for works were identified.

In the mid-nineties the park purchased a 4WD mounted self retracting dual-reel spray unit, which together with a more conventional trailer type unit combined to enable staff to tackle infestations deeper in the bush. Remote work was undertaken using hand-pulling and gas gun chemical applicators. Metsulfuron-methyl and glyphosate achieving excellent results.

Significant funding compared to previous years allowed a targeted annual control program. By 2002 an annual budget of $20 000 was standard. Rather than using internal staff, the program now used the services of short-term casual employees chosen for their fitness and weed control experience. The 4–5 person team were dedicated to the program, having no involvement in any other park maintenance duties.

Control works focused on the Eurobin, Kangaroo and Buffalo creek catchments, especially the Eurobin which remains today as the most heavily infested. There are a number of reasons for this. The first being the favourable habitat provided by the forest type and moist gullies, the second being the very steep and rough terrain which makes going extremely difficult and slow, and has hindered control efforts. Hence the requirement for the spray team to possess a high fitness level. And the third which is perhaps the least supported by substantial evidence is that the area harbours a significant Sambar deer population. It is proven that Sambar eat the fruit of Himalayan honeysuckle and spread seed in their faeces (Eyles 2003), but the degree to which infestation spread can be attributed to them is unknown.

High volume spraying with metsulfuron-methyl from the vehicle mounted unit off the tourist road at the top of the catchments, and from the bottom on the park boundary was successful in pushing the extremities of the infestations inwards. By joining hoses spraying could be achieved up to 400 m from the vehicle. At this length, combined with the steep and rough terrain, all team members would be involved as integral participants in the operation. One person would remain at the vehicle to monitor chemical and fuel levels and the hose that would regularly become tangled if left alone. Two would be spaced at intervals along the hose to assist with pulling it through the vegetation, and the fourth person would operate the spray gun. Communication between team members was via departmental radios.

The safety of staff in these situations was a constant consideration. There was a high potential for slipping and tripping, snake and insect bite, and with protective overalls on, heat exhaustion could occur quickly.

Despite being able to spray plants up to 400 m into the bush, there remained significant infestations just out of reach, some of these being very dense. This meant that there was a source from which seed could be spread each year. These areas were treated to some degree by using 7 litre pump-up spray bottles that could be carried deep into the bush, the basal bark method being applied (glyphosate mix) to each plant. The sheer number of plants, small chemical carrying capacity and inherently slow control technique meant that the infestations out of reach of the high volume spray were never effectively treated.

In early January 2003, what started as two small fires ignited from lightning strikes combined to change the approach to Himalayan honeysuckle control at Mt Buffalo. The Alpine Fires that burnt an estimated 1.19 million hectares of public land in North East Victoria and Gippsland had at their conclusion burnt approximately 90% of Mt Buffalo National Park.

All but a very small percentage of mature infestations were consumed in the fire. And inspections post-fire showed that all plants that were burnt showed no signs of recovery. This was an exciting time. Sites that were heavily infested and had proven difficult to access and treat were now devoid of honeysuckle. In one fowl swoop, for a brief period, the whole of Mt Buffalo excepting a few small pockets were free of Himalayan honeysuckle.

As months after the fire passed, further inspection revealed germination from seed bank. In drainage lines germination was crop-like. Heavy rain following the fires had washed large quantities of soil into creeks and the middle of gullies, carrying with it the seed that had accumulated over many years. Seedlings could be found on the flanks of gullies and on ridges, but too much less extent.

With these findings the opportunity was seized to embark on a large scale control program in the summer of 2003/2004. The Victorian Government – Bushfire Recovery Program that provided for the repair and replacement of assets, research and protection of natural and cultural values, and support of neighbouring communities ensured that the program was well funded. $75 000 was committed to the project in its first year.

The fire had provided a window of opportunity. Areas that were once almost impossible to walk through due to fallen timber and a thick shrub layer were now accessed with far less effort. As well, the juvenile state of the infestations meant that plants were easier to treat with less volume of herbicide. Those infestations that had been out of reach to high volume spraying, yet were too large to treat properly with small volume pump-up spray bottles could now be targeted. There would also be a timeframe of two growing seasons where these plants would not produce viable seed.

Rather than using casual staff, the project went to tender and was implemented using a pest plant management contractor. Gullies with semi-permanent and permanent water were targeted as a priority due to the high density of plants, and the fact that if not treated at the seedling stage and left to grow there would have been a requirement to use greater quantities of chemical. Highly undesirable in an aquatic environment with sensitive riparian native vegetation. By focusing on these areas at this stage of the plants growth, many infestations were removed by hand-pulling and through cautious use of the 'water friendly' form of glyphosate at a 2% rate.

Chemical was applied to foliage using 7 litre pump-up spray bottles, with a team of 4–5 people moving down gullies from their origin. The team would be spaced at a distance to ensure as best as possible that all plants were treated. In areas where infestations were well away from vehicle access and relatively high quantities of chemical was necessary, a hose with a tap at the end would be dragged in to a centralised point. At the nearest point on a road, the hose at the other end was connected to a vehicle mounted tank containing the chemical mix. This meant that crew members would not have to walk out to the vehicle each time they needed to re-fill. High volume spraying methods were not used.

In general, areas away from gullies on the flanks and ridges were left untreated. In many locations regrowth by primary colonisers was phenomenal, with bracken in particular rapidly forming a dense blanket obscuring the smaller honeysuckle seedlings. This meant that control efforts were unfeasible with search efforts to locate each plant too difficult and time consuming. Nevertheless it was recognised that these sites would require attention. And it was decided that they be left until the following season when the honeysuckle had grown and was easier to find.

Instead efforts were concentrated on gaining a better picture of the overall infestation. Surveying and mapping was completed for all previously known sites and also far wider into areas that had not previously been specifically searched to identify honeysuckle, but possessed favourable habitat. Where feasible control works were also undertaken. The results revealed the presence of the plant over a wider area than was recorded. This information was invaluable for the planning of the following year's program, and will continue to be vital for managers into the future.

The second year of the Bushfire Recovery Program saw a similar amount of money dedicated to the project, and in the 2004/2005 summer control works were again let to contract.

Areas that had seen control works the previous year were revisited, especially wet gullies that were targeted again as a priority. Works were undertaken in areas that had been left the previous year to due to native vegetation regrowth, however in most circumstances searching for and identifying honeysuckle was still very tedious. These areas will continue to pose a problem until such time that the honeysuckle has grown to a point where it is easily found. Control methods used were the same as those in 2003/2004.

Surveying and mapping continued, with results showing that in the majority of cases the severity of infestations had been significantly reduced by the previous year's efforts. In one of only a few sites remaining with a mature infestation, the Gorge area was visited. This area of the park is famous for its series of magnificent cliff faces, the longest of which is a 300 m vertical drop. An abseiling guide was engaged to enable park staff to gain access to the plants that hung precariously from the cliff walls.

By the conclusion of the two year post-fire program a great deal was learnt about Himalayan honeysuckle at Mt Buffalo. Much more is known about the spread and severity of the infestation across the park, and results of control works were very promising. However it is true that if the importance of managing this pest plant is not seen as an ongoing priority the infestation may return to its former severity. The next few years will ultimately tell whether the widespread fire of 2003 has been of benefit or hindrance to the control of this species at Mt Buffalo.

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POSTER SUMMARIES

An insecticidal exclusion method for studying biological control impacts on ragwort (*Senecio jacobaea* L.) and Paterson's curse (*Echium plantagineum* L.)

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The impact of biological control on weed populations can be evaluated in a variety of ways. These include:

- comparing weed infestations before and after biological control,
- contemporaneous comparisons of weed infestations at sites with and sites without biological control agents,
- assessments of correlations between agent numbers and parameters indicative of weed population dynamics (e.g. Swirepik and Smyth 2003), and
- experiments to manipulate biological control agent attack levels by physical exclusion or containment or pesticidal exclusion methods (e.g. Adair and Holtkamp 1999), or combinations of these (e.g. Smyth and Sheppard 2002).

This poster briefly outlines the insecticidal exclusion method we use for evaluating the effect of biological control on *Senecio jacobaea* L. (ragwort) *Echium plantagineum* L. (Paterson's curse) in Victoria and presents some information considered for insecticide selection.

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This summary is of a poster that was originally presented at 14th Australian Weeds Conference as:

Morley, T.B. and Bonilla J.C. (2004). An insecticidal exclusion method for studying biological control impacts on ragwort (*Senecio jacobaea* L.) and Paterson's curse (*Echium plantagineum* L.). Proceedings of the 14th Australian Weeds Conference, eds B.M. Sindel and S.B. Johnson, p. 380. (Weed Society of New South Wales, Sydney).

Establishment and dispersal of dock moth *Pyropteron doryliformis* (Ochsenheimer) (Lepidoptera: Sesiidae) in Victoria

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A biological control agent for docks (*Rumex* species) has been found in large populations in parts of northern Victoria, where it is dispersing widely and probably having a substantial impact. The Moroccan clearwing moth or dock moth (*Pyropteron doryliformis* (Ochsenheimer) was released in Victoria from 1991 to 1999. Most of these releases were undertaken by inserting 'egg sticks' (toothpicks with moth eggs glued onto them) into the cut stalks of dock plants. The most successful dock moth populations in Victoria occur on *Rumex crispus* in northern regions of the state.

This is a summary of research that was originally presented as a poster at and article in the proceedings of the 14th Australian Weeds Conference as:

Morley, T.B., Faulkner, S. and Faithfull I.G. (2004). Establishment and dispersal of dock moth *Pyropteron doryliformis* (Ochsenheimer) (Lepidoptera: Sesiidae) in Victoria. Proceedings of the 14th Australian Weeds Conference, eds B.M. Sindel and S.B. Johnson, pp. 381-4. (Weed Society of New South Wales, Sydney).

Gallery 750DF Herbicide tankmixes are safe to trees and vines with effective residual weed control

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Summary Wells (2004) reported that Dow AgroSciences had conducted 15 trials between 1990 and 2004 to determine the efficacy of tankmixes of isoxaben at 281.25–562.5 g ai ha^{-1} with either pendimethalin or oryzalin at their label rates. Seven trials showed tankmixes of isoxaben provided better control of broadleaf weeds than either of the commercial standards, pendimethalin at 2970–3960 g ai ha^{-1} or oryzalin at 2250–3400 g ai ha^{-1}.

Dow AgroSciences completed commercial demonstrations of isoxaben in tree and vine crops prior to registration. Six of these trials are reported in this paper. (A total of 19 trials were conducted, but results are only available for six at the time of writing).

Two trials were conducted in apples and four in grapevines. They showed 562.5 g ai ha^{-1} isoxaben applied in tankmix was safe to apples or vines and gave extended residual broadleaf weed control.

Introduction

Isoxaben has been registered in the USA and Europe for control of broadleaf weeds in vines and tree crops for over 10 years. It is highly selective to crops, broad-spectrum on weeds with diverse mode-of-action sites (Group K), immobile in soil and moderately persistent and has a high safety margin for use by operators and applicators. These factors together make it a good candidate for safe, effective, residual weed control.

This paper refers to small plot trial work completed from 1990 to 2004, but also reports on unreplicated demonstration trials showing efficacy and crop safety of isoxaben tankmixes.

Materials and methods

Six large scale demonstration trials were conducted in the Yarra and Goulburn Valleys of Victoria in summer of 2004/5. Farmers applied treatments with either tractor or four wheel motorbike mounted boom sprayers fitted with flat fan nozzles designed to apply 225–500 L ha^{-1} total spray volume. Treatments were timed just prior to a major rainfall event, so that herbicides were incorporated by rainfall. In three trials, standard treatments were compared to Isoxaben tankmixes. In the other three, Isoxaben alone was compared to a standard. In all trials standard treatments were generally applied at label recommended rates. Treatments are shown in table 1. Treatments were applied in a band about 1 m wide either side of vine or tree rows.

Crop injury was monitored periodically after treatment and weed control was assessed as weeds germinated after rain. A percent scale was used for assessment, where 100 = complete weed control. Control was compared to the untreated inter-row as a reference.

Results

Table 1 shows the results of the demonstration trials conducted in Victoria over the summer of 2004/5.

These results are consistent with those seen in vine work previously reported (Wells, 2004). Use of isoxaben in tankmixture gave improved weed control and for longer than where either oryzalin or pendimethalin were used alone. Other demonstration trials (unreported) done by Dow AgroSciences show similar findings.

Discussion

Many growers use knockdown herbicides for treatment of weeds under vine or tree crops. However, this practice is time consuming, is often at a time when other operations in orchards may be more critical and may result in significant injury to crops due to the non-selective nature of some treatments.

Use of isoxaben alone for susceptible weeds, or in tankmixes with oryzalin or pendimethalin when significant grass weed pressure is expected, has the potential to avoid these issues.

This practice has been tested and demonstrated in replicated small plot trial work since 1990 and non-replicated demonstration trials across southern Australia in 2004/5. This use is pending registration (August, 2005).

Acknowledgements

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Table 1. Residual weed control with Isoxaben applied alone or tankmixed in apples and grapevines, Victoria 2004/5

Site	Harcourt, Vic	Seville, Vic	Dixon's Ck., Vic	Shepparton, Vic	Nagambie, Vic	Milawa, Vic
Crop	Apples	Apples	Vines	Vines	Vines	Vines
Weeds	1	2	3	4	5	6
Days post-treatment	120 DAA	231 DAA	92 DAA	257 DAA	321 DAA	287 DAA
Treatment and rate (g ai ha^{-1})						
Standard or comparison treatment	70	75	70	0	0	0
Isoxaben 562.5				100	100	100
Isoxaben 562.5 +Oryzalin 3400	90	98				
Isoxaben 562.5 + Simazine 2380			100			
Standard or comparison treatment	Oryzalin 3400	Oryzalin 3400	Isoxaben 562.5 + Paraquat/Diquat	Oryzalin 3400	Pendimethalin 3300	Simazine 1500

1 Amaranths, Plantain, Subclover, wild radish, dandelion and fat hen. 2 Capeweed, catsear, dandelion, fat hen, plantain and red flowered mallow. 3 Plantain, subclover, wild radish and wireweed. 4 Capeweed, fat hen, milk thistle, storksbill, wild radish and subclover. 5 Capeweed, wild radish, Indian hedge mustard, blackberry nightshade, milk thistle and fat hen. 6 Capeweed, fat hen and wild radish.

Spraytopping as a management tool to reduce seed production in Chilean needle grass infestations

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Summary Two field and one glasshouse trial were established at Inverleigh and DPI, Frankston, Victoria, respectively to evaluate the effect of sub-lethal rates of glyphosate and 2,2-DPA on panicle and cleistogene seeds production of Chilean needle grass. One field trial was conducted during each spring of 2003 and 2004 on established tussocks and the glasshouse trial was done in spring 2004 using young tussocks raised from seedlings. Results in the first field experiment indicated that application of glyphosate at 510 g ha^{-1} from 3 September to 13 October prevented panicle seed development and produced the minimum number of filled and germinable panicle seeds. 2,2-DPA proved to be ineffective. The second field experiment showed that application of glyphosate at ≥135 g ha^{-1} on 18 and 27 October prevented production of filled and germinable panicle seeds. However, this level of control could be achieved at 1 October only with glyphosate at ≥270 g ha^{-1}. The glasshouse trial showed that glyphosate at 216 and 270 g ha^{-1} applied in October prevented the production of filled and germinable panicle seeds. Increasing glyphosate rates decreased stem and panicle seed germination linearly but did not influence basal seed germination. Glyphosate at ≥270 g ha^{-1} during November proved to be most effective in controlling stem seeds.

Introduction

Chilean needle grass (*Nassella neesiana* (Trin. & Rupr.) Barkworth) is a perennial exogenous stipoid grass that produces both panicle and cleistogene seeds. *N. neesiana* is widespread in pastures and natural ecosystems on the Northern Tablelands of New South Wales and in southern Victoria. It grows through the winter but provides a lower feed value than *Dactylis glomerate* L., which is considered as a moderate pasture grass when compared for protein, energy and digestibility (C. Grech personal communication). Under heavy infestations, pasture productivity decreases as much as 60% and causes significant reduction in stock-carrying capacity during the summer season (Anon. 2001, Gardener *et al*. 2003).

Chilean needle grass has very versatile reproductive system. Beside aerial inflorescences, it also produces cleistogenes on the stem nodes (Connor *et al*. 1993). Panicle seeds mature and fall off in mid to late summer followed by stem seeds and these then form the bulk of the soil seedbank. The stem seeds are concealed under leaf sheaths and each stem node has the potential to produce a few seeds on and above the ground nodes. Basal cleistogenes come up in singles seeds at the very base of the stem on the first node beneath the soil surface. The newly formed basal seeds are light dull yellow colour and are still held under the leaf sheath. As they mature, they become brown and thin and are released in the soil as the leaf sheath ruptures.

Gardener *et al*. (2003) observed potential panicle seed production of 22 203 seed m^{-2} depending upon the number of flowering heads per unit area. This dual mode of seed production diminishes the prospect of quick success of control/eradication measures. Spraytopping (sub-lethal herbicide application) has been widely employed as a tool in different cropping systems to reduce infestations of grasses, for the prevention of diseases and to enhance feed quality (Leys *et al*. 1991, Hill *et al*. 1996, Gatford *et al*. 1999).

This study was undertaken to evaluate optimum time of application during spring season for different glyphosate and 2,2-DPA rates that may preclude panicle and cleistogene seed development.

Materials and methods

Three experiments were conducted, two in the field and one in a glasshouse. The field trial sites were in *Phalaris* based pasture that was heavily infested with Chilean needle grass. The glasshouse trial was done on tussocks raised from panicle seeds. The field soil was loamy, whereas, in the glasshouse steam-sterilised potting mix (1:1 sand:pine bark) in 15 cm pots was used. In field trials no fertiliser was added, however, in the glasshouse trial Nutricote Black (16N, 1.4P, 8.3K) was applied at 6 g pot^{-1} in the beginning of the spring season. Herbicides in field trials were applied to 6 × 3 m plots with a hand held Azo-Dutch sprayer with spray volume 176 L ha^{-1}. In the glasshouse trial, application was done using a track-spray-unit with a spray volume 100 L ha^{-1}. Germination tests for cleistogene and panicle seeds were done for 50 seeds from each plot per pot (or maximum available if less than 50 seeds) in a germination cabinet at 25/15°C (alternating 12 h light/dark). Panicle seeds germination was tested four months while cleistogene seed germination was tested five months after panicle seed harvest. A random 100 panicle seeds per plot or pot were examined for filled seeds (squeezing the seeds with tweezers) and expressed as filled seeds ha^{-1}. The germinable seeds ha^{-1} was computed by multiplying the percent seed germination and filled seeds ha^{-1} data for each plot.

Treatments in each experiment were set in a randomised block design with four replications except the first field experiment (three replications). Except the glasshouse trial (from mid December to end January) the panicles were harvested in mid December. Stem and basal cleistogenes for the pot trial were assessed in April.

First field experiment

A field trial was established in spring 2003 at the Hamilton Highway, Inverleigh, Victoria. The site was selected in July 2003 and grazing was excluded until the end of the trial. The treatments comprised a six herbicide (glyphosate at 0.1275, 0.255 and 0.510 kg ha^{-1}; 2,2-DPA at 2.22 and 3.7 kg ha^{-1}; no herbicide placebo) by five times of application (3 September, 22 September, 3 October, 13 October and 27 October) factorial. Chilean needle grass tussocks were vegetative at the first two dates (3 September and October) and reproductive on 13 October (flag-leaf swelling) and 27 October (panicle emergence).

In each plot panicles were harvested from a centrally placed quadrat (50 × 50 cm). The panicle seeds were cleaned, sorted and weighed. A sub-sample of one hundred panicle seeds was drawn from each plot, weighed and results scaled to total number of seeds ha^{-1}. Appropriately transformed data was analysed as a six herbicide by four times of application (excluding 22 September as rain fell just after application) factorial, but with a residual error constructed from a randomised block analysis with all 6 × 5 = 30 treatments.

Second field experiment

This experiment was designed as a five herbicide treatment (glyphosate at 0, 135, 270, 405, 540 g ha^{-1}) by three application time (1, 18, and 28 October 2004) factorial, at the Roxby Estate, Inverleigh, Victoria. The tussocks were vegetative at 1 October, spiky stems at 18 October and full panicle emergence at 28 October. The experimental site had old Chilean needle grass tussocks.

The mature plants had 25–40 cm high tussocks with dead centres and green leaves growing from the margin. To get uniform growth in early spring, the tussocks were slashed in the winter season. The slashing and prolonged dry weather promoted young tillers with thin stems.

One hundred panicles (or maximum available if less than 100 panicles) were harvested separately from the experimental area (excluding 50 and 100 cm width and length, respectively, on both sides of the plot). The panicle seeds were cleaned, and sorted for each plot to estimate the ancillary characters viz. filled seeds, germinable seeds, seed germinations etc.

Measurements were analysed using general linear model analysis with effects for blocks and five specific combinations of treatment (Table 3). There was no evidence of effects between individual treatment combinations within these groupings (P >0.1). Analyses were restricted to treatment combinations that had variable data (not all zeros), and the residual error was constructed from deviations from all treatments present in the analysis (GenStat Committee 2005).

Glasshouse experiment

This was a five-glyphosate rate (0, 135, 216, 270, and 405 g ha^{-1}) by five times of application (first week of July, August, September, October, and November 2004) factorial, within a glasshouse at Frankston, Victoria. Chilean needle grass seedlings were raised from previous season's panicle seeds. Four-week-old seedlings were placed in jiffy pots and transplanted into 15 cm pots in April 2004. The tussocks were vegetative till October but were producing full panicle seeds in November. The mature panicles were harvested regularly from mid December to end of January and the seeds were cleaned and sorted for assessment. Watering was withdrawn at the end of February to terminate the experiment.

All the mature stems in each treatment were chopped off 1–2 cm above the soil surface and dissected for stem cleistogenes. The total number of stem seeds was scaled to 100 stems per pot. The clumps were dug out from the pots and assessed for basal seeds. In each pot, 20 mature stems bases were searched for basal seeds and scaled to 100 stems per pot.

For each measurement, response curves to glyphosate application rate were constructed for different application dates using generalised linear models, and then back transforming to the original scale (GenStat Committee 2005). Brief details are presented in Figures 1 to 6.

Results

Effect of herbicides

Glyphosate was the more effective herbicide in reducing the germinable and filled seeds and percent seed germination. The highest rate of glyphosate (0.510 kg ha^{-1}) had the maximum impact, resulting in the minimum number of germinable, filled seeds and percent seed germination (Table 1). 2,2-DPA was much less effective even at high rate. There was no evidence (P >0.1) that these herbicide effects differed with application time.

Table 1. Effect of herbicides applied at four times in spring on panicle germinable seed, filled seed and seed germination

Herbicide	Rate (kg ha^{-1})	Germinable seed ha^{-1} (× 10^{6})	Filled seed ha^{-1} (× 10^{6})	Seed germination (%)
Glyphosate	0.1275	1.3 (0.80)^{A}	4.0 (1.28)	23 (29)
Glyphosate	0.255	0.1 (0.71)	0.4 (1.19)	7 (16)
Glyphosate	0.510	0.0 (0.70)	0.0 (1.18)	0.4 (4)
2,2-DPA	2.22	8.8 (1.14)	19.0 (1.53)	47 (43)
2,2-DPA	3.70	5.5 (1.12)	4.0 (1.44)	27 (31)
Untreated	–	11.7 (1.22)	35.0 (1.70)	39 (39)
LSD (P = 0.05)		(0.16)	(0.12)	(12.0)

^{A} Transformed data in parenthesis: $\log_{10}$ (germinable seed + 5), $\log_{10}$ (filled seed + 15), and % seed germination (angular)

Table 2. Effect of herbicides and application times on total panicle seed production ha^{-1} (× 10^{6})

Herbicide	Rate (kg ha^{-1})	Times of application			
		3 Sep	3 Oct	13 Oct	27 Oct
Glyphosate	0.1275	21 (1.4)^{A}	9 (1.1)	13 (1.2)	6 (1.0)
Glyphosate	0.255	2 (0.8)	1 (0.7)	2 (0.7)	4 (0.9)
Glyphosate	0.510	0 (0.6)	0 (0.6)	0 (0.6)	2 (0.8)
2,2-DPA	2.22	42 (1.7)	18 (1.3)	14 (1.3)	29 (1.5)
2,2-DPA	3.7	2 (0.8)	41 (1.7)	15 (1.3)	21 (1.4)
Untreated	–	39 (1.6)	50 (1.7)	41 (1.7)	66 (1.8)
LSD (P = 0.05)			(0.38)		

^{A} Transformed data in parenthesis: $\log_{10}$ (panicle seed + 4)

Table 3. Glyphosate rates and time of application effect on Chilean needle grass panicle seed production

Variates	Mean					sed	
	Untreated (X)	Oct 1 at 135 g ha^{-1} (Y)	Oct 1 at ≥270 g ha^{-1} (X)	Oct 18 at ≥135 g ha^{-1} (X)	Oct 28 at ≥135 g ha^{-1} (X)	X v/s X Column	X v/s Y Column
Germinable seeds per 100 panicles (B)	913	124	0	0	0	–	129.3^{A}
Seeds per 100 panicles (C)	1572	1015	1104	332	750	79.1–111.5	122.9–143.2
Filled seeds % (B)	81	24	0	0	0	–	6.5^{A}
Germination % (B)	70	46	–	–	–	–	6.4^{A}

^{A} Only applicable for treatments with a value greater than 0

^{B} In these rows LSDs are obtained by multiplying sed by 2.262

^{C} LSD is obtained by multiplying sed by 2.030

In the glasshouse trial, all the herbicide rates (135, 216, 270 and 405 g ha^{-1}) killed the plants during the July application; but did not prevent panicle seeds developing during the November application (Figure 1). In August, September and October applications, the number of plants producing panicle seeds decreased with increasing glyphosate rates. For those plants producing panicle seeds, the response of both germinable and total panicle seeds to glyphosate treatments was similar, and at all the application times these seeds decreased with increased rates (Figure 2 and 3).

Cleistogene development and germination

Basal seeds exhibited a higher percent germination compared to panicle and stem seeds and they were unaffected by glyphosate treatment at any rate. However, panicle and stem seeds decreased with increasing glyphosate rates (Figure 4). Lower rates of glyphosate (135 and 216 g ha^{-1}) had less impact on stem cleistogene development during the August and September applications compared to higher rates (270 and 405 g ha^{-1}). During the October application all glyphosate rates except 135 g ha^{-1} gave same level of control. However, in the November application glyphosate at ≥135 g ha^{-1} stopped stem seed development (Figure 5). The lowest rate of glyphosate (135 g ha^{-1}) was found to be ineffective in preventing basal seed development but higher rates (≥ 216 g ha^{-1}) showed similar levels of basal seed control (Figure 6).

Herbicides and application time interactions

Medium and high rates of glyphosate (0.255 and 0.510 kg ha^{-1}) produced the minimum number of panicle seeds at all times of application (from 3 September to 27 October) along with the high rate of 2,2-DPA (3.7 kg ha^{-1}) at 3 September. The highest rate of glyphosate proved to be most effective in preventing the panicle seeds when applied any time from 3 September to 13 October (Table 2).

Glyphosate at the lowest rate (135 g ha^{-1}) at 1 October was less effective compared to higher rates (270, 405, 540 g ha^{-1}). Effects of the different glyphosate rates varied with time of application; on 18 and 28 October the lowest rate was sufficient to prevent the occurrence of filled and germinable seeds (Table 3), however, this level of control was observed on 1 October only with higher rates (≥270 g ha^{-1}).

Discussion

In this investigation glyphosate at higher rates (0.510 kg ha^{-1}) was a more effective herbicide for preventing Chilean needle grass panicle seed production than 2,2-DPA, particularly when applied from 3 September to 13 October. This effectiveness

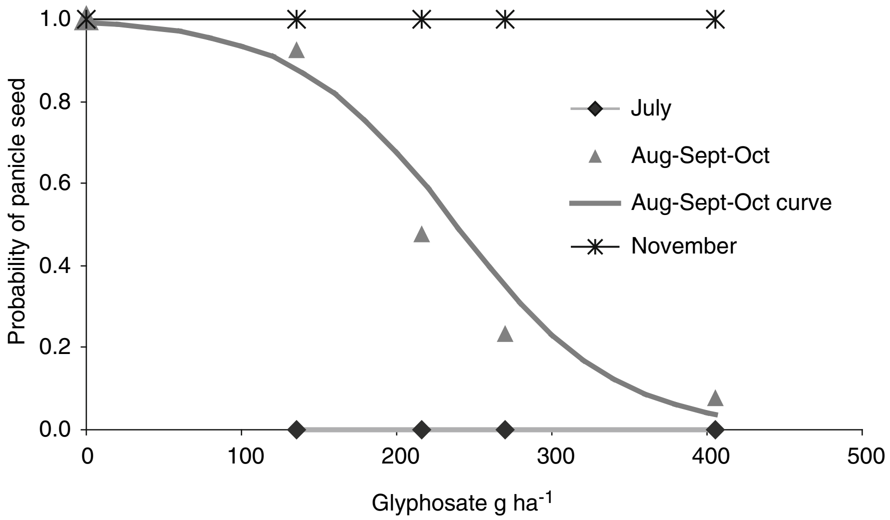

Figure 1. The effect of glyphosate rates and time of application on panicle seeds occurrence. The probability of panicle seed occurrence is adjusted for block and date on logistic transformed scale. Responses fitted using logistic regression with Bernoulli errors

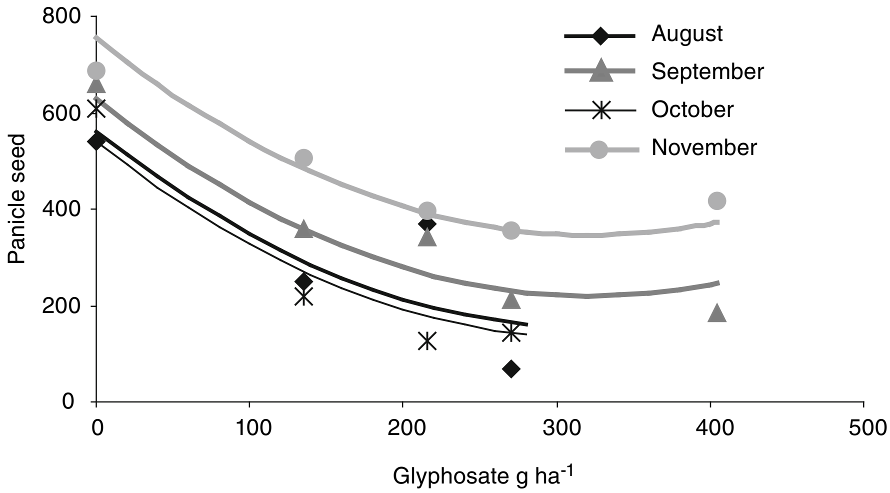

Figure 2. The effect of glyphosate rates and time of application on number of panicle seeds per pot, for those pots where panicle seeds were present. The number of panicle seeds is adjusted for block. Responses fitted using general linear regression

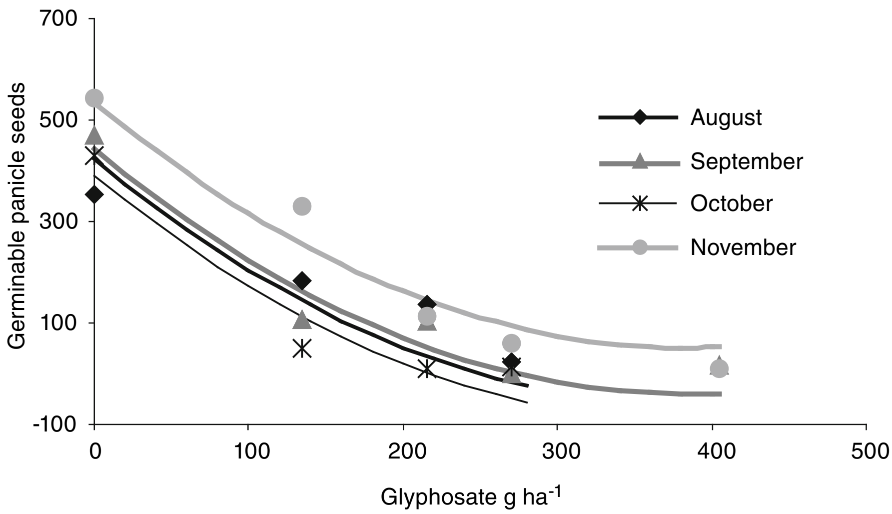

Figure 3. The effect of glyphosate rates and time of application on number of germinable panicle seeds per pot adjusted for block. The analysis is restricted to those pots where panicle seeds were present. Responses fitted using general linear regression

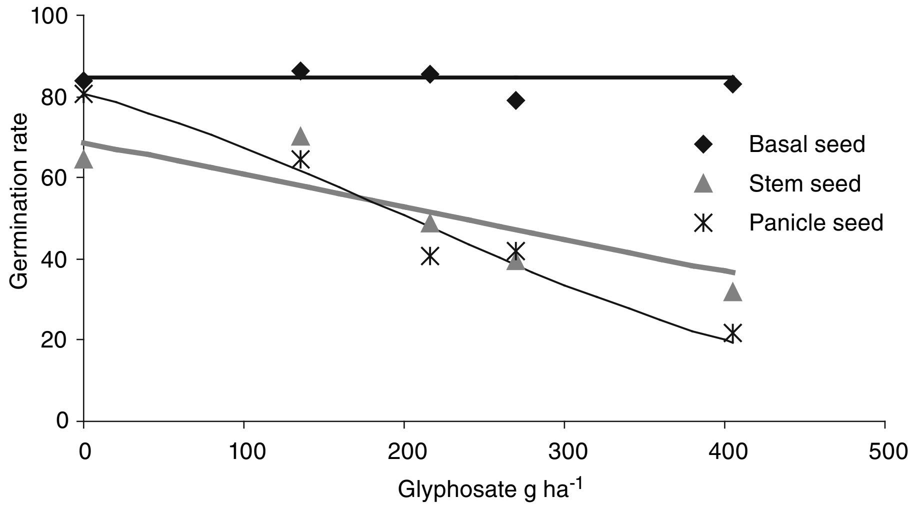

Figure 4. The effect of glyphosate rates on panicle, stem and basal seed germination. The germination rate is adjusted for block and date on logistic transformed scale. Responses fitted using logistic regression with over dispersed binomial errors

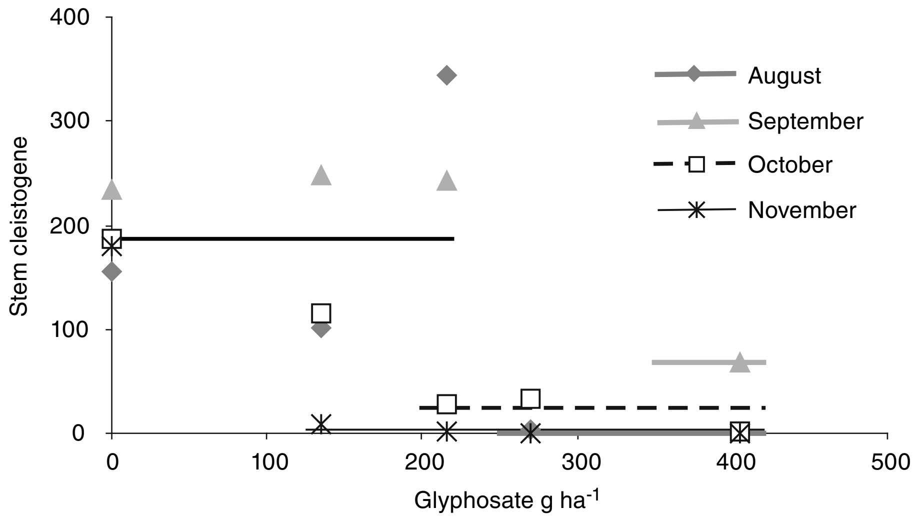

Figure 5. The effect of glyphosate rates and time of application on stem cleistogene. The number of stem cleistogene adjusted for block and date on transformed scale. Responses using general linear regression after log(y+50) transformation

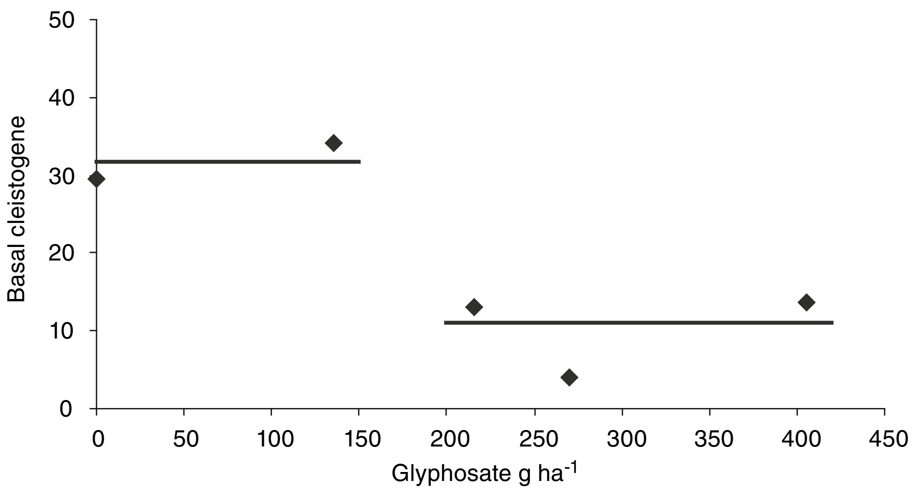

Figure 6. The effect of glyphosate rates on basal cleistogene development. The number of basal cleistogene adjusted for block and date on transformed scale. Responses fitted using general linear regression after log(y+10) transformation

of glyphosate may be attributed to the non-selective and translocated action, which quickly disables the plant from performing physiological processes needed for seed development and results in unfilled seeds or complete loss of panicles. However, 2,2-DPA even at higher rates (3.7 kg ha^{-1}) did not match the lowest rate of glyphosate (0.1275 kg ha^{-1}). The poor performance of 2,2-DPA may be attributed to slow action as it is absorbed through the roots and Chilean needle grass plants have a very short window of activity to complete seed formation and maturation. This explanation of the effect of 2,2-DPA is supported by early September application at 3.7 kg ha^{-1}, where it was comparable in effect to medium glyphosate rates (0.255 kg ha^{-1}).

In the second field experiment, a lower rate of glyphosate was not effective in preventing the production of germinable seeds when applied in early October, but was comparable to medium and high rates in mid and late October applications. To deal with anticipated poor tiller establishment, the old tussocks were slashed in August to ensure new growth in the early spring. Though slashing promoted new tillers, dry weather conditions in spring lead to thin stems. This may be the reason that weak stems did not withstand non-selective and knock down action of glyphosate and gave good performance at lower rates in mid and late applications.

On seedling-raised tussocks in the glasshouse, it was observed that increasing rates of glyphosate decreased the occurrence of panicle seeds during August, September and October applications (vegetative stage) but after the panicle emergence, glyphosate cannot prevent the production of panicle seeds. High rate of glyphosate (405 g ha^{-1}) in the first week of October and November could prevent the production of germinable seeds, as these application times coincide with late vegetative and panicle emergence stages, respectively. This reflects that the rate was enough to arrest the physiological activity of the plant. Since the basal seeds are at an advanced stage in the spring they escape the deleterious effect of glyphosate but panicle and stem seeds are developing during this period thus their production and germinability is influenced by glyphosate. The reason for basal seeds reduction by medium and high rates of glyphosate to a certain degree may be attributed to killing of some of the young stems in tussocks before they became reproductive. However, once the stem becomes reproductive, it is likely to produce basal seed (Gardener *et al*. 2003). The reason for reduction of stem seeds in November applications in all the glyphosate rates might be stems' death or very restricted stem growth because stem seeds mature mid summer when panicle seeds mature and fall off.

The overall conclusion from these experiments is that application of glyphosate at rates of 250 g ha^{-1} between August and October are likely to very substantially reduce production of viable Chilean needle grass seeds and may be a useful contribution to Chilean needle grass management. However 2,2-DPA is ineffective for this purpose unless applied early and at high rates. For glyphosate application as a spraytopping the timing is critical.

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Ecology of the invasive weed S*alvia verbenaca* (wild sage) in the rangelands of western New South Wales

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Abstract *Salvia verbenaca*, wild sage (Lamiaceae) is widespread in western and southern Europe. In Australia *S. verbenaca* is considered an environmental weed often growing on disturbed sites: tracks, roadsides and around earth tanks. Little is known about the ecology of this invasive species in Australia, in particular, optimum temperature requirements and density of soil stored seed bank. Objectives of this study were to determine: (i) seed longevity, (ii) optimum temperature requirements for seed germination and (iii) density of soil seedbank. Seeds were germinated under controlled conditions at temperatures of 20, 25, 30 and 35°C under 12 hour light/12 hour dark and 24 hour dark conditions. Thirty-two soil samples were collected from areas of *S. verbenaca* infestation. Soil samples were placed in trays in a heated glasshouse and watered daily. A significant difference was observed between the effects of the different light treatments (P=0.0000) and temperatures (P=0.0000). The highest germination observed for seed collected in 1996 was at 20°C under 12 h light/12 h dark with 100% germination occurring by the fourth day. The highest germination for seed collected in 2004 was at 25°C under 12 h light/12 h dark with 96% germination occurring by the sixth day. The soil seed bank study showed that the mean number of seedlings recruited per hectare was 6.23 ± SE 3.76. It appears that *S. verbenaca* qualifies as an invasive. As such, it is always safer to take appropriate action at an early phase of invasion rather than at a late stage in the infestation. To do this, we must first undertake studies such as this to understand the plant's ecological characteristics.

Flupropanate resistance in serrated tussock (*Nassella trichotoma*) in Victoria

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Field resistance to flupropanate, the only selective herbicide for serrated tussock, was suspected in 2001 at Diggers Rest, near Melbourne, Victoria. 'Resistant' and 'susceptible' plants were collected and grown on in a glasshouse. Seeds and re-potted tillers were tested with flupropanate at up to 6 kg ha^{-1}. At 15 weeks after spraying, only 'resistant' tillers showed no reduction in leaf number or height per plant. At 12 months, susceptible plants were killed by 0.37 kg ha^{-1}, while most 'resistant' plants were alive. At 18 months with 6 kg ha^{-1}, plant height and inflorescence number in 'resistant' plants were no different from those of control plants. Shoots in seedlings from 'resistant' plants were longer than shoots in seedlings from 'susceptible' plants in flupropanate concentrations of 100–1000 mg L^{-1}. This resistance to flupropanate has potentially serious consequences for control.

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